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DELIVERABLE D4.1
Report on Semantic Alignment & Linking of EEB-related Ontologies

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0.09	UPM, HYPERTECH	30 October 2019	Final modifications according to partner contributions and comments
0.10	FIT	31 October 2019	Submission to the EC

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Acronyms

Acronym	Meaning
AEC	Automation Engineering Construction
BEPE	Building Energy Performance Estimation
BIF	BIMERR Interoperability Framework
epJSON	EnergyPlus JSON
gbXML	Green Building XML
GIS	Geographical Information System
HVAC	Heating, Ventilating and Air Condition
IDD	Input Data Dictionary
IDF	Input Data File
IFC	Industry Foundation Classes
JSON	JavaScript Object Notation
OB	Occupant Behaviour
OWL	Web Ontology Language
obXML	Occupant Behaviour XML
simXML	SimModel XML
XML	eXtensible Markup Language
XSD	XML Schema Definition

EXECUTIVE SUMMARY

This Deliverable aims at addressing the topic of how well the data models and ontologies identified in T3.2 and documented in D3.2 cover the semantic scope of BIMERR data requirements. To this direction, the scope of the BIMERR ontology, preliminary data requirements envisioned for the BIMERR ontology/data model and their coverage by existing data schemas, as well as the semantic links identified among models, are analysed. The adopted methodology for carrying out this analysis is also described and exemplified along the document.

In summary, 48 preliminary requirements have been extracted from 16 use cases and their coverage in 13 ontologies (10 ontologies analysed and 3 equivalent to respective data models) and 20 data models by means of mapping each requirement to the ontologies and data models' content is analysed. At this point, it is worth mentioning that this set of ontological/data requirements is not fixed nor the final ones; refinements and on-going discussions concerning BIMERR architecture and components/tools to be developed indicate that the BIMERR data requirements collection is not just a straightforward process. Hence, the ontology and data model development task (T4.2) will start with a refinement, extension, filtering and prioritization of such requirements taking into account the results of on-going activities such as the BIMERR architecture definition. Therefore, a similar analysis might be needed in future steps for supplementary requirements to be identified in T4.2. Nevertheless, intuitions obtained from this work are clearly reusable for the next phases of the BIMERR ontology implementation.

1. Introduction

As already identified and reported in the BIMERR DoA and D3.2 [Poveda-Villalón et.al., 2019], during the development of BIM projects a variety of tools and systems offered by different vendors typically focus on a subset of the BIM model to accomplish their individual goals. In that sense, sharing data across phases and systems in a BIM project represents a complex process in which maximizing interoperability is crucial in order to allow two or more systems to exchange information and operate with it. Interoperability could be applied at different levels in information systems, namely, technical interoperability, syntactic interoperability and semantic interoperability.

In the context of BIMERR both syntactic interoperability (exchange data formats between systems) and semantic interoperability (exchange and processing of meaningful information in addition to raw data) will be addressed. On the one hand, a key aspect of ontologies to maximize interoperability is their reusability when expressed in ontology implementation language; an ontology implemented in OWL could be completely or partially reused in another ontology development project if the license permits. On the other hand, resources that are not implemented in an ontology language could be reused by means of transforming them into ontologies [Terrazas, 2011]. In this deliverable, a set of data models and ontologies identified in D3.2 are further analysed in order to have a closer look at the reusability potential of such resources according to the first set of data requirements identified for the BIMERR ontology and data model.

An overview of the work carried out in T4.1 "Analysis of EEB-related Ontologies and their Semantic Links" (reported in this document) and the context within BIMERR activities is depicted in Figure 1, where activities that have been conducted in this task and their interrelation with WP3 and other WP4 tasks are presented.

In more detail, within WP3, the data requirements collection, evaluation, planning and architecture design is planned to be performed. Currently, a full set of use cases from all stakeholders that represent different steps in the renovation

process has been collected and analysed in D3.1, while existing resources (data models and ontologies) related to the domain of building construction and renovation have been documented in D3.2.

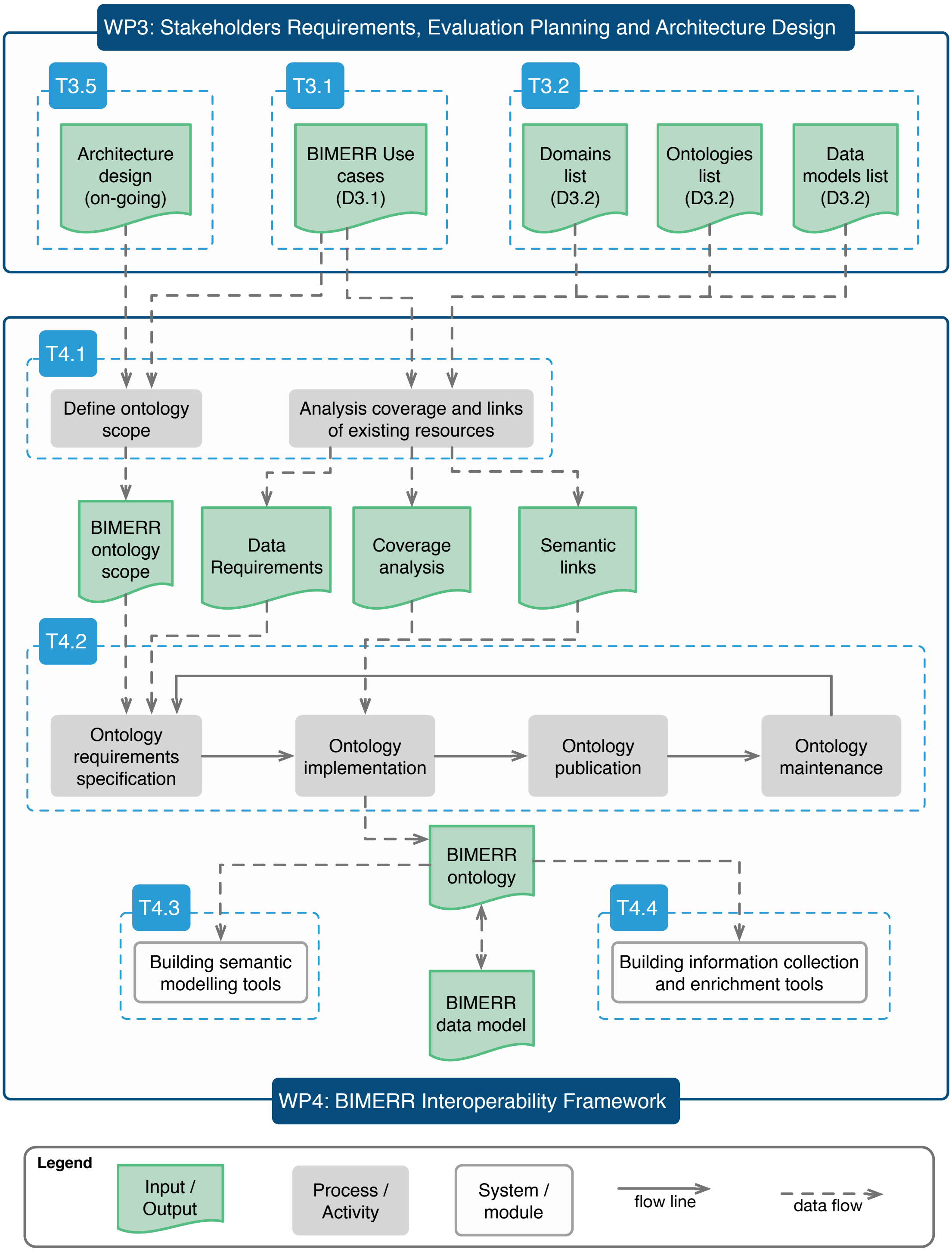

Figure 1. Overview of the relation between D4.1 with WP3 and WP4 tasks

As Figure 1 presents, during T4.1, the BIMERR ontology scope and potential preliminary data requirements have been analysed, considering the fact that the whole BIMERR architecture has not yet been finalized; in that sense, based on available resources available at this stage of development, this task has been analysed as a first attempt to define the BIMERR ontology and data model that will be developed and could be reused during T4.2.

To that end, current versions of architecture diagrams and documents developed as part of T3.5 along with the BIMERR use cases defined in T3.1 have been used as inputs for the BIMERR ontology/data model scope's definition. Furthermore, the use cases have been used to extract a first version of data requirements and to discern to what extent the resources identified in T3.2 (data models and ontologies) are potential candidates to be reused during the BIMERR ontology/data model development within T4.2. It is worth mentioning that the final information exchange requirements for the ontology and data model will be derived from the actual components/modules p and supplementary external data sources. These requirements will be identified mostly in the on-going T3.5 and other technical tasks and will serve as input for T4.2 in which detail requirements will be defined for the ontology and data model.

At this point it is highlighted that the ontology scope and the set of requirements described in this document will serve as input for the ontology/data model requirement specification activities in T4.2, where they will be refined, extended, prioritized and filtered; hence, all requirements considered in this document become information needs in the final version of the ontology/data model. Apart from that, the coverage analysis and semantic links presented in this document will serve as input during the ontology implementation, and more precisely during ontology reuse activities or during non-ontological resources reuse and reengineering activity that might be needed during T4.2.

Finally, the ontology to be developed along T4.2 is intended to be used within the BIMERR Interoperability Framework as shown in Figure 1. Even though the final architecture and connections are not finally defined, we envision the use of the

ontology in different tasks such as the building Semantic Modelling Tools creation (T4.3) and the building information collection and enrichment tools (T4.4). Note here that the use of the ontology might be direct or by means of transforming the ontology conceptualization to the agreed data model.

2. ONTOLOGY SCOPE

This section describes the ontology scope definition derived from the analysis of the project's aim and the current version of BIMERR system architecture. BIMERR aims at semantic interoperability to enable seamless building information exchange between existing third-party tools as well as internal tools that will be developed in the project.

The BIMERR Interoperability Framework (BIF) encapsulates the BIMERR ontology/data model and several interrelated components. While refinements of the BIMERR system architecture are still ongoing, at the time this document is written, several components have been identified to be included in the architecture. The identified components are: Building Semantic Modelling, Building Information Collection and Enrichment, Query Builder, and Building Information Secure Provisioning. In additions, the BIF will also interact with Legacy Systems, Digital Model Creation Tools and the BIMERR Middleware.

In order to define the ontology scope, we propose a list of functional requirements and analyse its relationship with the interrelated components mentioned above, as can be seen in Table 1. Each of the functional requirement states how the ontology can be used by a component, directly or by its transformation to the BIMERR data model, together with one of the MAY/SHOULD/MUST keyword.[1] This means that if there is a relationship between the requirement and a component, this requirement will be included in the scope of the ontology.

[1] The official explanation of this keyword can be seen at: https://tools.ietf.org/html/rfc2119

Table 1. Ontology scope and relation with BIF and other architecture components

Requirement	Legacy System	BIMERR Interoperability Framework				Digital Model Creation	Middleware
		Building Semantic Modelling	Information Collection & Enrichment	Query Builder	Building Inf. Secure Provisioning		
The ontology SHOULD be able to model raw data produced by building Digital Model Creation Tools	X						X
The ontology SHOULD be generic enough so that it can cover relevant concepts		X					
The ontology MAY be able to model the semantic data produced by the Building Semantic Modelling module		X					X
The ontology SHOULD be able to model the provenance of the semantic data produced by the Building Semantic Modelling module		X					X
The ontology MAY be able to model the links between the semantic data generated by the Information Collection and Enrichment module			X				X
The ontology MUST be able to model a unified view over the raw data generated by the Building Digital Model Creation Tools						X	
The ontology MAY be able to model relevant data resources accessible through the middleware							X
The ontology MAY be able to model various modalities of data ranging from static data to streaming one						X	
The ontology SHOULD provide the basic concepts to define in an easy way queries related to data exchanged between applications and stakeholders, in accordance with the applicable data access policies.				X			
The ontology MUST be available in different formats and seamlessly transformed to a data model.		X					

3. METHODOLOGY

This section presents the methodology that has been followed to analyse how well existing resources cover a preliminary set of data requirements identified, as well as to analyse the semantic links among those resources. As mentioned above, this preliminary set has been extracted from the use cases that have been reported in D3.1 and it is planned to be extended and be filtered during T4.2 tasks of the BIMERR ontology and data model development.

