BIMERR
RENOVATION 4.0

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Acronyms

Acronym	Meaning
ABAC	Attribute Based Access Control
BIF	BIMERR Interoperability Framework
BIM	Building Information Modelling
BIM-MP	Building Information Modelling Management Platform
BISP	Building Information Secure Provisioning
BOT	Building Topology Ontology
CDE	Common Data Environment
CSS	Cascading Style Sheets
ETSI	European Telecommunications Standards Institute
GIS	Geographic Information System
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
IFC	Industry Foundation Classes
IoT	Internet of Things
ISO	International Organization for Standardization
OASIS	Organization for the Advancement of Structured Information Standards
obXML	Occupant Behaviour XML
OWL	Web Ontology Language
PRUBS	Profile Resident Usage of Building System
PWMA	Project Workflow Management
RenoDSS	Renovation Decision Support System
RDF	Resource Description Framework
SAREF	Smart Appliances REFerence ontology
SKOS	Simple Knowledge Organization System
SPARQL	SPARQL Protocol and RDF Query Language
TC	Technical Committee
URI	Uniform Resource Identifier
WoT	Web of Things
W3C	World Wide Web Consortium

XACML	eXtensible Access Control Markup Language
XML	eXtensible Markup Language

EXECUTIVE SUMMARY

This deliverable describes the involvement of the BIMERR project in standardization as of M30 in the following aspects:

- The use of standards by BIMERR components
- The participation of BIMERR partners in relevant standards initiatives and fora
- The current contribution of the BIMERR project to standards

This deliverable includes the MS8 “standardization punch list”, which lists the standardization initiatives to be addressed by BIMERR partners and describes the current contributions to such list as well as additional efforts in line with standardization.

1. INTRODUCTION

This document (D10.12) summarizes the current involvement of BIMERR project in standardization activities and reports on the use of standards in the different BIMERR components. This deliverable also identifies potential liaisons between BIMERR components and standardization activities or results, these relations are taken as input to define the Milestone 8 "Standardization punch list" which is included in Section 4.

A broad review of standardization initiatives related to BIMERR has been presented in D3.2 [Poveda-Villalón et.al., 2019] focusing on those initiatives related to the domains of the different data assets being generated or shared by BIMERR applications, i.e. material, buildings, energy consumption, usage patterns and habits, weather, reality capture and Geographic Information System (GIS). In this document, the focus is not only on the domain specific standards but also on technology support ones, for example communication protocols over the web or authorization.

1.1 CONTEXT WITHIN BIMERR

One of the objectives of WP10 is to promote BIMERR outcomes to the appropriate standardization bodies and committees. For doing so, we have (1) surveyed the current participation of partners in standardization initiatives; (2) mapped the BIMERR components to the standards being used; and (3) identified potential outcomes of the project that could be promoted or used as input within standardization activities. This work and the experience of standardization activities led us to propose action points for promoting BIMERR outcomes to organizations as W3C WoT Working Group, W3C Linked Building Data Community Group and ETSI.

2. BIMERR Use of Standards

This section reports on the standards that are being used within BIMERR. These standards range from semantic models to authorization systems, including communication protocols and methodological practices. This document focuses on the most important standards in domains related to BIMERR that are actively being used by BIMERR partners. That is, as in many technological developments many standards are embedded in reused components for example those related to telecommunications as IEE 802 for Local Area Networks for the communication with sensors but in some cases that use is transparent to the development, therefore these type of very basic standards are not considered in this report.

2.1 Imaging System Standards

The **E57 committee**[1] from ASTM (American Society for Testing and Materials) focuses on the development of standards for 3D imaging system. These systems range from laser scanners to optical range cameras.

The E57 formats can be used to store point clouds, transformation matrix and pictures. Such files can be taken as input and be processed by the Scan-to-BIM BIMERR application developed by UEDIN.

2.2 Building and Energy Information Standards

The **Industry Foundation Classes (IFC)** is an open BIM standard elaborated by buildingSMART that facilitates the exchange of data between software applications in a collaborative environment in the AEC/FM sector. Nowadays, the data schema for IFC is regulated by the standard ISO 16739-1:2018 [ISO, 2018] that is defined in EXPRESS data

[1] https://www.astm.org/COMMITTEE/E57.htm

specification language, XML Schema definition (XSD), text encoding of the exchange structure and in Extensible Markup Language (XML).

Several BIMERR applications use IFC version 4.1 in STEP format, for example Scan-to-BIM to generate the initial building models in IFC or RenoDSS, BIM-MP and ARIBFA to process the original building models, as well as add or alter to the models at different stages.

Dynamic data, as **Occupant Behavior (OB),** has been pointed out as the main cause of uncertainty in building energy performance results. To address this problem, the Annex 66 project [IEA–EBC Annex 66, 2013] [2] started working in 2013 to provide a clear understanding of the energy-related occupant behavior in buildings. The main output of this work is the standardized Occupant Behavior XML schema (obXML).

The BIMERR application PRUBS makes use of the obXML model to describe occupant behavior data to be used in the building energy efficiency calculations.

In addition, the BIMERR ontology network has taken this standard as input to produce one of the ontologies of the network.

