Semantic Interoperability using Ontologies and Standards for Building Product Properties

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Abstract

Both standards and ontologies are among the important components to realize the vision of BIM (Building Information Modeling). They provide a community consensus for interpretation, communication and interoperability of building data. This consensus is pivotal in enabling diverse stakeholders and systems to seamlessly collaborate and share data across the entire building life cycle. In this paper we describe the development of ontologies for building product properties, aligning with standards, and demonstrate their usage in achieving semantic interoperability. First, a top-domain ontology, BPPO (Buiding Product Property Ontology), is developed for building product properties. This top-domain ontology is used to guide the development of domain ontologies for properties in different categories of products or groups of product categories. Subsequently, a domain ontology, LPPO (Lighting Product Property Ontology), is built for lighting product properties, with guidance from BPPO, in this work. The ontological terminologies of both BPPO and LPPO are aligned with the standards set forth by the BIM community. Furthermore, the ontologies have been used in an application to support and enhance the interoperability between the manufacturer's product database and the BIM platform.

Keywords

Ontology, Standard, Semantic Interoperability, BIM, Product Properties

1. Introduction

Today, BIM (Building Information Modeling) has evolved from level 0, which was focused on 2D CAD and exchange of paper-based drawings, to the level 3 which aims for a high level of integration and interoperability between different stakeholders and systems using digital and object-oriented building information models [1]. Ensuring interoperability among various software tools and platforms used by different stakeholders, such as architects, engineers, contractors, and facility managers, is crucial for the successful implementation and adoption of BIM processes. To address this challenge in implementing the BIM maturity level 3, both standards and ontologies play an important role.

In BIM, properties are critical as they serve to define and describe building elements. They provide essential information about the functions and characteristics of components, materials, and systems used in the construction. For example, the classification systems, such as the Uniclass [1], MasterFormat [2] and CoClass [3], organize and classify things based on their properties. To

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[1]https://www.thenbs.com/our-tools/uniclass
[2]https://www.csiresources.org/standards/masterformat
[3]https://byggtjanst.se/tjanst/coclass

support interoperability between different stakeholders and enhance the information exchange and integration in BIM, properties need to be created in an agreed manner on their naming, definition, measurement and other relevant aspects. In 2020 the EN ISO 23386 [2] was published as a standard to guide on how to define properties used in construction.

Product properties have been one of the central focuses within the context of BIM [3]. Building product manufacturers are important actors in building realization processes. Many product manufacturers have adopted BIM platforms to describe and share their product data through BIM objects. However, this approach has its own set of challenges in achieving interoperability between manufacturers' databases and the BIM platform [4]. Facilitating the exchange and integration of manufacturers' product data in BIM platforms at an early stage of the building life cycle is critical for the productivity of the construction processes.

Standardization efforts have placed a significant amount of attention on the product properties. Given the great amount of products used in the construction industry, one solution is to undertake standardization work for different categories or groups of product categories. For example, the standard Technical Specification (CEN/TS) SIS-CEN/TS 17623 [5], has been developed specifically for the products used in lighting systems. Furthermore, building upon EN ISO 23386:2020 as a foundation, the Technical Committee ISO/TC 274 Light and Lighting in cooperation with CIE Joint Technical Committee 6 [4] is currently conducting the work of producing an ISO standard specifically for lighting product properties, based on this CEN/TS SIS-CEN/TS 17623.

Recently, many studies (e.g. [6, 7, 8]) have promoted ontology and the Semantic Web technologies as potential solutions for supporting integration and interoperability in BIM. Specifically, ontologies can provide a standardized vocabulary and framework for representing the data and information, which will improve communication, collaboration, and decision-making among stakeholders. The ontology languages for the Semantic Web, e.g., RDFS [9] and OWL languages [10], can express explicitly the concepts and terms and their semantic descriptions in a machine readable manner. In addition to the ontology languages, the validation languages like SHACL [11] and rule languages such as SWRL [12], can be used to evaluate and infer over the specifications. For example, when digital BIM models are built and/or annotated using the concepts and terms, ontology and ontology-enhanced technologies can improve the quality of the models on their semantic descriptions and significantly increase the performance of accessing, integration and interoperability of building data using the models [13, 14].

In this paper we describe the development of ontologies for building product properties, aligning with standards, and demonstrate their usage in achieving semantic interoperability. First, a top domain ontology, Building Product Property Ontology (BPPO), was developed according to the standard EN ISO 23386:2020. This ontology will serve as a foundational knowledge for developing specific property ontologies for particular categories of products. Then, with the guidance of the top domain ontology, an ontology was developed for lighting product properties (LPPO). The development of the ontology LPPO also takes as the input the specifications identified in the standard SIS-CEN/TS 17623. Then the usage of the ontologies is demonstrated in an application to support the interoperability between manufacturer's product databases and BIM platforms.