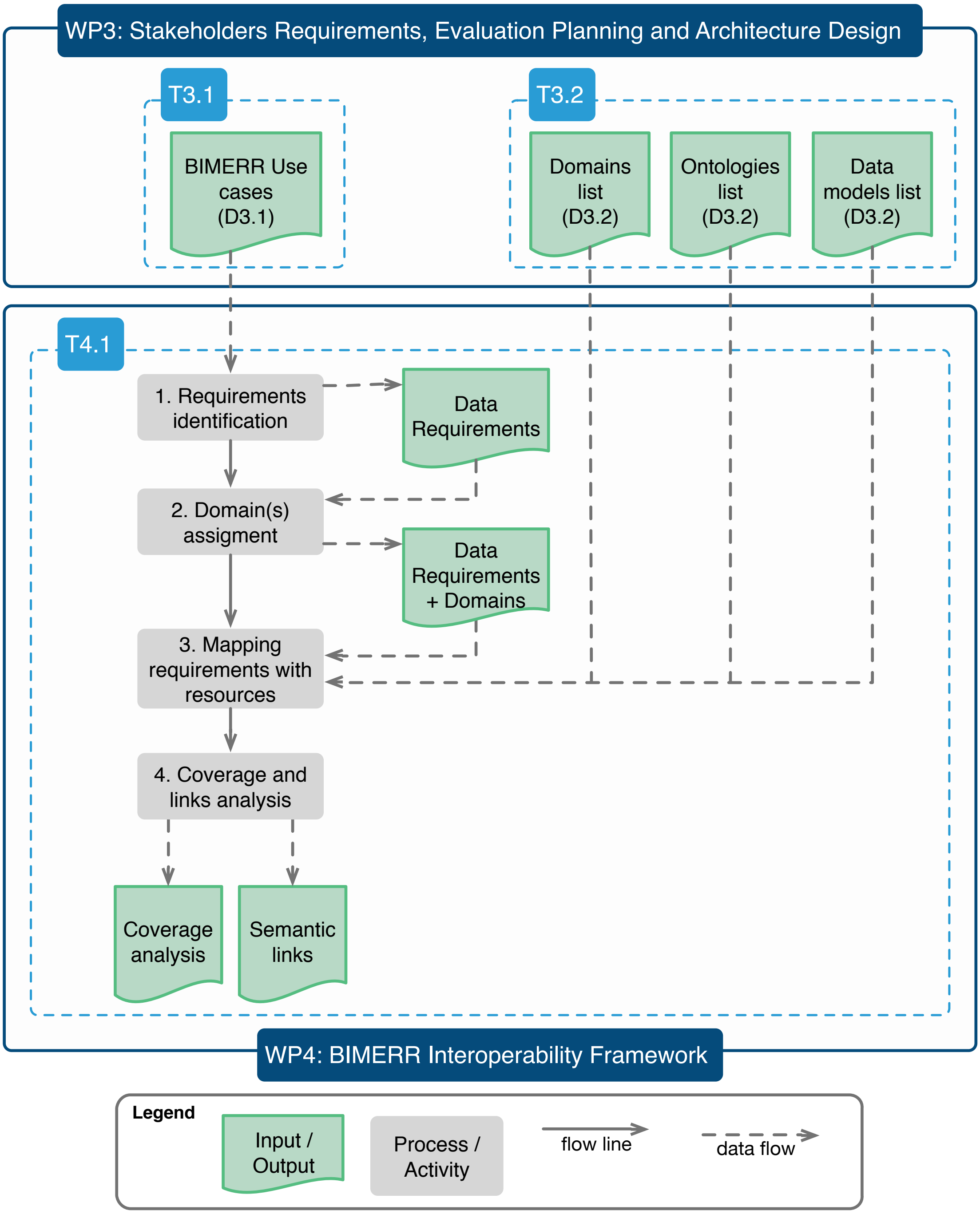

Figure 2. Methodology for coverage and semantic links analysis

The methodology (see Figure 2) consists of four main steps. The first step focuses on the identification of potential requirements taking as input the list of use cases defined for BIMERR in D3.1. In the second step, the identified requirements are associated with their corresponding domains as they have been identified in D3.2 (building, materials, energy consumption, usage patterns and habits, weather, reality capture and geography); however, new domains could arise at this step as it will be further detailed. In the third step, existing resources (i.e., ontologies and

data models) that have been reported in D3.2 are mapped with the identified requirements. Finally, the last step consists of a coverage analysis of the requirements and the semantic links identified between resources are generated as the final outputs of this methodology. In the following sections, further details for each step along with a running example are provided.

3.1 REQUIREMENTS IDENTIFICATION

To extract the first set of BIMERR data requirements, the 16 use cases described in D3.1 have been considered as input. In more detail, the content of each use case has been analysed to identify information exchange needs that could be potentially modelled by the ontology and data model. Typically, in the ontology engineering field, the ontological requirements are taken in the form of Competency Questions [Gruninger and Fox, 1995] which are natural language questions (interrogative form) that express questions the users would like to ask the ontology, treating it as a knowledge base. However, sometimes the ontological requirements could be written in the form of affirmative natural language sentences, expressing facts instead of interrogative. This technique could be applied for BIMERR data requirements elicitation. For this reason, along the BIMERR ontology/data model development, the data requirements could be expressed either as competency questions (which might have an answer or not) or natural language sentences (for which no answer is expected). For the case of this deliverable, all requirements have been defined, or rephrased in a second round, as natural language affirmative sentences.

For example, the Use Case 1 (name: "*Rapid scanning of the geometry of the building, semantic modeling and accurate representation in a BIM*") description provided in D3.1 reads as follows:

"Surveyors shall be able to rapidly capture information about the building geometry in order for BIM modelers to significantly accelerate the creation of accurate and semantically-rich building models. These models must contain all necessary information for the design team (architects, engineers) to proceed with the design of the energy renovation project. The model delivered by the Scan-to-BIM process should

thus contain the building structure and building components of particular value to effective energy renovation design." (taken literally from D3.1)

From this text, it can be extracted that there is a need to represent certain concepts such as building components, among other things, according to the text "*The model delivered by the Scan-to-BIM process should thus contain the building structure, and **building components**...*". Taking this information, and extra information about the different building components, into account the data requirement "*Building have architectural and structural elements as walls, doors, windows, radiators, etc*" is derived.

This process has been applied to the 16 use cases from which 64 preliminary data requirements have been extracted, while after a revision phase among the partners some requirements were proposed to be deleted (14), to be merged with more general requirement (5) or new requirements were proposed to be added (3), concluding to **48 requirements** to be considered in this step (Table 2 present the requirements together with other information added in the next step of the methodology).

3.2 ASSIGNING DOMAINS TO THE REQUIREMENTS

In this step, the data requirements have been classified according to the domains defined in D3.2, namely: Building, Material, Energy Consumption, Usage Pattern and Habits, Weather, Reality Capture and GIS. For instance, the requirement "*A Building has architectural and structural elements as walls, doors, windows, beams, slabs etc."* is assigned to the domain Building. Following this process, the 48 preliminary requirements identified in the previous tasks have been associated to one or more domains as shown in Table 2. The table also includes the requirements' provenance, that is where the requirement was extracted from, for traceability issues. Note here that extended versions of this Table include further columns, such as a column with notes that assign specific requirements about information needed to indicate that the partners involved in such domain will be required to provide more information if the requirement is selected for

implementation. For the sake of readability. such information is not included in Table 2.

As it might be expected, there could be requirements related to other domains, different from the mentioned ones, as the requirements have been deduced from another point of view different from the D3.2 document. In this sense, during this step new domains related to the data requirements have been identified and included to the list of domains to be considered during the BIMERR ontology and data model development. More precisely, the domain "Project management", which includes information about the process, tasks, roles, etc., has been identified during this step.

It should also be mentioned that according to the ontology requirements analysis the "Weather" and "Usage Pattern and Habits" domain do not appear as main topic of any of the requirements. However, having a broader view of the ontology use in the BIMERR system it is obviously relevant in order to integrate different type of data from external sources for the case of the weather domain, and actually some weather information is taken into account within the energy consumption domain. This situation only reveals again the different perspectives from which ontology and data model requirements could be extracted in a software development project.

Table 2. Requirement with their Associated Domains

Id	Domain(s)	Requirement	Extracted from
Req1	Project Management	There are different roles of a person to a renovation project as BIM modeler, building surveyor, architect, designer, engineer, BIM expert, urban planner, building manager, building occupant, building owner, consultant, health and safety manager, material manufacturer, project manager, subcontractor, vendor/supplier, foreman, site manager, worker.	D3.1
Req2	Building	Building elements have a well-defined geometry that can be represented from different perspective (architectural, structural, energy performance simulation, etc.)	D3.1 UC-01
Req3	Building	A Building has a unique ID, an identifier which expresses the building uniqueness and separates it from other building entities	D3.1 UC-01

Req4	Building	The as-is state of the building includes geometry (point clouds) and texture (imagery)	D3.1 UC-01
Req5	Building, GIS	The geolocation and orientation of the building includes geo-coordinates (transformation matrices)	D3.1 UC-01
Req6	Building	A building has a spatial arrangement	D3.1 UC-01
Req7	Building	A Building has architectural and structural elements as walls, doors, windows, beams, slabs etc.	D3.1 UC-01
Req8	Building	A Building has at least one Building Information Modeling (BIM) model	D3.1 UC-01
Req9	Building, Energy Consumption	Building systems include heating/cooling, ventilation components etc.	D3.1 UC-02, D3.1 UC-01
Req10	Building	Building networks include pipes, cables, etc.	D3.1 UC-02, D3.1 UC-01
Req11	Project Management	A BIM model has mandatory and optional information requirements which could be photos, notes, documents, etc.	D3.1 UC-02
Req12	Reality Capture, Building	An IoT sensor/device, that measures specific environmental parameters, has a unique ID	D3.1 UC-03
Req13	Reality Capture, Building	An IoT sensor/device, which has an ID, is connected wirelessely to a network for transmitting data through the internet	D3.1 UC-03
Req14	Reality Capture, Building	IoT sensor measurements might be about ambient data as temperature, humidity, CO2, VOC, luminance, etc.	D3.1 UC-03
Req15	Energy Consumption	Occupant profiles might contain information for energy use/production, presence and comfort	D3.1 UC-03
Req16	Energy Consumption, Building	Energy consumption of a building could be measure by IoT devices	D3.1 UC-03
Req17	Material, Building	Construction materials include timber, concrete, cigarette butts, cardboard, etc	D3.1 UC-04
Req18	Material	Construction materials have thermal properties	D3.1 UC-04
Req19	Material, Building	Construction materials have cost properties	D3.1 UC-04
Req20	Material	Construction materials have LCC/LCA properties	D3.1 UC-04
Req21	Project Management	There are methods for time and cost estimation	D3.1 UC-05
Req22	Project Management	Renovation process includes the plan and schedule of project activities	D3.1 UC-05
Req23	Project Management	A project manager receives time and cost contrains and buidling related information to plan the project activities	D3.1 UC-05, D3.1 UC-6
Req24	Project Management	There are external stakeholders who need to provide a permission for the project to be realized, such as local building offices, technical offices, construction services	D3.1 UC-07
Req25	Project Management	A building permit needs to be in place an available to ensure that the project plans comply with local standards for land use, zoning, construction and contains documents, such as drawings, site investigations, engineering reports, time plan	D3.1 UC-07
Req26	Project Management	A tender notice allows subcontractors to bid their services or materials in order to undertake works of the project. It includes	D3.1 UC-07

		cost estimates regarding work cost and material cost deriving from the project specifications	
Req27	Material	Workers need information about materials, quantities to be used, exact location where the tasks need to be performed.	D3.1 UC-08
Req28	Building, Reality Capture	Smart equipment includes smart glasses, tablets, smart phones, etc.	D3.1 UC-08
Req29	Reality Capture, GIS	Head-Mounted device are used to recognize the location of construction project and it will provide a list of scheduled tasks to workers.	D3.1 UC-08
Req30	Project Management	There are different types of KPI like Demand Response KPIs, Energy KPIs, Occupants Comfort KPIs, Indoor Air Quality KPIs, Economic KPIs, Predictive Maintenance KPIs, LCA/LCC KPIs, etc.	D3.1 UC-09, D3.1 UC-14, D3.1 UC-15
Req31	Project Management	The renovation activities are planned for a specific execution time	D3.1 UC-09
Req32	Project Management	The site manager keeps track of the project progress	D3.1 UC-09
Req33	Project Management	The renovation activities have a response time	D3.1 UC-09
Req34	Project Management	The renovation activities are organized in tasks	D3.1 UC-09
Req35	Project Management	The project activities have a given status and progress	D3.1 UC-09
Req36	Project Management	Workforce and foreman report on progress and unexpected events of the project to the manager.	D3.1 UC-09
Req37	Reality Capture, Project Management	Site manager and workers can use AR-enabled applications to identify geometrical changes	D3.1 UC-10
Req38	Material, Project Management	Occupants can use smart phones to report changes	D3.1 UC-10
Req39	Project Management	Changes reported could be about geometry, materials, etc.	D3.1 UC-10
Req40	Material, Building	Site managers, worker, foreman, building occupant and Building Owner could be affected by threats and dangers	D3.1 UC-11
Req41	Project Management	In a construction site there might be risks like safety hazards leading to accidents and injuries, equipment damage, etc.	D3.1 UC-11
Req42	Project Management	In a BIM model, health and safety instruction and training material could be included	D3.1 UC-11
Req43	Project Management	The site manager creates the health and safety reports	D3.1 UC-12
Req44	Project Management	A health and safety report might include issues known by site managers or by workers, like exposed electricity cables, or observed by occupants.	D3.1 UC-12
Req45	Material, Building	Renovation scenarios simulations are used to select the best energy-performing scenario.	D3.1 UC-13
Req46	Material, Building	Renovation measure options are related to technologies, materials, systems, etc.	D3.1 UC-14

Req47	Energy Consumption	Ambient information like temperature, humidity, CO2, Volatile Organic Components (VOC), luminance, etc. might be taken into account during the project	D3.1 UC-15
Req48	Energy Consumption	There are target KPIs	D3.1 UC-16

3.3 REQUIREMENT MAPPING WITH EXISTING RESOURCES

In this step, all requirements are mapped with the existing resources (i.e., ontologies, data models and standards) that are available in their corresponding domains. More precisely the complete list of resources taken into account are:

Ontologies

- **SAREF**: The SAREF (Smart Anything REFerence) ontology [ETSI, 2015] is a reference ontology and designed to present a core IoT model and to enable semantic interoperability in the IoT, that could be extended and adapted in order to cover specific domains.
- **SAREF4bldg**: Saref4bldg [ETSI, 2016a] is an extension of the SAREF ontology for building devices and spaces. It has been designed for Architecture, Engineering and Construction fields.
- **SAREF4ENER**: This is the extension of SAREF for the EEBus and Energy@Home project to deal with energy domains [ETSI, 2017].
- **SAREF4CITY**: This ontology extends the SAREF ontology for the Smart Cities [Espinoza-Arias et. al., 2019] domain focusing on the IoT perspective of city data.
- **oneM2M**: The oneM2M [ETSI, 2016b] base ontology aims at developing technical specifications addressing the need for a common M2M Service Layer that can be readily embedded within various hardware and software.
- **W3C SSN/SOSA**: This ontology is the second version of the Semantic Sensor Ontology in which the concept of actuator has been included [Haller et. al., 2018]. It represents a standard ontology developed within the W3C Semantic Sensor Network Incubator Group (SSN-XG).
- **W3C BOT**: BOT [Rasmussen et. al., 2017] ontology is designed as a minimal OWL DL ontology for representing associations between sub-elements of a building. This ontology aims to combine the with several domain specific ontologies by following the common W3C principles of reuse.
- **OEMA**: This ontology is an attempt to unify existing heterogeneous ontologies that represent energy performance and contextual data. One of

the goals of the OEMA[4] ontology network is to provide a common representation of energy data.