The **ISO 19650** international standard series focuses on information management over the whole life cycle of a built asset when employing building information modelling. It comprises a set of 5 parts, namely: Part 1 – Concepts and principles, Part 2 – Delivery phase of the assets, Part 3 – Operational phase of the assets, Part 4 – Information exchange (under development) and Part 5 - Security-minded approach to information management.

The ISO 19650 parts 1, 2, 4 and 5 are used by different BIMERR modules and applications. More precisely the BIF, Scan-to-BIM and RenoDSS, in particular, are aligning with the principles of the Common Data Environment (CDE) and the naming and metadata

[2] https://annex66.org/

recommendations for Information Containers. In addition, the PWMA's delivery execution plan is in effect a Master information delivery plan (MIDP) , being based on a process map that identifies, at a high level, the deliverables (what), responsibility (who), method (how) and timeline/sequence (when) for the overall renovation design and construction process.

OpenID Connect 1.0[3] is a simple identity layer on top of the OAuth 2.0 protocol. It allows Clients to verify the identity of the End-User based on the authentication performed by an Authorization Server, as well as to obtain basic profile information about the End-User in an interoperable and REST-like manner.

In BIMERR we use the OpenID Connect protocol for authentication and secure exchange of profiles among users and applications. This protocol uses OAuth 2.0 flows internally to authenticate users and clients. The flows prescribe different authentication mechanisms with respect to the provided credentials such as username, password, secret, and certificate. Each flow typically involves exchanging these credentials with an Identity Provider and getting back a verifiable security token.

The eXtensible Access Control Markup Language[4] (**XACML**) is an OASIS (Organization for the Advancement of Structured Information Standards) standard addressing the basic requirements of a policy language for expressing system security policies and corresponding methods.

The BIMERR Building Information Secure Provisioning (BISP) empowers the BIMERR Interoperability Framework with an out-of-the-box Attribute Based Access Control (ABAC) mechanism, which supplies the data consumers with the requested data to the supported format. To this end, a standardized approach has been taken into account that derives from the XACML model. More specifically, in the context of T4.5, an attribute-based mechanism has been developed, which allows the definition of the access policies through a set of rules. These rules are composed of attributes that contain information

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[3] https://openid.net/connect/

[4] http://xml.coverpages.org/xacml.html

regarding users, applications, and other resources. Then, a decision on whether a given user or application may access a given dataset in a particular way is produced. This approach constitutes the core business logic of the BISP tool by following the XACML standard, which defines a declarative, fine-grained, attribute-based access control policy language that aims to support the aforementioned mechanism.

Sensor Measurements Lists (**SenML**)[5] is a standard data model for carrying simple sensor data. The data following the SenML model can be serialized into various portable representations such as JSON and CBOR with very limited computing resources. Moreover, large amounts of data in SenML can be efficiently parsed by consumers incrementally and without requiring extensive memory and computation. The SenML model is used across the BIMERR platform to exchange sensor data, operational measurements by gateways as well as sensor annotations.

2.3 W3C Web Standards

The World Wide Web Consortium (W3C) is an international standardization community founded and led by the web inventor Tim Berners-Lee. It is devoted to developing protocols and guidelines to ensure the long-term growth of the web and the final goal is to leverage the full potential of the World Wide Web.

Two of the main core standard technologies for building web pages are **HTML** (the Hypertext Markup Language) and **CSS** (Cascading Style Sheets). HTML[6] is a language for describing the structure of web pages and provides the means to publish online documents, retrieve online information, design forms for conducting transaction and

[5] https://datatracker.ietf.org/doc/html/rfc8428

[6] https://www.w3.org/html/

include other media content in the web pages. CSS[7] is the standard language for describing the presentation of web pages, that is the layout, colors and fonts.

The Hypertext Transfer Protocol (**HTTP**) is an application-level request/response protocol that uses extensible semantics and self-descriptive message payloads for flexible interaction with network-based hypertext information systems. It is defined in collaboration between W3C and the Internet Engineering Task Force (IETF[8]).

HTML and CSS standards are being used in the BIMERR ontology network portal and for each of the published ontologies, in order to describe the information and provide the layout. HTTP protocol is being used as publishing protocol. More details about publication using HTTP are provided in the next section regarding the particular use of the protocol in the context of the semantic web.

2.4 W3C Semantic Web Standards

In order to develop the BIMERR ontology network a number of standard technologies defined under the umbrella of the semantic web have been used.

The Resource Description Framework (**RDF**[9]) is a standard data model defined by the W3C to describe resources on the web. The basic structure of this data model is called "triple" and it is composed of three elements, namely: "subject", "predicate", and "object". This data model represents the basis for the linked data developments, that is, the technology used to represent data, classifications, and their relations.

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[7] https://www.w3.org/Style/CSS/

[8] https://www.ietf.org/

[9] https://www.w3.org/TR/rdf11-primer/

The Web Ontology Language (**OWL**[10]) is an ontology implementation language designed to represent shared ontologies on the web based on RDF. It is defined by the W3C. This language extends the capabilities of other ontology languages, such as RDF-S[11], by means of incorporating a new vocabulary with attached formal semantics that includes inference features. OWL allows creating classes, hierarchies, and properties, as well as RDF-S, but also creating for class axioms.