[4]https://cie.co.at/technical-work/division6/technical-committees

The rest of this paper is organised as follows. In Section 2 we present the well-known standards and ontologies developed for properties in the field of BIM, specially concerning semantic interoperability. In Section 3 we describe the development of the ontologies BPPO and LPPO with the guidance of standards and describe the ontologies. In Section 4 we presented the usage of the developed ontologies to support semantic interoperability in an application. Finally, the paper concludes in Section 5.

2. Related Work

In the realm of BIM, foundational texts like the BIM Handbook (e.g. [15]) identifies the significance of semantic interoperability in improving communication and collaboration in the construction industry. Recently, it has been acknowledged wihtin BIM that using ontologies to represent and organize BIM data is a solution to improving semantic interoperability [7, 16, 17]. Ongoing standardization efforts by organizations such as ISO and buildingSMART [5] also underscores the importance of standards in achieving semantic interoperability. In other domains that are more advanced in addressing issues of semantic interoperability than BIM, works have also discussed various issues related to the development and application of standards and ontologies. Additionally, they emphasize the importance of collaboration and integration between ontologies and standards to support semantic interoperability [18, 19, 20]. Today, much work has been done on developing ontologies to facilitate a common understanding of building information, thereby supporting semantic interoperability. In this section we discuss briefly well-known standards, data dictionaries and ontologies that are relevant for describing properties, especially product properties, within BIM.

2.1. Maintaining properties according to EN ISO 23386:2020

The standard EN ISO 23386:2020 specifies the requirements on describing, authoring and maintaining properties used in the construction industry. The standard intends to establish interoperability between data dictionaries and build a network of the data dictionaries for properties. The mappings between the terms used in the interconnected data dictionaries need to be maintained. In the network, each property should be identified by a globally unique identifier (GUID). Each property is described by a number of attributes. An attribute may follow the management rules, such as ”mandatory” and ”calculated”. The value of an attribute can be a single value, an enumeration or multiple values of a certain type. Several properties can be organized into a group.

2.2. Product Properties in Data Dictionaries

In this section, we discuss how product properties are described in several well-known BIM data dictionaries. The overview is presented in Table 1. All the data dictionaries are multi-disciplines and are not specifically designed for product properties or any one particular category or groups of categories of building products. The terms in these data dictionaries can be read by

[5] https://www.buildingsmart.org/

Standard	Domain	Format	GUID	Interconnected
Uniclass	multi-disciplines	tables, API	No	No
MasterFormat	multi-disciplines	tables, API	No	No
UniFormat	multi-disciplines	tables, API	No	No
ETIM	technical products	XML	No	No
IFC Schema	multi-disciplines	EXPRESS, XSD, ifcOWL	Yes	No
bSDD	multi-disciplines	tables, JSON, RDF, XML, API	Yes	Yes
CoClass	multi-disciplines	API	No	Yes

Table 1
Data dictionary standards

human, by machine via machine languages or via APIs. Not all data dictionaries use GUID to identify properties. Most of the data dictionaries have been used by the industry for many years and have a well established coding system. bsDD has made effort to conform to EN ISO 23386:2020. It uses URIs as GUID to uniquely identify terms. The mappings between the terms for interconnected data dictionaries, i.e. "interconnected" in Table 1, are not well implemented in most of the data dictionaries. Although most of the data dictionaries do not contains mapping to other data dictionaries, the mapping is critical for semantic interoperability, specially when multiple data dictionaries are used a BIM project. Thus, the mappings between the terms in several different data dictionary have been studied in various research work, e.g. [21, 22].

2.3. Ontologies for Product and Product Properties

There has been a significant amount of effort to introduce ontology into BIM. For example, the BIMSO ontology [23] was developed to encode all the elements from the UniFormat II using OWL ontology language. ifcOWL [24, 25] has been a big project done by the International buildingSmart consortium [6], which is to encode all the elements in the IFC Schema using OWL ontology language. The Linked Building Data Community Group of the World Wide Web Consortium (W3C) [7] developed an ontology for describing the core topological concepts of a building, the Building Topology Ontology (BOT) [26]. It has focused on the high-level description of storeys and spaces, the building elements they may contain, and their 3D geometry. The Building Product Ontology (BPO) [27] was developed to provide a top level ontology for describing building products. It has focused on providing a framework to describe assembly structures and component interconnections of building product components, and enable to attach properties to components. We have aligned the properties represented in our ontologies to the class `Product` in the BPO. Oraskari [28] demonstrates an API which enables to generate OWL ontology using the terms retrieved from bsDD data dictionaries for specific purposes.

Representing properties using ontology is an important area of research within the context of BIM. A number of work has been focused on representing properties using ontology. In [21] the authors discussed the complexity of the property ontology when converting IFC to RDF data.