- **SEAS Weather**: The Seas Weather ontology[2] is designed as a vocabulary for the ITEA SEAS (Smart Energy Aware Systems) project to represent weather information.
- **Geonames**: The Geonames ontology [3] provides descriptions for geographical features, in particular those defined in geonames.org.
- **ifcOWL**: ifcOWL ontology [Pauwels, 2016] is an open specification for Building Information Modeling (BIM) data . ifcOWL is significant to BIMERR as it allows the specification of building life-cycle relevant data by open linked data standards.
- **SimMODEL OWL**: This model is an OWL implementation of SimModel to represent its information in RDF.
- **E+OWL**: E+OWL is an OWL Implementation of EnergyPlus IDD. In combination there exists a Java application with three main functions: (1) EnergyPlus IDD transformation to a schema that uses Web Ontology Language (OWL) format; (2) EnergyPlus IDF transformation to instances that are represented in OWL format; and (3) the OWL format instances transformation back to EnergyPlus IDF file for simulation.

Data models

- **IFC**: buildingSMART [buildingSMART, 2014] is the leading international organisation on exchange of information between software in the Architecture, Engineering and Construction (AEC) industry. Industry Foundation Classes (IFC) is buildingSMART's first developed data model (currently IFCv.4), created for information/data exchange among different actors of the building sector who are not using the same vendor specific software. IFC represents the "operating system" responsible for transporting information/data between different software applications.
- **Basic data formats (reality capture domain)**: There are some basic data formats to present the spatial coordinates and potentially RGB information for reality capture domain such as, PLY [Turk, 1994], PTX [Bourke, 2015] and E57 [Huber, 2011].
- **cobie**: COBie (Construction-Operation Building information exchange) is a non-proprietary international technical standard (specification) for delivering and capturing asset data among the involved parties. It was

[2] https://ci.mines-stetienne.fr/seas/WeatherOntology
[3] http://www.geonames.org/ontology/documentation.html
[4] https://innoweb.mondragon.edu/ontologies/oema/index-en.html

revised to comply with international standards. A general schema has been presented in COBie format [Sabbagh, 2019].

- **BO-IDM**: BO-IDM (BIM Oriented Indoor Data Model) has been designed to provide the indoor navigation. It is a BIM based data model. This model has been presented as the BIM oriented modelling methodology in 2013 [Isikdag, Zlatanova, & Underwood, 2013].
- **BISDM**: The BISDM (Building Interior Space Data Model) is an open data model, that was developed in 2007 by ESRI and it is based on Geographic Information System (GIS). This model enables spatial features (e.g. walls, doors) to link to the external features and offers the analysis of route tracing and transportation analysis [Grisé & Wittner, 2008].
- **GML3**: The Geography Markup Language (GML) is an XML grammar for presenting geographical features. It presents as a modelling language for geographic systems as well as an open interchange format for geographic transactions on the Internet.
- **NBIMS Cobie**: Represents the acceptance version of Cobie as part of National Building Information Model Standard.
- **cityGML**: CityGML is an open data model to present common definition of the basic entities, attributes and relations of a 3D, city or landscape, model. CityGML's features are significant for BIMERR to model buildings [El Mekawy, 2011].
- **GBXML**: The GBXML model (Green Building schema) [GBXML] presents interoperability between building design and engineering analysis software by providing the transfer of building information via an XML-based data schema. It can be used as a data storage/exchange format for building information.
- **baubook.info**: baubook[5] is a database of building material and their ecological and structural-physical aspects. There are 3616 building products from 359 vendors are presented in the database.
- **eurobau.com**: Eurobau.com[6] data model presents a detailed technical information (product measurements, u-values, etc.) on more than 100.000 building products from hundreds of vendors.
- **oekobaudat.de**: Oekobaudat[4] is a database and presents around 1200 life cycle assessment datasets for building materials, construction, transport, energy and disposal processes.
- **GaBi**: The GaBi [5] is a construction material database to provide the regionalized Life Cycle Assessment (LCA) information of around 2600 construction materials.

[7] https://www.oekobaudat.de/fileadmin/downloads/Einreichung/2018-03-20_ILCD-EPD_Defin_CPEN2018.pdf
[8] http://www.gabi-software.com/international/databases/gabi-databases/construction-materials/
[9]https://corporate.accuweather.com/accuweather-advantage

- **AccuWeather**: AccuWeather[9] is used for forecasting about the weather events for saving lives and properties and also helps to make better decisions.
- **Weather2020**: Weather2020[10] presented as a tool to get the warning of disaster and all weather information. It uses tested models and LRC methodology for temperature and precipitation forecast of weather events.
- **OpenWeather**: OpenWeather[11] is most frequently used model to provide current, hourly and long term forcasting with historical data.
- **Vector data model**: This data model presents objects as geometrical elements with well-defined boundaries. These elements can be a line, point or a polygon
- **Raster data model**: In this model, the earth surface is quantized as a grid of square cells. A set of x, y coordinates identified each cell uniquely which is significant to the origin of the grid
- **EnergyPlus JSON/IDD**: EnergyPlus [Ivanova, 2015] has been taken as BEPE engine for the energy consumption estimation in BIMERR. The syntax specification of this data model are epJSON and IDD (Input Data Dictionary).
- **obXML:** obXML (Occupant Behaviour XML) data models are designed to present the energy-related occupant behaviour in buildings. They are based the Drivers–Needs–Actions–Systems (DNAS) framework [Hong, 2015].
- **Simmodel SimXML:** This is a XML-based data model [O'Donnell, 2012] to present the BIM related information such as building geometry, building elements, materials, zones, spaces and HVAC systems.

It should be mentioned that the ontology freeclass was identified in D3.2 however it has not been analysed since it is not currently maintained. In addition, since the E+owl and SIMmodel OWL ontologies identified in D3.2 are the OWL representations of EnergyPlus IDD and SimXML data models, only the respective data models have been analysed to avoid redundancies. The same case occurs for the IFC OWL ontology [Pauwels, 2016], which is an OWL representation, for this reason only the IFC data model analysis is shown. Finally, as NIMBS Cobie is a version of Cobie it is not shown in the analysis either.

The complete set of mappings for ontologies are show in Table 3. In this table, columns represent the ontologies that are analysed and rows represent the requirements. For each cell, the concept(s) from the given ontology that are related to the given requirements are included, if any. For example, the requirement "*Building elements have a well-defined geometry that can be represented*

from different perspective (architectural, structural, energy performance simulation, etc.)", is mapped to saref4bldg ontology by means of the concept "*saref4bldg:Building*" defined in such ontology which is a concept linked too geometry properties, so the requirement is covered to some extent.

Empty cells mean that the ontology does not provide support for that requirement. For the sake of readability, when three or more consecutive requirements are not covered by any ontology, rows are merged into one row and the requirements involved are noted as a list of identifiers. When more than one concept from a given ontology are involved in the coverage of one specific requirements, they are listed and separated by comas ",".

The complete set of mappings for data models are shown in Table 4, Table 5 and Table 6. For the sake of example, the requirement "Building have architectural and structural elements as walls, doors, windows, beams, slabs, etc." is mapped to IFC data model by means of the concepts "*IfcArchitectureDomain, IfcHvacDomain, ifcElectricalDomain, ifcStructuralElementsDomain, ifcPlumbingFireProtectionDomain, IfcSpatialZone; IfcWall; IfcSlab; IfcDoor; IfcWindow; IfcPanel; IfcCurtainWall; and their sub-classes.ifcColumn, IfcArchitectureDomain, ifcStructuralElementsDomain, ifcBeam*" defined in the IFC model.

Note here that the basic format for reality capture, oekobaudat.de and GaBi data models are not included in the table, since they do not cover any of the requirements extracted, although they have been analysed and will still be part of potential resources to be reused. These resources might not cover the requirement coming from the use cases for this analysis, but might be valuable for other requirements coming from legacy data or applications.

Table 3. Ontology concepts mappings to identified requirement.

Req	saref	saref4bldg	saref4ener	saref4city	One M2M	W3CSSN /SOSA	W3C bot	oema	SEAS Weather	Geonames
R1										
R2		Building					Building			gn:Feature, wgs84_pos:long, wgs84_pos:long, gn:nearbyFeatures
R3										
R4										
R5		Building		Facility						gn:Feature, wgs84_pos:long, wgs84_pos:long
R6										
R7		BuildingSpace					Element			
R8										
R9		BuildingDevice								
R10										
R11										
R12	Sensor	Sensor				Sensor				
R13	Device	Device	Device	Device	Device	System	Element			
R14	IlluminanceUnit, Temperature									
R15 / R27										
R28	Device	Device	Device	Device	Device	System	Element			

R29	Task									gn:Feature, wgs84_pos:long, wgs84_pos:long
R30	Temperature			KeyPerformanceIndicator				Humidity, Temperature	AirTemperature, FeatureOfInterest, WeatherDescription, WeatherState, WeatherReport	
R31	Time									
R32										
R33	Time									
R34	Task									
R35/ R37										
R38	Device	Device	Device	Device	Device	System				
R39/ R46										
R47	Temperature							Humidity, Temperature	WeatherPhenomenon, Wind, WindSpeed, AirTemperature, FeatureOfInterest, WeatherDescription, WeatherState, WeatherReport	
R48				KeyPerformanceIndicator						

Table 4. Data models concepts mappings to identified requirement (part 1: building and materials data models)

Req	IFC	cobie	BO-IDM	BISDM	CityGML	GML3	GBXML	baubook. info	eurobau .com
R1	IfcActor, IfcOwnerHistory, IfcPerson, IfcOrganization, IfcActorRole	objContact (ifcActor)					PersonInfo		
R2	IfcArchitectureDomain, IfcBuilding	objFacility (ifcSite), objFloor(ifcBuildingStorey), objSpace(ifcSpace), objZone(ifcZone), objType (ifcElementType), objComponent	Storey, Stairs, Column, Beam Wall	Floor, FloorplantLine, FloorSection, InteriorSpace	Geometry	AbstractBuilding	Building, Area, Space, ShellGeometry, SpaceBoundary, BuildingStorey, PlanarGeometry		
R3	IfcBuilding					AbstractBuilding	Building		
R4	IfcPointCloud								
R5	IfcSite; IfcBuilding; IfcGeometricRepresentationContext; IfcLocalPlacement;								
R6	IfcSpatialElement; IfcRelSpaceBoundary								
R7	IfcArchitectureDomain, IfcHvacDomain, ifcElectricalDomain, ifcStructuralElementsDomain, ifcPlumbingFireProtectionDomain, IfcSpatialZone;	objType (ifcElementType), objComponent (ifcElement)	Storey, Stairs, Elevator(?), Column, Beam, Slab, Door, Window, Wall	BISDM3 Assets: ArchitecturalFixture, StructuralArea, StructuralMember,StructuralFixture		Room, Opening(Window, Door), BoundarySurface	Surface, Construction, WindowType, Blind, LightingSystem	constructions, building materials, housing technolog	Building material

	IfcWall; IfcSlab; IfcDoor; IfcWindow; IfcPanel; IfcCurtainWall; and their sub-classes.ifcColumn, IfcArchitectureDomain, ifcStructuralElementsDomain, ifcBeam							y, building element	
R8									
R9	IfcHvacDomain, IfcElectricalDomain, IfcEnergyConversionDevice, ifcPlumbingFireProtectionDomain, IfcSharedBldgServiceElements	objSystem (ifcSystem)	WallPart, ColumnPart, BeamPart, SlabPart ("Wall or a Slab is still a 3D object (composed of parts,which can contain the cabling and pipes that are passing inside")	BISDM3 Assets:HVACArea,HVACEquipment, ElectricalEquipment, ElectricalArea,		BuildingInstallation	AirLoopEquipment; HydronicLoopEquipment		
R10	IfcHvacDomain, IfcElectricalDomain, IfcFlowSegment; IfcPipeSegment; IfcCableSegment, IfcHvacDomain, IfcElectricalDomain, IfcSharedBldgServiceElements	objConnection	WallPart, ColumnPart, BeamPart, SlabPart	BISDM3 Assets: PlumbingArea, PlumbingConduit,PlumbingFixture,HVACConduit,ElectricalConductor		BuildingInstallation	AirLoop, HydronicLoop	distribution systems	
R11	IfcAnnotation, IfcDocumentReference IfcDocumentInformation	objContact,objFacility,objFloor,objSpace,objType,objComponents,objSpare,		BISDM3 Core: Photo,PhotoLocation					

		objResource,objJob							
R12	IfcSensor	obType (ifcSensorType)							
R13									
R14	IfcTimeSeries	objType (ifcSensorType)					Schedule		
R15	IfcTimeSeries		Space (Occupancy, Usage type)				IndoorAirQuality, Schedule		
R16	IfcEnergyMeasure					AbstractBuilding	Results, Meter		
R17	IfcMaterial; IfcMaterialLayer; IfcMaterialLayerSet	objType (ifcMaterial), objResource	MaterialType				Material; Layer; Construction		
R18		obj Contact (ifcActor)					PersonInfo		
R19	IfcMaterial; IfcMaterialLayer; IfcMaterialLayerSet						Material; Layer; Construction		
R20	IFcCostItem,						Cost, Life		
R21		objResource					Cost, Life		
R22		objJobs							
R23	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.	objJobs, objContact (ifcActor)					PersonInfo		
R24		objContact (ifcActor)							

R25	IfcPermit	objDocuments (ifcRelAssociatesDocument)							
R26		objDocuments							
R27/ R29									
R30	IfcTimeSeries						Results, Schedule		
R31					TimePeriod, TimeLengthType				
R32	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.	objContact (ifcActor)					PersonInfo		
R33					TimePeriod, TimeLengthType				
R34		objJob (ifcTask), objIssue (ifcActionRequest)							
R35									
R36	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.	objContact (ifcActor)					PersonInfo		
R37	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.	objContact (ifcActor)			Geometry, measureDescription		PersonInfo		
R38									
R39									

R40	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.						PersonInfo		
R41			Space, MaterialType, WindowPart, DoorPart						
R42									
R43	IfcOwnerHistory; IfcPerson; IfcOrganization; IfcActorRole etc.	objContact (ifcActor)					PersonInfo		
R44									
R45 R45									
R46	ifc:CostItem	objType, objComponent, objSystem, objIssues				Appearance, SurfaceData			
R47	IfcTimeSeries						Schedule		
R48									