SPARQL Protocol and RDF Query Language **(SPARQL**[12]**)** is a query language for RDF data established as official recommendation of the W3C. This language allows for mandatory or optional pattern matching in order to query the database. In addition, SPARQL allows for the application of constraints over the queries by stating the graph(s) over which the query should be checked. The results of the SPARQL queries could be a set of values or RDF graphs.

These standards, RDF and OWL, shape the technical basis on top of which ontologies that enable the semantic interoperability are described. The BIMERR ontology network modules are developed using the OWL language which is in turn serialized as RDF files. In addition, the RDF data model is also used by the Knowledge Graph Generator (KGG) that transforms external data sources to RDF and provides a SPARQL endpoint to allow querying the data.

In addition to these technologies, in the context of Linked Data some recommendations have been made in order to guide the development and publication of data. First, we should mention the Linked Data principles[13] described by Tim Berners-Lee taken literarily:

1. *Use URIs as names for things.*

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[10] https://www.w3.org/TR/owl-ref/

[11] https://www.w3.org/TR/rdf-schema/

[12] https://www.w3.org/TR/sparql11-query/

[13] https://www.w3.org/DesignIssues/LinkedData.html

2. *Use HTTP URIs so that people can look up those names.*
3. *When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL)*
4. *Include links to other URIs, so that they can discover more things.*

Therefore, in the ontology and KGG publication, HTTP and the best practices for publishing ontologies[14] provided by the W3C are also used.

2.5 Ontology Standards

Reusing ontologies is considered a best-practice as reuse promotes in a straightforward way the development of more interoperable ontologies while saving resources during ontology development. In this sense, the BIMERR ontology network has been built considering the reuse of existing ontologies when possible. From the reused ontologies, the following ones are provided by standardization bodies, therefore, considered standard ontologies:

2.5.1 W3C ontologies

The above mentioned W3C standardization body has developed a number of ontologies or vocabularies to harmonize semantic definitions of particular domains by applying the technologies defined in the context of the semantic web, that is RDF, RDF-S and OWL. The following standard ontologies provided by the W3C are being reused within the BIMERR ontology network and the BIMERR middleware.

- The Thing Description (TD[15]) ontology (**WoT** ontology) represents an RDF axiomatization of the TD information model[16], one of the building blocks of the Web of Things (WoT). This ontology is used within the BIMERR middleware to

[14] https://www.w3.org/TR/swbp-vocab-pub/

[15] https://www.w3.org/2019/wot/td

[16] https://www.w3.org/TR/wot-thing-description/

represent metadata of various devices deployed in renovation sites. The metadata described how to securely interact with devices at the protocol level.

- **Time** OWL ontology[17]: This W3C ontology provides semantic definitions for temporal concepts and relationships. This ontology is used within the BIMERR ontology network to represent temporal entities and durations.
- The Building Topology Ontology [Rasmussen, et al, 2019] (**BOT**[18]) is an OWL ontology for defining relationships between sub-components of buildings. It is intended to be extended by different use cases. It should be mentioned that this ontology is not a W3C recommendation but a Community Group Report, more precisely from the Linked Building Data Community Group. However, due to the consensus reached between the group and its impact, it could be considered a de-facto standard ontology. This ontology is extended by the BIMERR building module.
- The **wgs84_pos** vocabulary[19] is one of the first vocabularies made available for the W3C. It supports the representation of geographical points using simple geo-coordinates and location relations. It is used to represents geographical points and their coordinates within the BIMERR ontology network.
- The Simple Knowledge Organization System (**SKOS**[20]) vocabulary is designed to link and share knowledge organization systems, being formalized in OWL and defining mainly concept schemas and concepts. Knowledge Organization systems are different types of schemas to organize information in order to ease knowledge management. These types of schemas include classifications, thesauri, glossaries, dictionaries, etc.

[17] https://www.w3.org/TR/owl-time/

[18] https://w3id.org/bot#

[19] http://www.w3.org/2003/01/geo/wgs84_pos

[20] http://www.w3.org/2004/02/skos/core

2.5.2 *ETSI ontologies*

ETSI (European Telecommunications Standards Institute) is an independent European standardization organization within the telecommunications industry. Within ETSI, the SmartM2M Technical Committee (TC) focuses on the machine-to-machine communications developing standards to enable M2M services and applications in combination with IoT technologies. In this context, the TC addresses the connection of smart applications through the SAREF ontology.

The Smart Appliances REFerence ontology (**SAREF**) is a standard for smart appliances published by ETSI TC SmartM2M [ETSI, 2015] in 2015. SAREF is a reference ontology that provides an important contribution to enable semantic interoperability in the IoT. This standard subsequently evolved into a second version published in March 2017 [ETSI, 2017a] which has been recently updated to the third and current version [ETSI, 2020].

The SAREF family of ontologies[21] currently includes also Technical Specifications that extend the SAREF ontology to ten different domains, namely: energy (SAREF4ENER [ETSI, 2020a]), environment (SAREF4ENVI [ETSI, 2020b]), and buildings (SAREF4BLDG [ETSI, 2020c]), Smart Cities (SAREF4CITY [ETSI, 2020d]), Industry and Manufacturing (SAREF4INMA [ETSI, 2020e]), Smart Agriculture and Food Chain (SAREF4AGRI [ETSI, 2020f]), Automotive (SAREF4AUTO [ETSI, 2020g]), eHealth/ageing-well (SAREF4EHAW [ETSI, 2020h]), wearables (SAREF4WEAR [ETSI, 2020i]) and water (SAREF4WATR [ETSI, 2020j]).