Table 5. Data models concepts mappings to identified requirement (part 2: GIS, energy consumption, and usage patterns and habits domains)

Req	Vector data model	Raster data model	EnergyPlus JSON/IDD	obXML	Simmodel SimXML
R1					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R2	Polygon; Volume	Coordinates; tile_type	Building		SimBuilding_Building_Default
R3			Building	Building	SimBuilding_Building_Default
R4 / R6					
R7			BuildingSurfaceDetailed; FenestrationSurfaceDetailed	Spaces	SimSpatialZone; SimWall; SimSlab; SimDoor; SimWindow; SimPanel; SimCurtainWall
R8					
R9			HVAC templates; HVAC Forced Air Units; HVAC Radiant	Systems; HVAC; Lights; Windows; PlugLoad; Thermostats;ShadesAndBlinds	SimFlowCompoundEqmt_UnitaryZoneEqmt; SimFlowEnergyTransfer_RadiantDevice; SimFlowEnergyTransfer_ConvectiveHeater; SimFlowTerminal_AirTerminal; end their sub-classes
R10					SimFlowSegment_Pipe; SimFlowSegment_Cable
R11					
R12					SimSensor
R13					
R14			Schedule:Compact; Schedule:File	Drivers; Time; Environment	SimTimeSeriesSchedule
R15			Schedule:Compact; Schedule:File	Behaviors; Movement Behavior; Needs; Thermal; IAQ	SimTimeSeriesSchedule
R16					SimMeasureType_EnergyMeasure

R17					SimMaterial; SimMaterialLayer; SimMaterialLayerSet
R18					SimOwnerHistory; SimPersonAndOrganization; etc.
R19					SimMaterial; SimMaterialLayer; SimMaterialLayerSet
R20					SimCost_LifeCycleCost; SimCost_UtilityCost; SimCost_ComponentCost
R21					
R22					
R23					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R24/ R29					
R30		Continuous Data (Temperature, Elevation)			SimSimulationOutputRequest_TimeSeriesVariables
R31					
R32					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R33/ R35					
R36					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R37					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R38					
R39					
R40					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.

R41					
R42					
R43					SimOwnerHistory; SimPerson; SimOrganization; SimActorRole etc.
R44/ R46					
R47		Continuous Data (Temperature, Elevation)			SimTimeSeriesSchedule
R48					

Table 6. Data models concepts mappings to identified requirement (part 3: weather domain)

Req	AccuWeather	Weather2020	OpenWeather
R30	Temperature.Metric.Value;Temperature.Metric.Unit;Temperature.Imperial.Value;Temperature.Imperial.Unit; RealFeelTemperature;RelativeHumidity;WeatherText	temperatureHigh;temperatureLow;temperatureHighCelcius;temperatureLowCelcius	temp;humidity;temp_min;temp_max;coord: {lon:,lat:};weather: [{description}]
R47	Temperature.Metric.Value;Temperature.Metric.Unit;Temperature.Imperial.Value;Temperature.Imperial.Unit; RealFeelTemperature;RelativeHumidity;WeatherText	temperatureHigh;temperatureLow;temperatureHighCelcius;temperatureLowCelcius	temp;humidity;temp_min;temp_max;coord: {lon:,lat:};weather: [{description}]; wind: {speed}

3.4 COVERAGE AND SEMANTIC LINKS ANALYSIS

In the final step of the methodology the coverage of the identified resources from the previous step is analysed, where we attempt to quantify to what extend the preliminary use-cases requirements are covered by the resources considered so far and to identify existing gaps. Apart from that, this step also includes the analysis of links between resources, towards detecting overlaps between models.

Since the outputs of this step are extensive and details need to be provided, we decided to present them in separate sections. More precisely, Section 4 presents the coverage analysis of requirements in existing resources while section 5 will present the semantic link analysis between resources.

4. COVERAGE ANALYSIS

Subject of this section is to present a deep analysis on how well existing resources cover the preliminary set of potential requirements derived from the BIMERR use cases reported in D3.1. For each of the identified requirements it can be analysed whether it is, in principle, covered by each resource. We say that a resource covers a requirement if there are entities of the resource that are relevant to the requirement, as shown in previous section. The coverage analysis report is divided into data models coverage (Section 0) and ontology coverage (Section 4.2). The data model coverage analysis results are shown first, since there are 3 ontologies (ifcOWL, E+OWL and SIM Model OWL) which are OWL representations of the corresponding data models, therefore only the mappings with the data models are shown to avoid repetition. However, their owl representations are considered in the ontologies coverage analysis.

Each subsection is further subdivided to analysis results for each domain in order to show the information in a more modular way. Domains that have been considered consist of those identified in D3.2 (building, materials, energy consumption, usage patterns and habits, weather, reality capture and GIS) and those raised from the use cases analysis (Project management). In addition, it has been commented that none of the requirements deals with the weather domain, therefore the grouping of requirements to show the coverage of the resources will refer to all the domains except "Weather".

4.1 COVERAGE ANALYSIS IN DATA MODELS

In this section, requirements are analysed for their coverage in the existing data models according to their domains. We have analysed all requirements with their domains in all data models and presented the coverage of existing requirements in separate tables.

4.1.1 Data model coverage in Building Domain

At first, we have analysed the requirements that are related to the Building domain in all existing data models. There are total 19 requirements related with the Building domain and 4 requirements (R8, R13, R28, R45) are not covered by any data model. A coverage matrix is presented in Table 7 to show the coverage of each requirement in existing data model.

Table 7. Coverage Matrix for Building Domain

	R2	R3	R4	R5	R6	R7	R8	R9	R10	R12	R13	R14	R16	R17	R19	R28	R40	R45	R46
IFC	√	√	√	√	√	√		√	√	√		√	√	√	√		√		√
Basic data formats (reality capture domain)																			
Cobie	√					√		√	√	√		√		√					√
BO-IDM	√					√		√	√					√					
BISDM	√					√		√	√										
GML3	√																		
CityGML	√	√				√		√	√				√						√
GBXML	√	√				√		√	√			√	√	√	√		√		
baubook.info						√			√										
eurobau.com						√													
AccuWeather																			
Weather2020																			
OpenWeather																			
Vector data model	√																		
Raster data model	√																		
EnergyPlus JSON/IDD	√	√				√		√				√							
obXML		√				√		√				√							
Simmodel SimXML	√	√				√		√	√	√		√	√	√	√		√		

4.1.2 Data model coverage in Material Domain

There are total 9 requirements related with the Material domain and 3 (R27, R38, R45) requirements are not covered by any data model. A coverage matrix is

presented in Table 8 to show the coverage of each requirement in existing data model.

Table 8. Coverage Matrix for Material Domain

	R17	R18	R19	R20	R27	R38	R40	R45	R46
IFC	√		√	√			√		√
Basic data formats (reality capture domain)									
Cobie	√	√							√
BO-IDM	√								
BISDM									
GML3									
CityGML									√
GBXML				√					
baubook.info									
eurobau.com									
AccuWeather									
Weather2020									
OpenWeather									
Vector data model									
Raster data model									
EnergyPlus JSON/IDD									
obXML									
Simmodel SimXML	√	√	√	√			√		

4.1.3 Data model coverage in Energy Consumption Domain

There are total 5 requirements related with the Energy Consumption domain and 4 requirements (R9, R15, R16, R47) are covered by analysed the data model. A coverage matrix is presented in Table 9 to show the coverage of each requirement in existing data model.

Table 9. Coverage Matrix for Energy Consumption

	R9	R15	R16	R47	R48
IFC	√	√	√	√	
Basic data formats (reality capture domain)					
Cobie	√				
BO-IDM	√	√			
BISDM	√				
GML3					
CityGML	√		√		
GBXML			√		
baubook.info					
eurobau.com					
AccuWeather				√	
Weather2020				√	
OpenWeather				√	
Vector data model					
Raster data model				√	
EnergyPlus JSON/IDD	√	√			
obXML	√	√			
Simmodel SimXML	√	√	√	√	

4.1.4 Data model coverage in Reality Capture Domain

In this domain there are 6 requirements (R12, R13, R14, R28, R29, R37) and 3 requirements (R12, R14, R37) are covered by analysed data models. A coverage matrix is presented in Table 10 to show the coverage of each requirement in existing data model.

Table 10. Coverage Matrix for Reality Capture Domain

	R12	R13	R14	R28	R29	R37
IFC	√		√			√
Basic data formats (reality capture domain)						
Cobie	√		√			√
BO-IDM						
BISDM						
GML3						√

CityGML						
GBXML			√			√
baubook.info						
eurobau.com						
AccuWeather						
Weather2020						
OpenWeather						
Vector data model						
Raster data model						
EnergyPlus JSON/IDD			√			
obXML			√			
Simmodel SimXML	√		√			√

4.1.5 Data model coverage in GIS

There are total 2 requirements related with the GIS domain and one (R5) requirement is covered by analysed data model. A coverage matrix is presented in Table 11 to show the coverage of each requirement in existing data model.

Table 11. Coverage Matrix for GIS Domain

	R5	R29
IFC	√	
Basic data formats (reality capture domain)		
Cobie		
BO-IDM		
BISDM		
GML3		
CityGML		
GBXML		
baubook.info		
eurobau.com		
AccuWeather		
Weather2020		
OpenWeather		
Vector data model		
Raster data model		
EnergyPlus JSON/IDD		
obXML		

Simmodel SimXML		

4.1.6 Data model coverage in Project Management Domain

There are 22 requirements as shown in Table 12, related with project management domain. Only 5 requirements (R35, R38, R39, R42, R44) are not covered by analysed domains.

Table 12. Coverage Matrix for Project Management Domain

	R1	R11	R21	R22	R23	R24	R25	R26	R30	R31	R32	R33	R34	R35	R36	R37	R38	R39	R41	R42	R43	R44
IFC	√	√			√		√		√		√				√	√					√	
Basic data formats (reality capture domain)																						
Cobie	√	√	√	√	√	√	√	√			√		√		√	√					√	
BO-IDM																			√			
BISDM		√																				
GML3										√		√				√						
CityGML											√										√	
GBXML			√		√				√		√		√		√	√					√	
baubook.info																						
eurobau.com																						
AccuWeather									√													
Weather2020									√													
OpenWeather									√													
Vector data model																						
Raster data model									√													
EnergyPlus JSON/IDD																						
obXML																						
Simmodel SimXML	√				√				√		√				√	√					√	

4.1.7 Data models coverage overview

In this section a general overview of the coverage of each data model for each domains is provided in the form of radar charts (Figure 3 to Figure 19). In such figures the number of requirements defined for each domain are indicated

between parenthesis and are also represented in the chart with red dotted lines. The number of requirements covered by each data model are represented in the chart by blue solid lines.