The BIMERR network of ontologies reuses several SAREF ontologies for different purposes, more precisely:

- The **core SAREF**[22] ontology is used throughout the BIMERR ontology network to represent general concepts such as devices, units of measure, measurement, feature of interest, etc. Such concepts are domain agnostic and normally

[21] https://saref.etsi.org/

[22] https://saref.etsi.org/core/

specialized in each ontology module for particular domains such as weather or occupancy profile.

- The SAREF extension for building (**SAREF4BLDG**[23]) is used to represent hierarchies of building devices in the building and occupancy profile modules.
- The SAREF extension for Smart Cities (**SAREF4CITY**[24]) is reused to model KPIs and their assessments.

2.5.3 Other standard ontologies

There are horizontal domains for which standard ontologies already exist, for example, metadata and provenance. In order to annotate the ontologies being developed the **Dublin Core Metadata Element** set [Dublin Core, 2012] ontology[25], defined by the Dublin Core Metadata Initiative[26], is being used to annotate information as creator, description publishers, title, license, etc.

[23] https://saref.etsi.org/saref4bldg/

[24] https://saref.etsi.org/saref4city/

[25] https://dublincore.org/specifications/dublin-core/dcmi-terms/

[26] https://dublincore.org/

3. BIMERR PARTICIPATION IN STANDARDIZATION BODIES

The current participation of BIMERR partners in standardization initiatives is summarized in Table 1. Partners are listed in the rows in alphabetic order and the standardization initiatives in which they are involved are listed in the columns. Currently, 4 out of 16 partners are involved in standardization initiatives. For each partner, the level of participation in each initiative is indicated by the following numbered code:

1: Already involved and keen to continue

2: Recently involved - track record

3: Recently involved - monitoring but not actively contributing

4: Keen to become involved

The W3C Linked Building Data Community Group [27] (LBDCG) aims to enable all stakeholders in the building life cycle to query and access necessary data for supporting their business use cases by using semantic web technologies. These semantic web technologies can be applied to buildings (geometry, products, topology and usage) and infrastructure data (roads, railroads, bridges). This group combined the building information modelling (BIM) and Web of Data technologies to describe several requirements and use cases for linked data-based application across the building's life cycle. UPM is part of the LBDCG since its initiation and co-organizes the LDAC workshop (where the LBDCG members meet) since 2015. UPM participates regularly in the LBDCG meetings. UCL has recently joined the group and XYLEM is keen to become involved.

The W3C Web of Things (WoT) Working group aims at creating standard specifications and test suites for the Web of Things architecture. The Discovery Task Force[28] aims at defining a distribution mechanism for WoT Thing in order to facilitate the access to WoT things and services while supporting security and privacy. FIT and UPM are involved in the WoT

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[27] https://www.w3.org/community/lbd/

[28] https://www.w3.org/WoT/activities/tf-discovery/

Discovery Task Force. BIMERR attends weekly meetings and participates in the WoT Plugfests that take place every quarter. The involvement of BIMERR in the WoT Working Group is led by FIT.

As already mentioned, the ETSI SmartM2M Technical Committee has developed the SAREF ontology for IoT interoperability and a number of extensions of such core ontologies in different domains as building devices, smart cities, etc. UPM is involved in the development of such extensions and the evolution of SAREF ontology since 2016.

The BACnet Semantic Interoperability Working Group focuses on the development of semantic formalism to represent the context of building systems and their relations. It aims at defining an ASHRAE standard 223P Semantic Data Model for Analytics and Automation Applications in Buildings. The BIMERR participation in this working group has started during the project lifetime by UPM and UCL. UPM attends bi-weekly meetings to monitor the activity and to identify potential collaboration opportunities.

The ISO/IEC JTC1/SC 4[29]1 technical committee focuses on the standardization of the Internet of Things and Digital Twins. UPM has recently joined the subproject 21823-3 SI "Internet of Things (IoT). Interoperability for IoT Systems. Part 3: Semantic interoperability."

Table 1. Current involvement of BIMERR partners in standardization initiatives

	W3C LBD Group	W3C Web of Things	BACnet SI-WG ASHRAE 223P	ISO/IEC JTC1 SC41 21823-3 SI	ETSI
FIT		1			
UPM	1	1	3	3	1
UCL	3		3		
XYLEM	4				

[29] https://www.iec.ch/dyn/www/f?p=103:7:507930206579908::::FSP_ORG_ID:20486

4. BIMERR CONTRIBUTION TO STANDARDIZATION

This section presents the Milestone 8 "Standardization punch list" that comprises the technical contributions and conclusions from the project to standardization initiatives. Moreover, contributions identified as potential input to standardization fora are also presented. The list of target standardization initiatives comprises:

- W3C **Web of Things** WG (**FIT** leading, UPM):
  - To propose the BIMERR Use case.
  - To contribute to the WoT directory description. Origin: BIMERR Middleware.
  - To develop the Reference for WoT Thing Directory. Origin: BIMERR Middleware.
- W3C **Linked Building Data** CG (**UPM**):
  - To propose BIMERR Use case.
  - To promote BIMERR models.
- **ETSI ontologies** (**UPM**):
  - SAREF4BLDG review based on BIMERR experience.

At the time of writing this document some actions have already been taken addressing standardization initiatives. More precisely:

- BIMERR Use case has been published[30] within the W3C WoT Interest Group; attached as Annex 7.1.
- Significant contributions to and editing of the Web of Things (WoT) Discovery[31].
- Contributions to development of tooling for WoT Discovery implementation reports.
- Reference implementation for WoT Thing Directory[32].
- WoT core ontology extension for discovery[33] available in Annex 7.2.

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[30] https://www.w3.org/TR/2021/NOTE-wot-usecases-20210518/#connected-building-energy-efficiency

[31] https://www.w3.org/TR/wot-discovery/

[32] https://github.com/linksmart/thing-directory

[33] https://github.com/w3c/wot-discovery/tree/main/context

- BIMERR use cases proposed to LBD CG[34] provided as Annex 7.3.
- Proposed LBD group talk about BIMERR Ontology Network.

Other actions taken in relation with standardization efforts include:

- FIT and UPM participating as Program Committee of the W3C Smart Cities workshop organized by the W3C[35].
- UPM participation in EEB sister projects meeting to promote a joint effort to propose common models to LBDCG and ETSI ontologies.
- UPM participation in LBDCG calls to support the creation of working groups to develop models for energy efficiency use cases.
- Identified potential liaison with IFC 5.
- HYP initiated contacts with the StandICT project[36] for joining efforts towards standardization.
- Attend CEN-CENELEC webinar about BIM and CEN/TC 442.
- Participation in the European Commission survey on H2020 projects in the context of the upcoming codes of practice “Code of Practice for researchers on standardisation”

[34] https://github.com/w3c-lbd-cg/lbd/pull/20

[35] https://www.w3.org/2021/06/smartcities-workshop/index.html

[36] https://www.standict.eu/

5. CONCLUSIONS

This deliverable has summarized the involvement of the BIMERR project in standardization as of M30 in the following aspects:

- The use of standards by BIMERR components.
- The participation of BIMERR partners in relevant standards initiatives and fora.
- The current contribution of the BIMERR project to standards.

BIMERR partners have contributed to the definition of use cases in two W3C groups taking as input BIMERR use cases. They have been, or are in the process to be adopted by the corresponding groups for their own objectives.

One conclusion about the participation in standardization initiatives is the importance of the type of committee or forum targeted for contribution. More precisely in the case of the W3C working groups, the inputs are processed in a faster way as the working groups have defined timelines with expected deliverables. However, the lack of such commitments from other type of groups as community groups leads to slower progress.

In future, it is expected that BIMERR contributions to standardization will be focused on the semantic technologies area, in the shape of both: (1) models or reviews of existing ontologies like SAREF4BLDG, possibly in collaboration with sister projects, and (2) implementation for the WoT discovery task force.

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7. Annexes

7.1 W3C WoT: Use Cases and Requirements - Connected Building Energy Efficiency

Submitter(s)

Farshid Tavakolizadeh

Target Users

- device owners
- device user
- directory service operator

Motivation

Construction and renovation companies often deal with the challenge of delivering target energy-efficient buildings given specific budget and time constraints. Energy efficiency, as one of the key factors for renovation investments, depends on the availability of various data sources to support the renovation design and planning. These include climate data and building material along with residential comfort and energy consumption profiles. The profiles are created using a combination of manual inputs and sensory data collected from residents.

Expected Devices

- Gateway (e.g. Single-board computer with a Z-Wave controller)

Z-wave Sensors:

- Power Meter
- Gas Meter
- Smart Plug
- Heavy Duty Switch
- Door/Window Sensors
- CO2 Sensor
- Thermostat
- Multi-sensors (Motion, Temperature, Light, Humidity, Vibration, UV)

Expected Data

- Ambient conditions
- Occupancy model

Description

Renovation of residential buildings to improve energy efficiency depend on a wide range of sensory information to understand the building conditions and consumption models. As part of the pre-renovation activities, the renovation companies deploy various sensors to collect relevant data over a period of time. Such sensors become part of a wireless sensor network (WSN) and expose data endpoint with the help of one or more gateway devices. Depending on the protocols, the endpoints require different interaction flows to securely access the current and historical measurements. The renovation applications need to discover the sensors, their endpoints and how to interact with them based on search criteria such as the physical location, mapping to the building model or measurement type.

Privacy Considerations

The TD may expose personal information about the building layout and residents.

Gaps

There is no standard vocabulary for embedding application-specific meta data inside the TD. It is possible to extend the TD context and add additional fields but with too much flexibility, every application may end up with a completely different structure, making such information more difficult to discover. In this use-case, the application specific data are:

- the mapping between each thing and the space in the building model
- various identifiers for each thing (e.g. sensor serial number, z-wave ID, SenML name)
- indoor coordinates

There is no standard API specification for the WoT Thing Directory to maintain and query TDs.