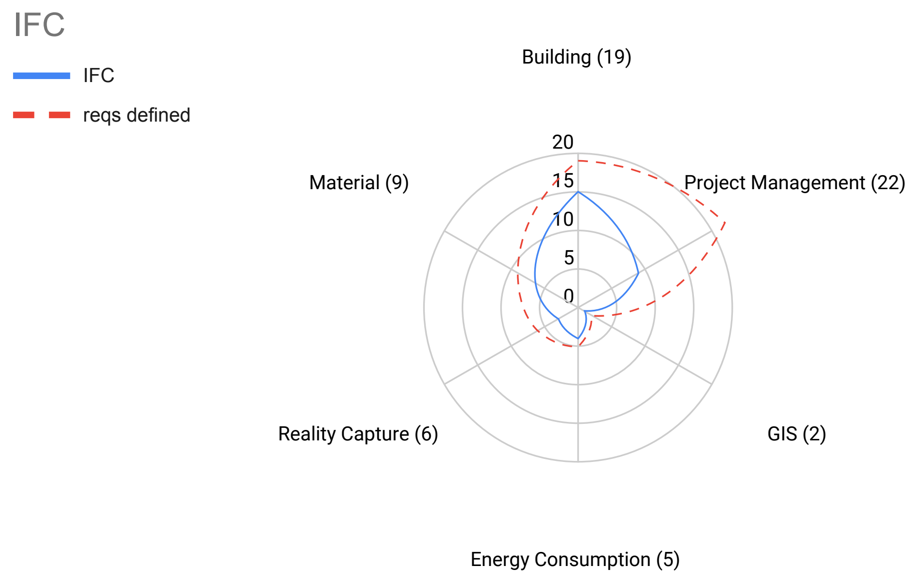

Figure 3. IFC coverage by domain

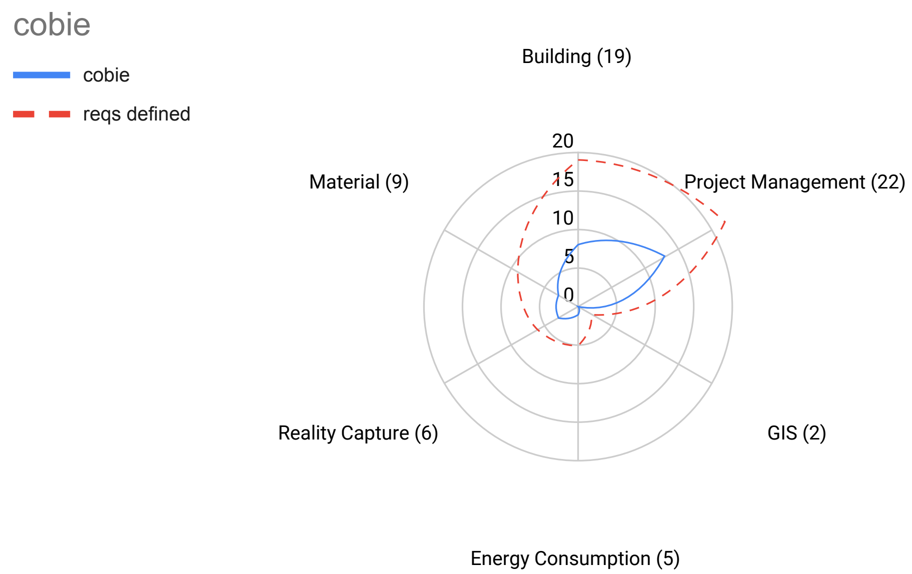

Figure 4. cobie coverage by domain

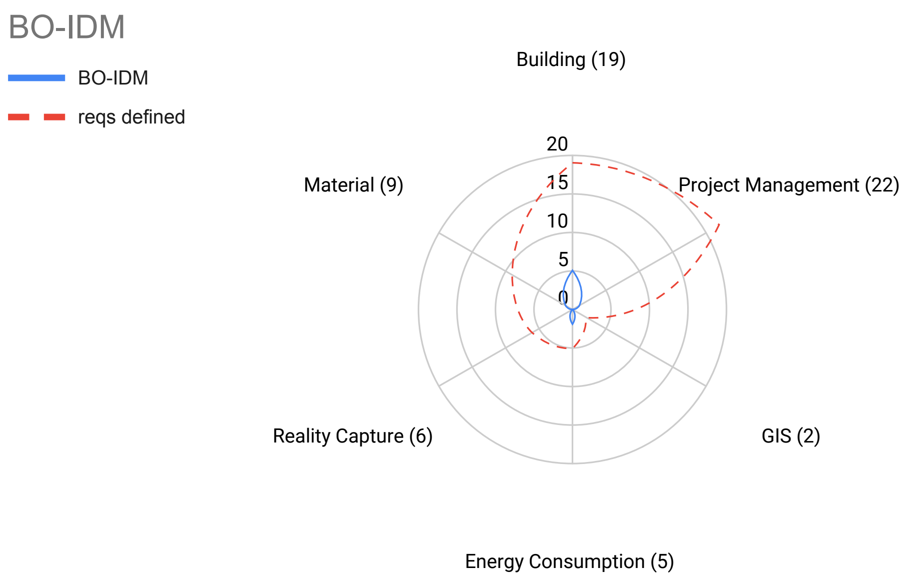

Figure 5. BO-IDM coverage by domain

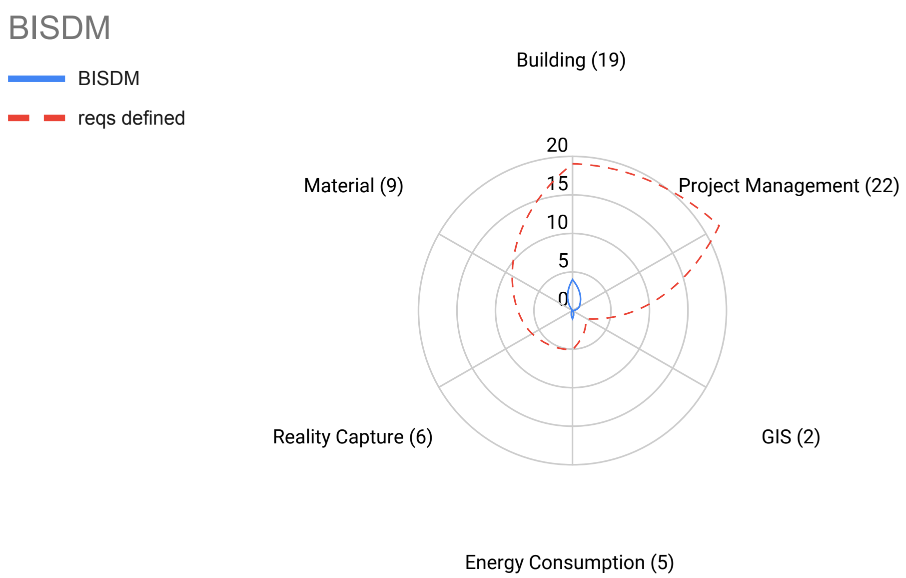

Figure 6. BISDM coverage by domain

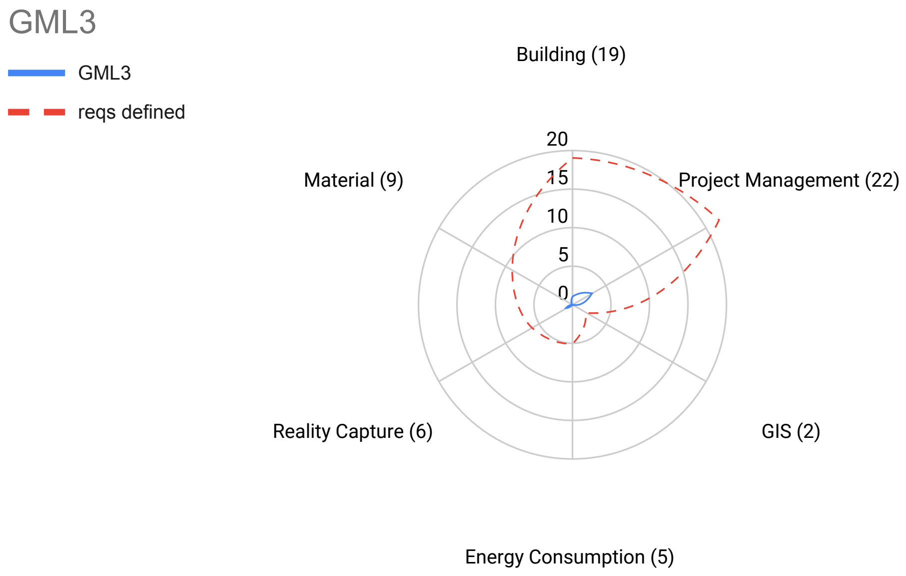

Figure 7. GML3 coverage by domain

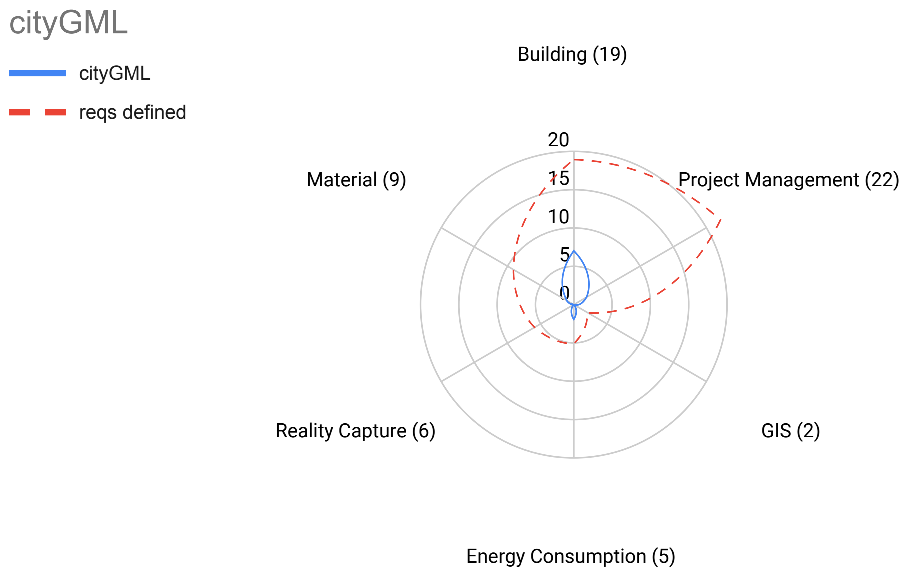

Figure 8. CityGML coverage by domain

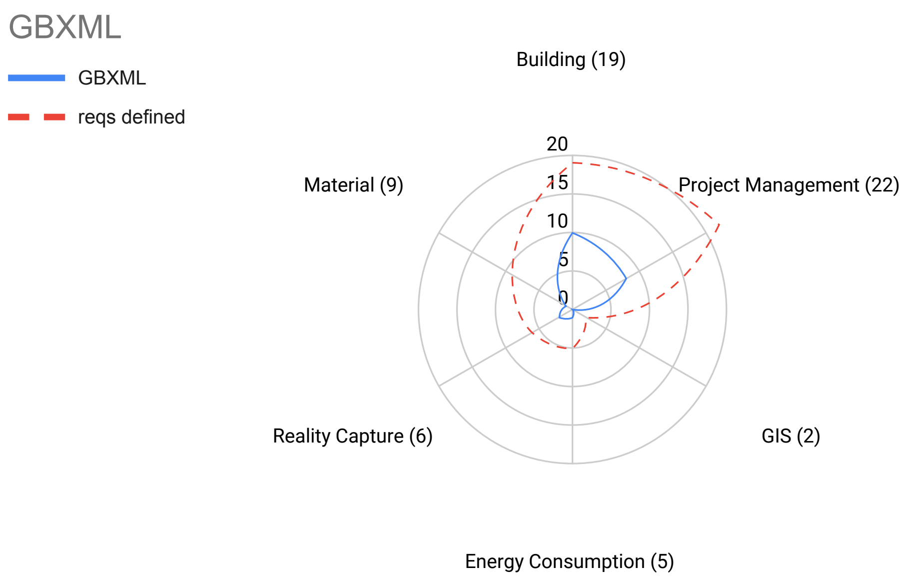

Figure 9. GBXML coverage by domain

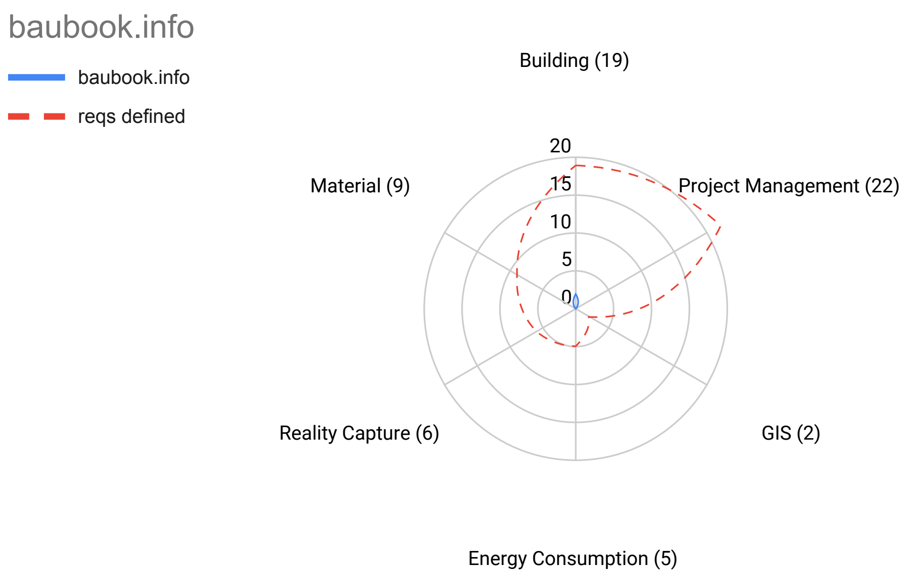

Figure 10. baubook.info coverage by domain

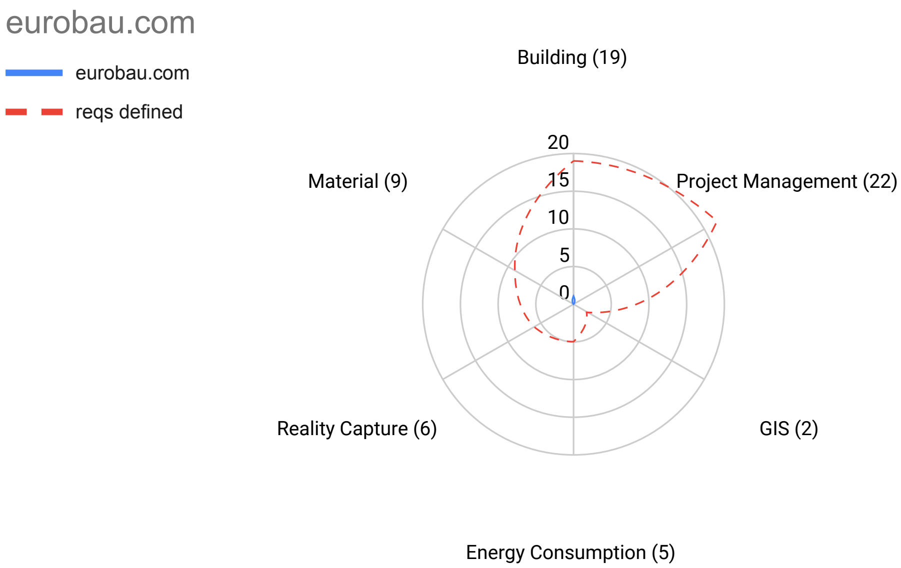

Figure 11. eurobau.com coverage by domain

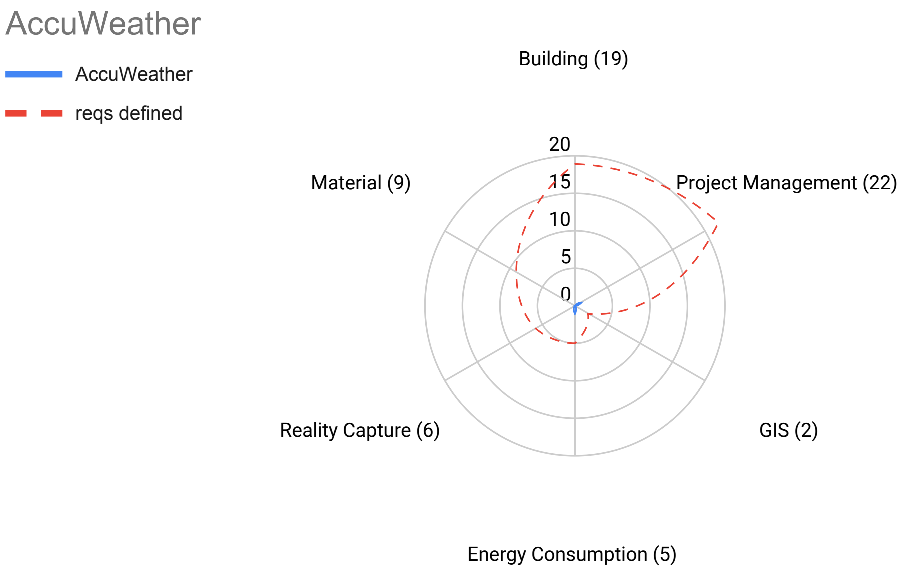

Figure 12. AccuWeather coverage by domain

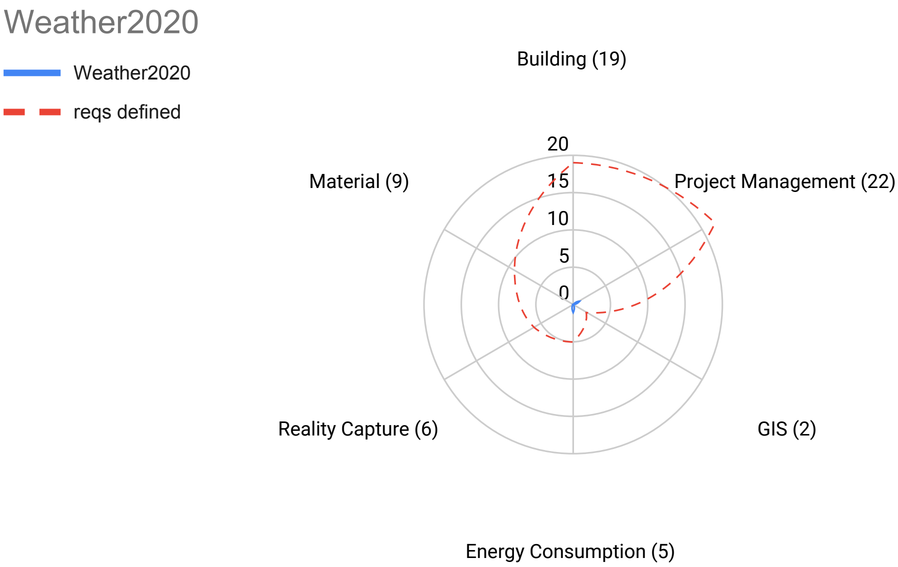

Figure 13. Weather2020 coverage by domain

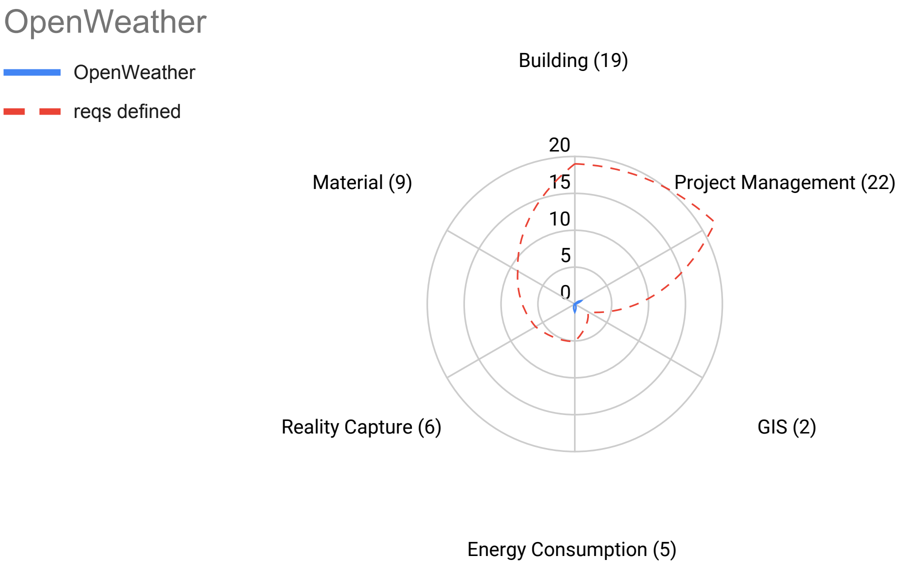

Figure 14. OpenWeather coverage by domain

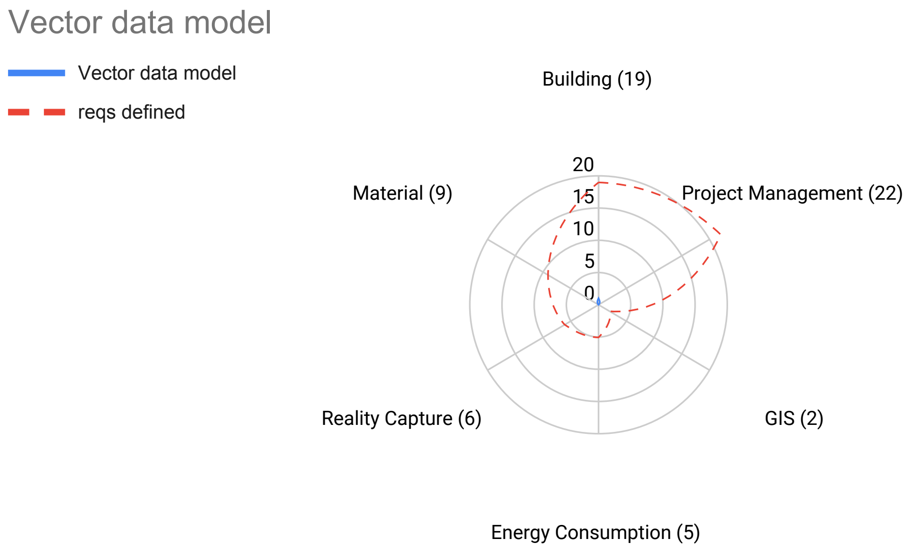

Figure 15. Vector data model coverage by domain

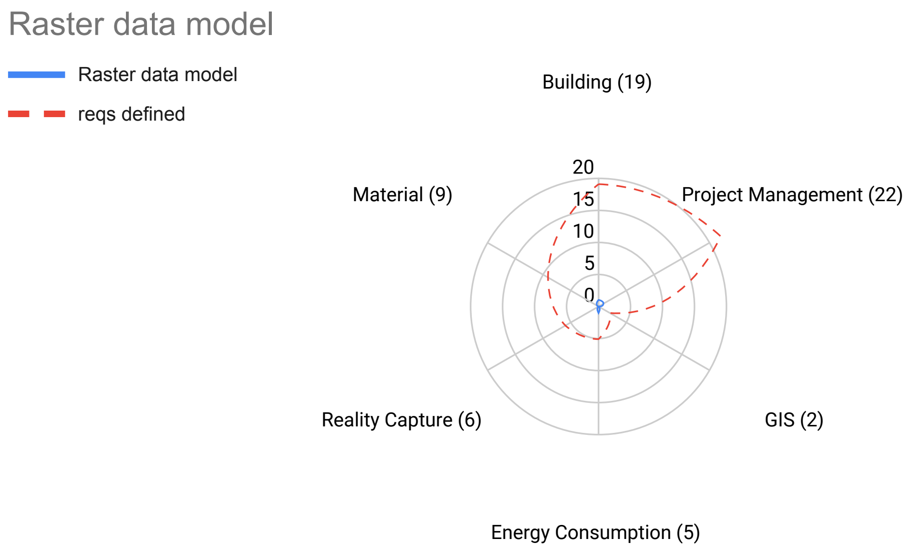

Figure 16. Raster data model data model coverage by domain

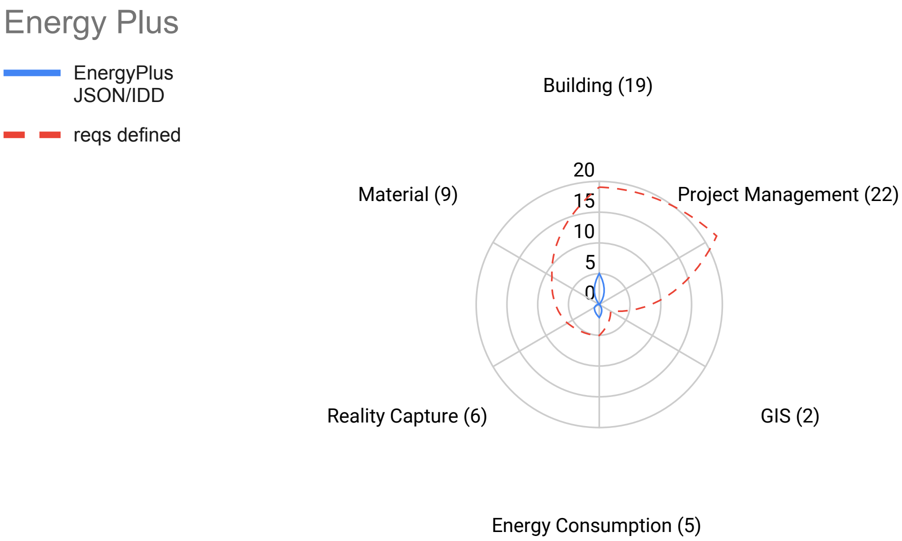

Figure 17. Energy Plus coverage by domain

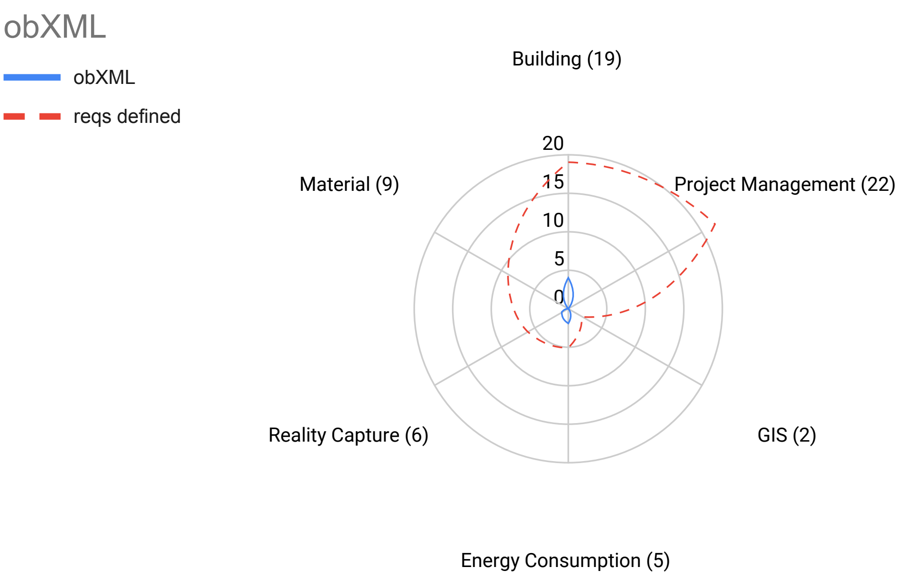

Figure 18. obXML coverage by domain

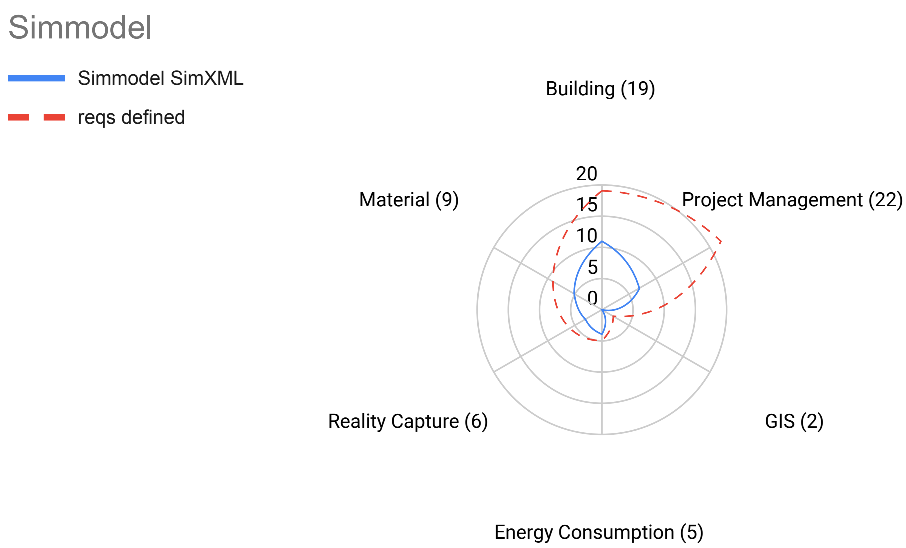

Figure 19. Simmodel coverage by domain

4.2 COVERAGE ANALYSIS IN ONTOLOGIES

In this section, requirements are analysed according to their coverage in the proposed ontologies grouped by domains. In the following, each subsection will show a table which summarizes which ontologies have at least one term related to the given requirement. It should be considered that this is an indication of potential resource to be reused, however it does not means that the ontology completely fulfils the requirement nor that it is perfectly suit for purpose. Each table shows the requirements for which at least one of the associated domain is being presented or analysed.