Existing Standards

- OGC SensorThings model includes a properties property for each Thing which is a non-normative JSON Object for application-specific information (not to be confused with TD's properties which is a Map of instances of PropertyAffordance

7.2 W3C WoT: Discovery ontology

```
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix vann: <http://purl.org/vocab/vann/> .
@prefix discovery: <https://github.com/w3c/wot-discovery#> .
@prefix td: <https://www.w3.org/2019/wot/td#> .
@prefix schema: <http://schema.org/> .
@base <https://github.com/w3c/wot-discovery#> .

<https://github.com/w3c/wot-discovery#> rdf:type owl:Ontology ;
        dc:creator "Andrea Cimmino" ;
        dc:creator "Farshid Tavakolizadeh" ;
        owl:versionInfo "0.1.2" ;
        dc:title "WoT discovery ontology" ;
        dc:description "Ontology code created by Chowlk" .

#################################################################
# Object Properties
#################################################################

### discovery:hasRegistrationInformation
discovery:hasRegistrationInformation rdf:type owl:ObjectProperty ;
        rdfs:domain td:Thing ;
        rdfs:range discovery:RegitrationInformation ;
        rdfs:label "registration" .

#################################################################

# Data Properties

#################################################################

### schema:dateCreated
schema:dateCreated rdf:type owl:DatatypeProperty ;
        rdfs:domain discovery:RegitrationInformation ;
        rdfs:range xsd:dateTime ;
        rdfs:label "created"@en .

### schema:dateModified
schema:dateModified rdf:type owl:DatatypeProperty ;
        rdfs:domain discovery:RegitrationInformation ;
        rdfs:range xsd:dateTime ;
        rdfs:label "modified"@en .

### schema:expires
schema:expires rdf:type owl:DatatypeProperty ;
```

```
        rdfs:domain discovery:RegitrationInformation ;
        rdfs:range xsd:dateTime ;
        rdfs:label "expires"@en .

### discovery:ttl
discovery:ttl rdf:type owl:DatatypeProperty ;
        rdfs:domain discovery:RegitrationInformation ;
        rdfs:range xsd:unsignedInt ;
        rdfs:label "ttl"@en .

### discovery:retrieve
discovery:retrieved rdf:type owl:DatatypeProperty ;
        rdfs:domain discovery:RegitrationInformation ;
        rdfs:range xsd:dateTime ;
        rdfs:label "retrieved"@en .

#################################################################

# Classes

#################################################################

### td:Thing
td:Thing rdf:type owl:Class ;
        rdfs:label "Thing" .

### discovery:RegitrationInformation
discovery:RegitrationInformation rdf:type owl:Class ;
        rdfs:label "RegitrationInformation" .

### discovery:ThingLink
discovery:ThingLink rdf:type owl:Class ;
        rdfs:label "ThingLink" ;
        rdfs:subClassOf td:Thing .

### discovery:ThingDirectory
discovery:ThingDirectory rdf:type owl:Class ;
        rdfs:label "ThingDirectory" ;
        rdfs:subClassOf td:Thing .

#################################################################
# Instances
#################################################################

#################################################################
# General Axioms
#################################################################
```

7.3 W3C LDB: Linked Building Data Use Cases

Vast amounts of heterogeneous data are generated and used during the life cycle of a building. An example is product data, which describes the building and the elements that make up the building. This includes the geometric models for each product. Examples of (building) products include walls, windows, pipes, ducts, light switches, sensors and other devices. With these data as a basis, and through their connection to more fine-grained data, such as sensor measurements data, usage data, intelligent domotic system data, geographical data and weather data, highly advanced services can be supplied over the Web to various end users.

From an industrial point of view, using Linked Data technologies and adopting common Knowledge Graph models is essential to exploiting building data on the web for a range of important use cases, including those related to indoor navigation (e.g. shop navigation, evacuation and disaster, etc.), energy efficiency simulation (e.g. retrofitting, behavioural change, etc.), web-based facility management, and many more. Here we list use cases being addressed directly by the LBD community group.

Building Geometry Data on the Web

Geometry plays a central role in supporting these use cases. A key challenge is the seamless integration of multiple geometric models[1]. The Semantic Web approach enables several geometries to exist side by side on the web coming from different sources or workflows and applied in a variety of construction-related tasks[2]. Here we present three high level use cases:

Use Case 1: Varied representation of building geometric data within the BIM domain

In Building Information Modeling (BIM), authoring tool designers are able to create a digital model consisting of objects that represent building elements, rooms and abstract things like mechanical systems. It is further possible to describe relationships between these objects and attach attributes to them. The main selling point of BIM has, however, been the ability to represent objects with parametric 3D geometry. Since BIM authoring tools operate on proprietary data models, however, interoperability is limited to file based exchanges of a final model that can then be referenced into 3rd party tools used by other stakeholders of a project.

With Linked Data, the references can be described at object level and, hence, it is possible to extend the definition of an object in another stakeholder’s model. The model of the building owner could consist only of functional requirements for the building. A second model of the architect contains the building geometry and in-between building elements, zones are formed. These zones need to fulfil the functional requirements described by the building owner. A third model of the structural engineer only references the locations of load-carrying columns, walls and slabs, and specifies the structural requirements for those. A fourth model for energy simulation specifies thermal requirements etc. For this to work, it is necessary to have a formal way of representing geometry and relationships between the different coordinate systems.