It is worth to remind that IFCOWL, E+ OWL and SIM Model OWL are not shown for readability issues and to avoid duplicates as they are equivalents to the data models IFC, EnergyPlus and SimXML shown in the corresponding section. However, such ontologies are considered for the overall coverage analysis.

4.2.1 Ontology coverage in Building Domain

At first, we have analysed the requirements that are related with the Building domain in all existing ontologies. There are total 19 requirements related with the Building domain. A coverage matrix is presented in Table 13 to show the coverage

of each requirement in existing ontologies. According to this analysis, there are 8 requirements (R2, R5, R7, R9, R12, R13, R14, R28) of building domain that are covered by *saref, saref4bldg, saref4ener, saref4city, SSN/SOSA, W3C bot* and *Geonames* and 11 requirements (R3, R4, R6, R8, R10, R16, R17, R19, R40, R45, R46) are not covered by any of the analysed ontologies.

Considering the ifcOWL, E+OWL and SimModel OWL ontologies, according to the respective data models analysis, the requirements covered would include in addition R3, R4, R6, R10, R16, R17, R19, R40 and R46.

Table 13: Coverage Matrix in Ontologies for Building Domain

	R2	R3	R4	R5	R6	R7	R8	R9	R10	R12	R13	R14	R16	R17	R19	R28	R40	R45	R46
Saref										√	√	√				√			
saref4bldg	√			√		√		√		√	√					√			
saref4ener											√					√			
saref4city				√							√					√			
oneM2M											√					√			
W3C SSN/SOSA										√	√					√			
W3C bot	√					√					√					√			
Oema																			
seas Weather																			
Geonames	√																		

4.2.2 Ontology coverage in Material Domain

There are 9 requirements related with the material domain and presented in the Table 14. According to the analysis, only 1 requirement (R38) is covered by *saref, saref4bldg, saref4ener, saref4city ,oneM2M, and SSN/SOSA,* ontologies while 8 requirements (R17, R18, R19, R20, R27, R40, R45, R46) are not covered by analysed ontologies.

Considering the ifcOWL, E+OWL and SimModel OWL ontologies, according to the respective data models analysis, the requirements covered would include in addition R17, R18, R19, R20, R40 and R46.

Table 14. Coverage Matrix for Material Domain

	R17	R18	R19	R20	R27	R38	R40	R45	R46
Saref						√			
saref4bldg						√			
saref4ener						√			
saref4city						√			
oneM2M						√			
W3C SSN/SOSA						√			
W3C bot									
Oema									
seas Weather									
Geonames									

4.2.3 Ontology coverage in Energy Consumption Domain

In the Energy Consumption domain, there are total 5 requirements presented in Table 15. In this domain, 3 requirements (R9, R47, R48) are covered in *saref, saref4bldg, saref4city, oema, and seas* ontology. According to the analysis, 2 requirements (R15, R16) are not covered in this domain.

Considering the ifcOWL, E+OWL and SimModel OWL ontologies, according to the respective data models analysis, the requirements covered would include in addition R15 and R16.

Table 15. Coverage Matrix for Energy Consumption Domain

	R9	R15	R16	R47	R48
Saref				√	
saref4bldg	√				
saref4ener					
saref4city					√
oneM2M					
W3C SSN/SOSA					
W3C bot					
Oema				√	
seas Weather				√	
Geonames					

4.2.4 Ontology coverage in Reality Capture Domain

In the Reality Capture domain, there are total 6 requirements as described in Table 16. In this domain, 5 requirements (R12, R13, R14, R28, R29) are covered by *saref, saref4bldg, saref4ener, saref4city, oneM2M, SSN/SOSA, and bot* ontology. According to the analysis, only 1 requirement (R37) is not covered by the analysed ontologies.

Considering the ifcOWL, E+OWL and SimModel OWL ontologies, according to the respective data models analysis, the requirements covered would include in addition R37.

Table 16. Coverage Matrix for Reality Capture Domain

	R12	R13	R14	R28	R29	R37
saref	√	√	√	√	√	
saref4bldg	√	√		√		
saref4ener		√		√		
saref4city		√		√		
oneM2M		√		√		
W3C SSN/SOSA	√	√		√		
W3C bot		√		√		
oema						
seas Weather						
Geonames						

4.2.5 Ontology coverage in GIS Domain

In GIS domain, there are total 2 requirements (R5, R29) as shown in Table 17. In this domain, both requirements would be covered, R29 by *saref* and *geonames,* which also covers R5 as well as saref4bldg and saref4city.

Table 17. Coverage Matrix for GIS Domain

	R5	R29
Saref		√
saref4bldg	√	
saref4ener		
saref4city	√	
oneM2M		
W3C SSN/SOSA		
W3C bot		
Oema		
seas Weather		
Geonames	√	√

4.2.6 Ontology coverage in Project Management Domain

Project management domain is also analysed as it arise from the use cases. There are 22 requirements related with this domain and described in Table 18. But only 5 requirements (R30, R31, R33, R34, R38) are covered by *saref*, ,saref4bldg, saref4ener, *saref4city,* oneM2M, *SSN/SOSA*, *oema, and geonames* ontologies. According to the analysis 17 requirements (R1, R11, R21, R22, R23, R24, R25, R26, R32, R35, R36, R37, R39, R41, R42, R43, R44) are not covered by any analysed ontology. As this domain was not considered during the resources search in D3.1 it is expected to not to have much coverage with the list of current ontologies and data model considered. Therefore, if the data to be exchanged within BIMERR interoperability framework is related to this domain, a new search for resources covering this type of dat should be carried out during T4.2.

Considering the ifcOWL, E+OWL and SimModel OWL ontologies, according to the respective data models analysis, the requirements covered would include in addition R1, R11, R23, R25, R32, R36, R37 and R43.

Table 18. Coverage Matrix for Project Management Domain

	R1	R11	R21	R22	R23	R24	R25	R26	R30	R31	R32	R33	R34	R35	R36	R37	R38	R39	R41	R42	R43	R44
saref									√	√		√	√				√					
saref4bldg																	√					
saref4ener																	√					
saref4city									√								√					
oneM2M																	√					
W3C SSN/SOSA																	√					
W3C bot																						
Oema									√													
seas Weather									√													
Geonames									√													

4.2.7 Ontologies coverage overview

In this section a general overview of the coverage of each ontology for each domains is provided in the form of radar charts (Figure 20 to Figure 29). In such figures the number of requirements defined for each domain are indicated between parenthesis and are also represented in the chart with red dotted lines. The number of requirements covered by each ontology are represented in the chart by blue solid lines. For the case of ifcWOL, E+OWL and SIMModel OWL, the coverage shown for their respective data models apply.