Case study - Heritage data

During built heritage projects (e.g. restoration, maintenance, historical research) a large amount of stakeholders collaborate. Each stakeholder assembles and generates a wide variety of data, including 2D and 3D geometries ranging from survey geometry (e.g. a point cloud or complex mesh), over 2D plans and maps (historical situation, previous restorations, derived from survey data, etc.) to volumetric 3D models. These geometries are used to get an overview of the historical and existing situation of the building, for communicating the location of damages or valuable historical elements in the building or to express the intention of the restoration design. Because of the wide variety of geometric data, a large amount of common geometry schemas (text-based and binary, open and proprietary) are currently used in practice. Instead of developing RDF-based geometry schemas for each specific case, alternative methods such as the application of RDF literals to embed geometry descriptions (~ GeoSPARQL 1.0) or to reference external geometry files are considered. In that case, the usage of existing geometry schemas and their tools can be continued. Built heritage stakeholders need to be able to link such geometry descriptions to building elements, damages and building spaces they describe. Each described object can have multiple geometry descriptions (different geometry schema, describing an object at multiple moments in time, different amount of detailing/resolution, etc.), potentially coming from different stakeholders. Geometry metadata (accuracy, author, resolution, derived geometry descriptions, file size, etc.) is necessary to reuse the geometry in a collaborative setting as it gives an indication of the geometry provenance. Other metadata (used geometry schema, coordinate system, etc.) might help users in the automatic processing of the data by their geometry applications. Three domain independent ontology modules have been developed in previous collaborative research and are applied in a built heritage PhD research project named "Flemish Cities in Transition"[3].

Relevant data standards: Ontology for Managing Geometry[4] (OMG - https://w3id.org/omg#), the File Ontology for Geometry formats[5] (FOG - https://w3id.org/fog#) and the Geometry Metadata Ontology (GOM - https://w3id.org/gom#).

Case study - Product descriptions

With the heterogeneous environment of the construction sector, providing suitable product descriptions for any use case and software application is hard to achieve. While open source exchange formats, i.e. IFC and STEP, can be used to describe products in a uniform manner to realise a communication across domains, the amount of required geometric detail is not addressed. For example, lights to indicate emergency exits are needed in different geometric detail. The electrical engineer only needs to know the position of the lighting fixture, whereas the architect requires the bounding box to consider for the design and safety engineers want to know the material, colour and shape of the lighting fixture to ensure that is clearly visible. On the other hand, the manufacturer needs to model the product in its highest geometrical detail for their own production chain. If the manufacturer provides the highest geometrical detail, the product description will become too large to be handled if multiple instances are places within the model. Hence, the geometrical detail needs to be broken down, ideally individually in respective of singular use cases, resulting in multiple geometry descriptions for the same object. By applying Linked Data, the attachment of multiple geometry descriptions to a singular object can be realised easily, maintaining means to differentiate between the descriptions and identify singular ones to connect them to their respective use cases. Yet, if the original geometry description changes, the derived geometry descriptions must be identified and updated, as well.

Use Case 2: Data integration between building data and geospatial

Geometric data plays a central role in the geospatial domain, architectural design and construction industry. For upcoming, new approaches on how to store building data, such as the Semantic Web, however, no universal common agreement exists on the combination of geometric and non-geometric data. Thus, it can be unclear to users on how to represent their geometries, leading to a decelerated application and advancement of making building data available over the web. This gap can only be bridged if a common approach on the representation of geometries on the web is achieved.

Geospatial data integration with building data in Ireland

In Ireland, the Ordnance Survey Ireland (OSi) has a substantial dataset (over 50 million objects), called Prime2, which includes not only GIS data (polygon footprint, geodetic coordinate), but also additional building-specific data (form and function). The ADAPT research centre working with the Ordnance Survey Ireland has begun publication of their geospatial data using GeoSPARQL[6], with a subset of their buildings data (building name, geolocation, and form and function) in the county of Galway now being available as RDF[7].

This provides authoritative URIs for Irish buildings which can be used to interlink building data from other domains, such as products, sensors, energy, etc. The potential also exists to support the conversion of their 2D building footprints into a simple 3D geometric model, given some additional properties (height). An existing schema such as the Industry Foundation Classes, and ifcOWL serialization can be supported, but tend to be overly verbose (use of lists for each vertex in a point for example) and geometric and non-geometric data are overly entwined. The possibility to define 3D geometries using less complex geometry schemas would be a huge advantage within the building information modelling domain. This is an important step towards the iterative integration of ever more complex BIM models which can support a range of different use cases into the wider web of data.

Relevant data standards: BOT, ifcOWL, GeoSPARQL

Open data sets: http://data.geohive.ie/downloadAndQuery.html

Use Case 3: Managing provenance in building data

During the design stages of a construction project, the building's design changes quite rapidly, and often there are derived consequences of these changes. The cooling demand of a zone is dependent on the solar heat gain through windows and if the windows change, so does the cooling demand. This affects the capacity requirement of the fan coil in the room and potentially the size of the pipes supplying this fan coil, the pump circulating the cooling water and the size of the chiller. The danish consulting engineering company Niras uses Linked Data to model these interdependencies. The architect's BIM model is parsed to a knowledge graph described with the Building Topology Ontology (BOT) and the Ontology for Property Management (OPM) is used to capture each state/version of geometrically derived properties as the design changes. Small task specific web applications access and extend the knowledge graph through SPARQL queries and uses OPM to relate a derived property to the properties that will affect it. In the current setup, 2D-geometry is extracted as WKT literals and 3D-geometry as OBJ literals. Geometry changes are registered by string comparison. In the UI, the state of the model geometry at the beginning and end of a given time interval is visualised.