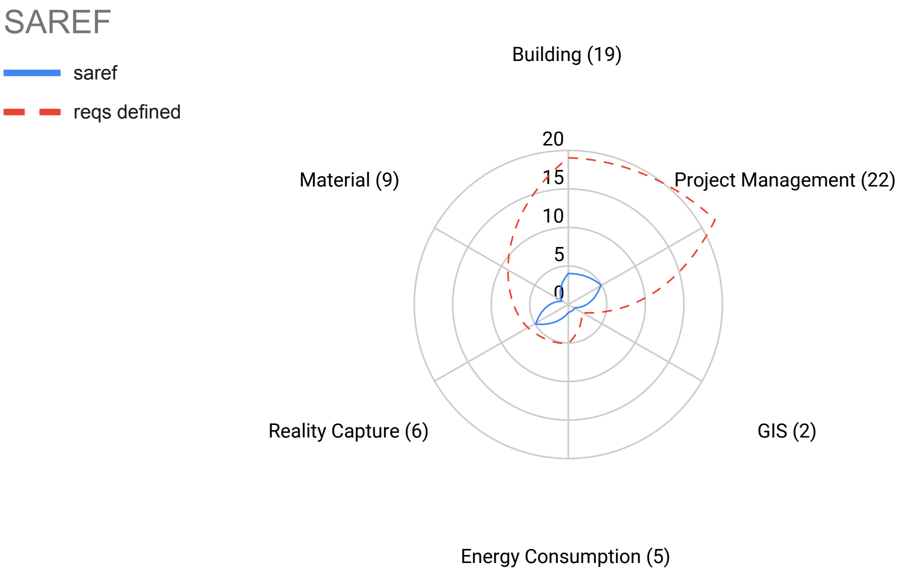

Figure 20. SAREF coverage by domain

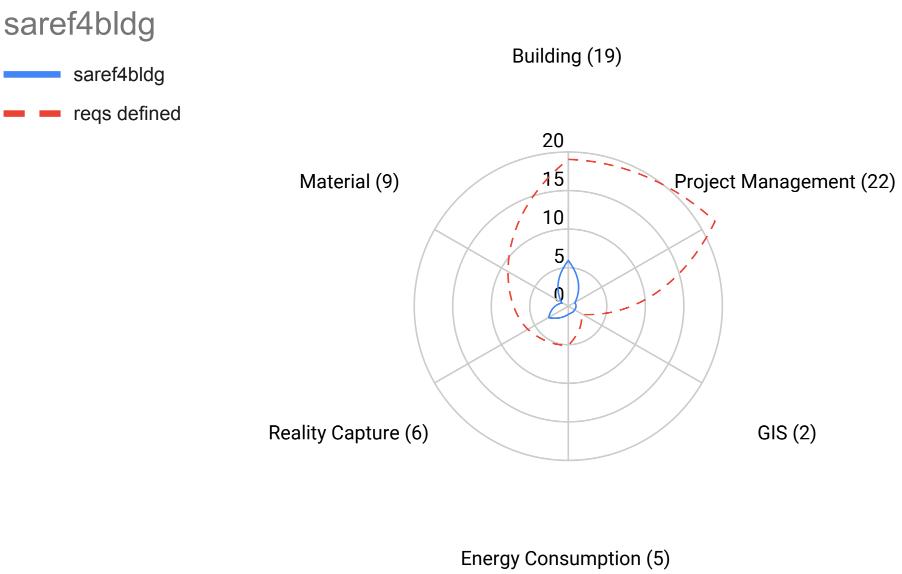

Figure 21. saref4bldg coverage by domain

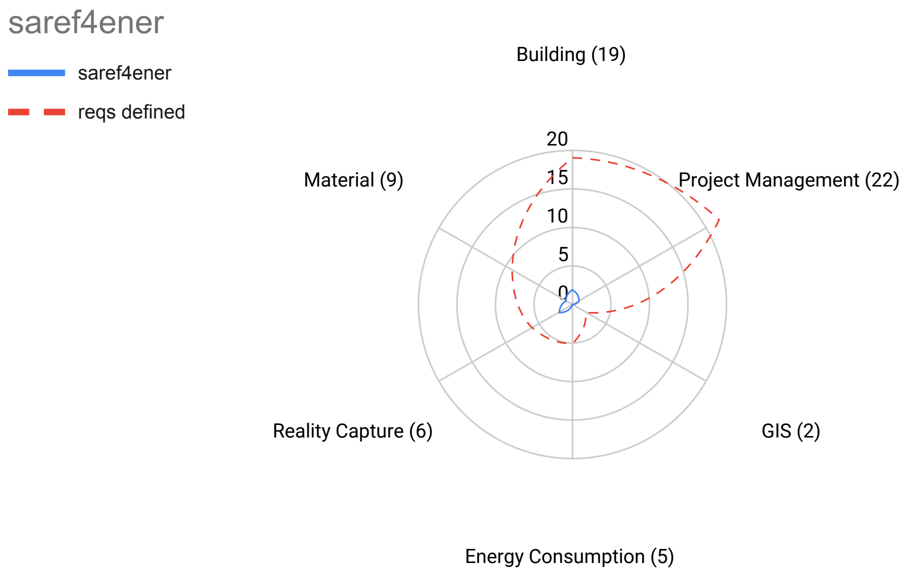

Figure 22. saref4ener coverage by domain

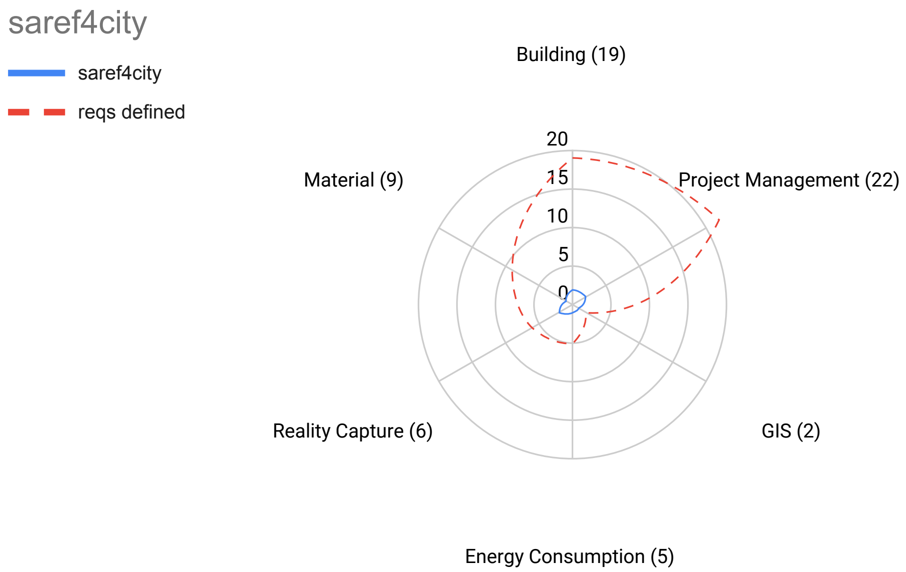

Figure 23. saref4city coverage by domain

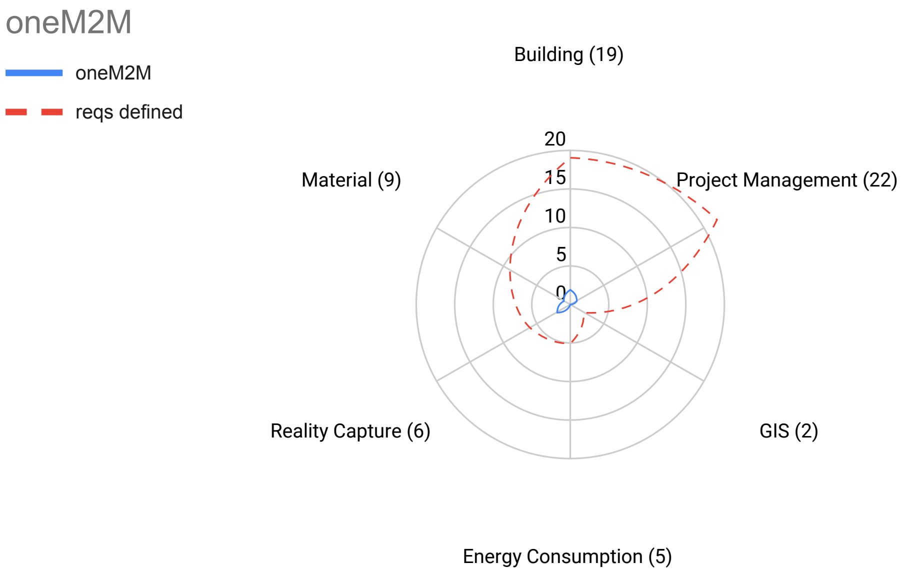

Figure 24. oneM2M coverage by domain

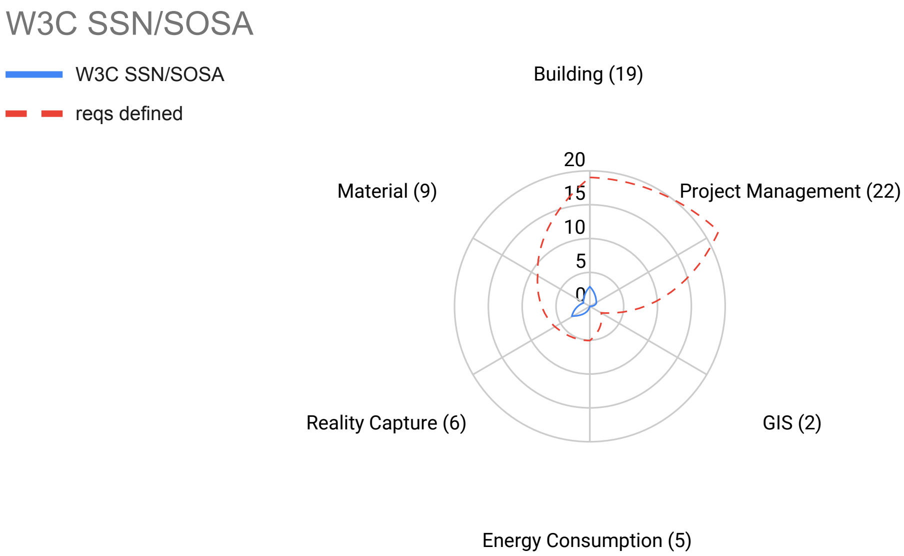

Figure 25. W3C SSN/SOSA coverage by domain

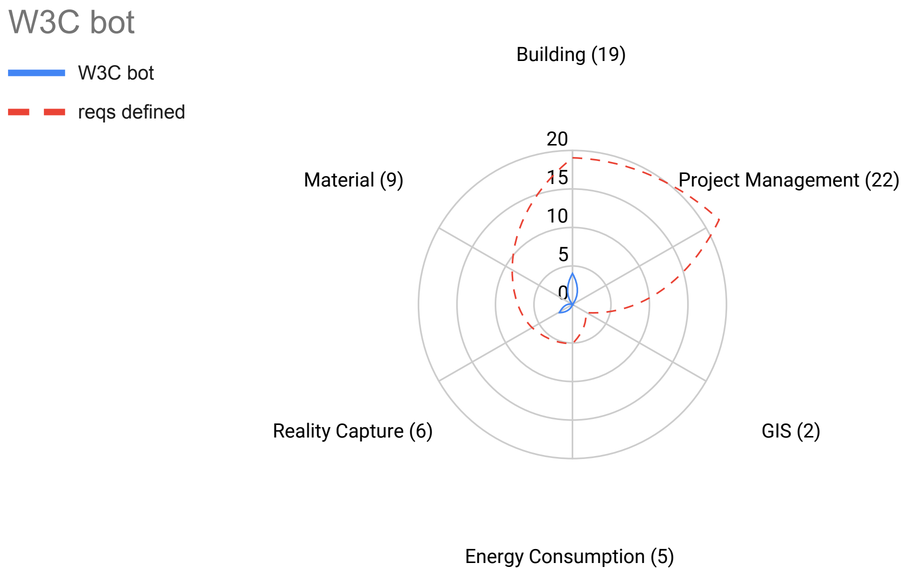

Figure 26. W3C bot coverage by domain

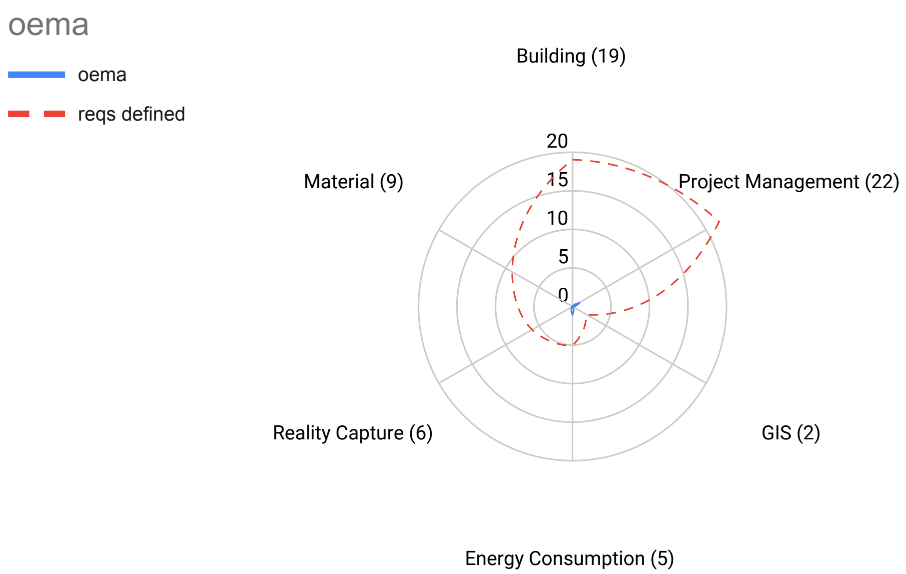

Figure 27. oema coverage by domain

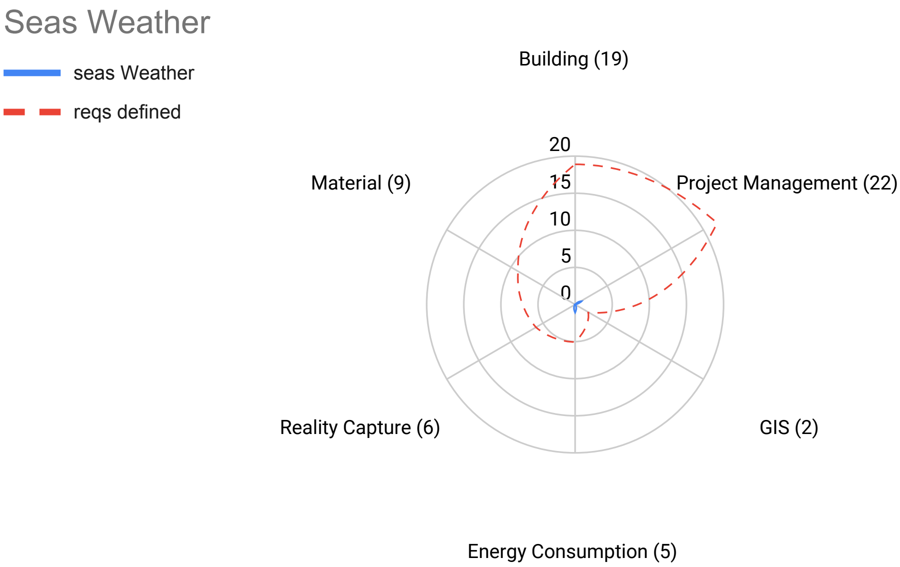

Figure 28. Seas weather coverage by domain

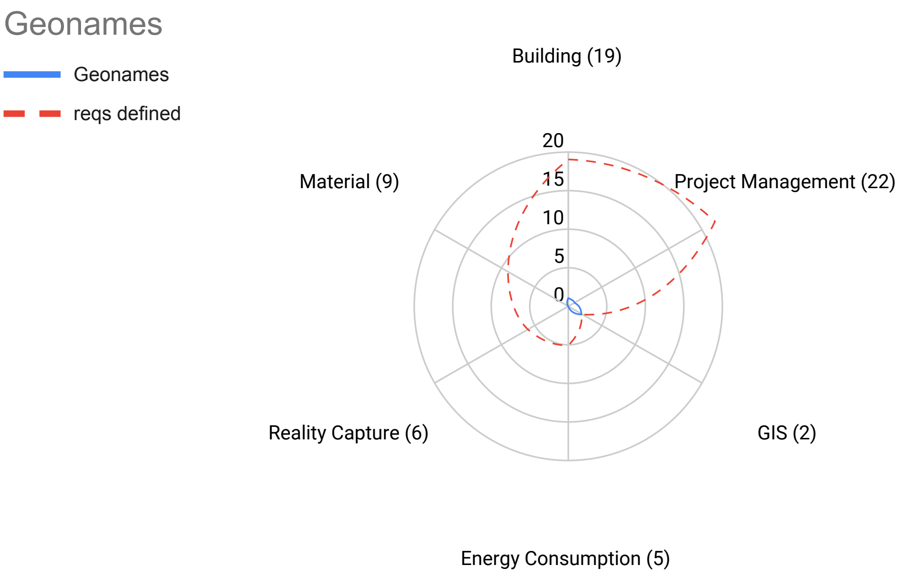

Figure 29. Geonames coverage by domain

5. SEMANTIC LINK ANALYSIS

In Section 4, an analysis of the existing resources with respect to their capability on capturing the identified requirements has been presented. Results of section 4 have been taken as input to present the Semantic Link Analysis of requirements in existing resources. Semantic links [Pernelle, 2016] hold the relationship between two different resources and present the concept information available in different resources. Semantic links between ontologies are used to present the association in the existing ontologies. In our case, the existence of semantic links between two resources, suggest that the resources contain the related concepts that relevant to the set of requirements, which means that it is possible to link information encoded in those concepts.

In Section 4, we analysed 10 ontologies (and 3 equivalents to analysed data models) and 21 data models to present a semantic link analysis of proposed set of requirements. It has been observed that some ontologies are more suitable for building coverage as saref4bldg or W3C bot, however they only represent buildings and their spaces in a quite general way and could be only linked at a high level to specific ontologies as IFC OWL.

Several ontologies are suitable for devices representation such as SAREF, its extensions and *SSN/SOSA*. In fact, SAREF family of ontologies gradually adopts the SSN/SOSA conceptual models, therefore they are quite well aligned in the definition of devices and systems. In contrast, although oneM2M adopts the device concept, it does not capture devices information in detail, since it is more oriented to services, functions and processes.

Several ontologies such as *saref, oema* and *seas* are linked to *Temperature, Humidity, EnergyEquipment, Illuminance* concepts while for coordinates, features and grid presentation, ifcOWL and Geonames ontologies are suitable for different concepts such as *IfcCoordinateOperation, IfcGridAxis* and *Feature.*

Finally, regarding ontologies there are some common points modelling ambient properties between SAREF ontologies, oema and the SEAS module.

With regards to the data models, in the building domain we observe that several concepts play a central role that link the analysed data models. For examples, the concept of Building and its components are represented to a more specific or general extent, by most of the data models, namely IFC, cobie, BO-IDM, BISDM, GBXML, SIMXML and GBXML. More specifically, for the case of building components, like doors, windows, wall, etc, there is strong relation between IFC, BO-IDM CityGML and Simmodel.

Regarding materials, there are common concepts between IFC, cobie, BO-IDM, Simmodel and GBXML in terms of defining material, material types and material layers.

Different models like IFC, cobie, GBXML and Simmodel provide concepts for modelling roles involved in projects even though they use different terms to refer to them, like “actor”, “person” or “role”. However, correspondences among them could be defined.

With respect to energy consumption, there are similar concepts defined in EnergyPlus, GBXML and Simmodel that define “schedule” and OBXML that defines the related concept “behaviour”. In addition, the HVAC concept appears to be represented in IFC, EnergyPlus, SimXML, obXML and BI-SDM but in different levels of detail.

For the spatial information, links between the models cobie, GBXML, OBXML that define “Space”, SimXML that defines “SpatialZone” and ifc that defines “IfcSpatialZone” can be observed.

As for the weather domain, we analysed 3 data models (AccuWeather, Weather2020 and OpenWeather) and we observe that there exists a strong relationship between them given the fact that all of them have similar concepts for describing weather-related properties (e.g., temperature, humidity).

6. CONCLUSIONS

One of the main goals of BIMERR project is to provide semantic interoperability among different data sources. As a first attempt towards this goal, a survey of ontologies and data model was presented in the D3.2. In this deliverable, a methodology has been presented to identify a preliminary subset of requirements, as they derived from the use cases, and their coverage from existing resources (ontologies and data models). Currently, 48 conceptual requirements have been identified and analysed. Results of how well existing ontologies and data models can capture the conceptual requirements have been thoroughly presented in the previous sections. A summary of the analysis' conclusions is presented in Table 19; note that since each requirement can be considered in one or more domains, the number of requirements in Table 19 is greater than 48. For the sake of clarity, the ontologies IFC OWL, E+OWL and SimModel OWL results have been identical to the IFC, EnergyPlus and SimXML data models, respectively.

On the one hand, existing ontologies and data models seem to be able to capture a wide range of the preliminary/conceptual requirements. However, during T4.2, the cost of transforming non ontological resources into ontologies and analysing the modelling decisions of existing ontologies (e.g. to check that there are no conceptual errors), maintenance of existing resources, organizations that support them, their availability in open formats and under an open licence should also be considered.

Table 19. Requirements Summary in ontologies and data models

Domains	Requirements	Ontologies		Data models	
		Covered	Not covered	Covered	Not covered
Building	19	17	2	15	4
Material	9	7	2	6	3
Energy Consumption	5	5	0	4	1
Reality Capture	6	6	0	3	3
GIS	2	2	0	1	1
Project Management	22	13	9	17	5

In light of the given results, it is obvious that the most complete resources are IFC (and therefore its corresponding ontology ifcOWL), cobie, BO-IDM and BISDM for building information, and SimModel. Such result was expected, since SimModel is a combination of IFC and EnegyPlus schemas.

Besides the rich content of the IFC model and its ontological representation, that are expansive and may contain multi-faceted information regarding the building (geometry, HVAC, Quantities, Processes, etc.), we have to take into account that to meet the BIMERR data requirements, either a subset (here the Model View Definition (MVD) specification allows to define, in a formal way, such a subset in the form of precise exchange requirements) or possible extensions of it may be request.

Regarding the weather data, even though this domain does not appear in the use cases, it is considered as external data to be taken into account in the architecture for some components/modules. Results have shown that the SEAS weather ontology offers a better coverage than the weather-related data models, that is, AccuWeather, Weather2020 and OpenWeather. However, hourly weather data requirements that have been raised from specific energy simulation engines may affect the results of the weather domain analysis and may require further data models to be analysed.

For the case of the project management domain the data models IFC and cobie followed by GBXML and SimModel are the most promising. As mentioned above, is should be known which specific data about this domain will be handled in the system in order to reuse and existing model, look for other resources in the domain or model from scratch.

While it seems that the reality capture domain would be covered by the ontologies analysed, it should be taken into account that the requirements and the mappings at this stage are done at a high level, therefore it is likely the some specialization of the existing terms is needed to fully cover the data.

Note here that a similar analysis for additional domains may be requested during the ontology and data model development. Therefore, this deliverable consists the first vision of the existing ontology and data models coverage analysis, while final results will be presented in D4.2, where the BIMERR system architecture and its components/modules data requirements will be well-defined and finalized.

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