Building Navigation and Accessibility

Use Case 1: Inferring on walking path

Finding the shortest walking path from point A to point B in a building. Finding each circulation element on the way. Circulation elements : spaces, stairs, elevators, corridors, spaces, doors, opening, ramps.

Relevant data standards: ifcOWL

Use Case 2: Calculating widths of corridors with complexe shapes

Corridors can have multiple aisles (even atriums) with different widths. How to divide it into part with specific width.

Relevant data standards: gbXML

Building Energy

Use Case 1: Calculating transfer surfaces

Calculating transfer surfaces from space to space (or zone) through walls for energy performance calculation.

Relevant data standards: ifcOWL

Building Products

Use Case 1: Separating BIM product from BIM project descriptions

Current BIM models are stored in proprietary formats, such as those of Revit, iTWO, ArchiCAD. With a software-independent data storage, one window description could be used for many project descriptions. For this purpose, IFC is not sufficient due to the lack of equation-based geometry descriptions. More information can be found here - https://github.com/projekt-scope/scope-data-service

Relevant data standards: BOT, OCC, OOP, ifcOWL, OPS

Buildings and Infrastructure

In the Netherlands, based on an extensive ontology we created a fully operational data infrastructure where municipalities store, use and analyse their asset data in commercially available software applications. Data exchange from these asset management applications conform our national standard (in RDF/RDFS/OWL2/Turtle) leads to neutral linked datasets in a triplestore on a national data platform, where validation (against predefined conformance classes), conversion to various data formats (XML, GML, WFS, CVS, Geopackage), a GIS viewer, open publication and a SPARQL endpoint serve all kinds of uses of the data.

Relevant data standards: GWSW ontologie

- https://apps.gwsw.nl

Open data sets:

- SPARQL endpoint - https://sparql.gwsw.nl, but also at our national geo-information platform
- https://www.pdok.nl/introductie/-/article/stedelijk-water-riolering- (all in Dutch, sorry!)

Building Renovation

During building renovation projects large amounts of heterogeneous data are exchanged between the different applications involved in the process (IFC files generated by Scan to BIM apps, Workflows created by Management tools, and so forth). Even though IFC files can be used to exchange core building-related data such as building elements or geometric information, they cannot capture complementary information that could bring additional functionalities to the applications used in the renovation process. With an ontology working as the central interoperability framework for all these tools, we can capture information from different domains, interconnect them, and facilitate the following applications:

Use Case 1: Rapid scanning of the geometry of the building, semantic modeling, and accurate representation in a BIM

In the BIMERR research project, the aim is to provide a set of tools to support renovation projects in the design and construction phase. The integration of all these heterogeneous applications is being addressed by a semantic layer which is based on ontologies.

During the inspection stage of the buildings, 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. Finally, a semantic enrichment process of the BIM model generated by Scan to BIM tools is carried out by assigning materials and properties to the building elements, obtaining a more accurate representation of the building. After some postprocessing, the model is sent to the BIMERR Interoperability Framework for its storage and instantiation of the building data model, which contains main topological elements (Stories, apartments, spaces, etc.) and the relations between them.

Related Deliverables: 2.3 BOT - Building Topology Ontology

Use Case 2: Collection of data about the building systems through BIM-based internal audit support tools and interaction with building managers and occupants.

This use case is being developed in the context of the BIMERR research project. Accelerate the collection of data about the building systems through BIM-based audit support tools. By means of mobile application and AR-glasses, both occupants or workers can directly link annotations or issues to the different topological elements of the building (stories, spaces, etc), that can be sent to other applications for their analysis. This information is really critical for a renovation project since it will provide valuable input to workers towards safely and properly performing the renovation works and avoiding either incidents/ damages to the backbone infrastructure of the building or accidents caused (by drilling a gas pipe or cutting an electricity line cable).

Related Deliverables: 2.3 BOT - Building Topology Ontology

Use Case 3: Adapt design to the actual building use, including accurate information about occupancy and schedules, comfort requirements/ preferences and energy uses

This use case is being developed in the BIMERR research project. Beyond the static components of a building that can be extracted and modeled by tools using visual information, renovation for energy efficiency also requires detailed information about the energy consumption of the building – and more importantly, information to understand why and how energy is consumed, so that accurate post-renovation consumption projections can be made. The enrichment of the building model with more accurate information about occupancy and schedules, comfort requirements/ preferences, and energy uses, will allow the adaptation of the design to the actual building use. Related Deliverables: 2.3 BOT - Building Topology Ontology

Use Case 4: Stakeholders' systems exchange appropriate and "understandable" data between each other.

This use case is being developed in the BIMERR research project. Typically, once the executive design is completed, the project management team provides all the information (drawings, site investigations, time plan, etc.) to local authorities in order to acquire the building permit for the project. Once the permit is granted, this information is transformed into the tender offer, upon which the subcontractors will provide their quote for undertaking the works. Vendors will also provide their quotes for services/materials based on the same information. During the actual renovation phase, the above-mentioned information pack is transformed into engineering drawings and passed to the site manager and foreman who in turn has to communicate the information to the working crews.

Related Deliverables: 2.3 BOT - Building Topology Ontology

References for Annex

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