[6] https://www.buildingsmart.org/
[7] https://www.w3.org/community/lbd/

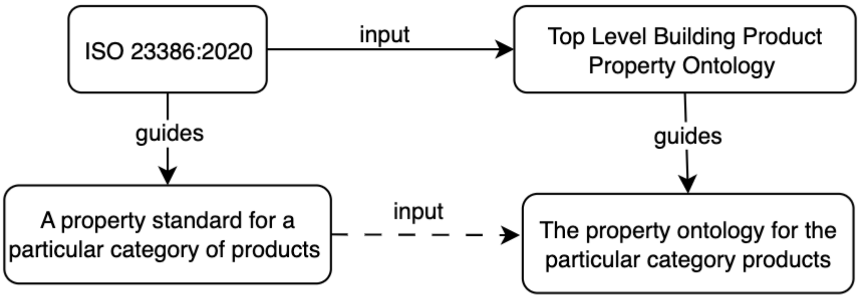

Figure 1: The ontology development process

The BIMDO ontology (Building Design Ontology) extends the BIMSO ontology with the design properties for building elements [16]. The Ontology for Property Management (OPM) [29] is an ontology developed to managing property changes of a building element. It has focused on describing temporal properties that are subject to changes as the building design evolves. In [30] the authors developed a top domain ontology, the Interconnected Data Dictionary Ontology (IDDO), mainly to support NLP (natural language processing) methods to extract property knowledge from unstructured guidelines or building codes into a structured class hierarchy.

In the work presented in this paper the development of the top domain product property ontology has been in accordance with the requirements and specifications identified in the ISO standard that were developed to support the implementation of BIM. The ISO standard gives the recommendations on how to describe properties including how to manage property changes, status and versions. The aim for developing the top domain ontology is to facilitate the development of specific ontologies for categories or category groups of products.

3. The Building Product Property Ontology (BPPO) and the Lighting Product Property Ontology (LPPO)

In general, the ontology development in this work has followed the NeOn ontology engineering methodology [31] and has focused on applying *scenario 2* (reusing and re-engineering non-ontological resources). We used OWL 2 DL as the representation language for the ontology. During the development process, one knowledge engineer and one domain expert from the area of building and construction were involved.

As shown in Figure 1, the ontology development process is organized into two phases. In the first step, a top domain ontology Building Product Property Ontology (BPPO) is developed. It defines the representation of building product properties, conformed to the requirements specified on properties in the standard EN ISO 23386:2020. This ontology will provide a foundation for building more specialized property ontologies for a particular product category or groups of product categories. Figure 2 shows the example attributes specified in the standard for describing property. Each row in the table records one attribute. Each attribute is described by a few parameters. The main transformation rules applied to create the ontology BPPO from the tabular structured data in the standard is given as below:

Name	Description	Example	Interconnected dictionaries management rule	Request form management rule	Type	List of values
globally unique identifier	globally unique identifier generated using an algorithm in conformity with standard ISO/IEC 11578:1996 See RFC4122	936DA01F-9ABD-4D9D-80C7-02AF85C822A8	Mandatory, calculated		String Single-value	
Status	Status of the property during its life cycle.		Mandatory Calculated		enumeration Single-value	Active Inactive
Date of creation	Date of validation of the property creation request.	2014-04-30T10:39:53Z	Mandatory Calculated		Date In accordance with ISO 8601 Format=YYYY-MM-DDThh:mm:ssTZD	
...						
Country of use	Country in which the property is used.	FR US	Mandatory	Mandatory	Choose multiple-values	In accordance with ISO 3166-1

Figure 2: Example property attributes specified in EN ISO 23386:2020

Algorithm 1 Transform attributes in standard to ontology elements

create a class Property
for each attribute **do**
  if *Interconnected dictionaries management rule*
    or *Request form management rule* is mandatory **then**
    create a property for the class Property
    if *Type* is single-value **then**
      add the property range as specified in *Type*
    else if *Type* is enumeration single value **then**
      create a class to enumerate the values specified in *List of values*
      add the class as the property range
    else if *Type* is multiple-values **then**
      the property range will be defined in specific property ontology
    end if
  end if
  add the description and example of the attribute using rdfs:comment
    and skos:example respectively
end for

The fragment of the BPPO shown in Figure 3 represents the example property attributes shown in Fig. 2. The class `Property` has the relation `propertyOf` to the class `Product` in the BPO. `Property` has overlapping with the classes `Attribute` and `RangedAttribute` in the BPO, but logically they are not equivalent and do not have subclass/superclass relationships, so `skos:related` is used to represent the associations between them. The definition of the class `Status` is given as $\texttt{Status} \equiv \{\texttt{active, inactive}\}$. The range of the property `usedInCountry` is defined as `owl:Thing`, since the country list is specific to particular product property ontology. For example, when a property is used in the countires Sweden and UK, the range is defined using a class `countriesUsingProperty` given $\texttt{countriesUsingProperty} \equiv \{\texttt{Sweden, UK}\}$. As

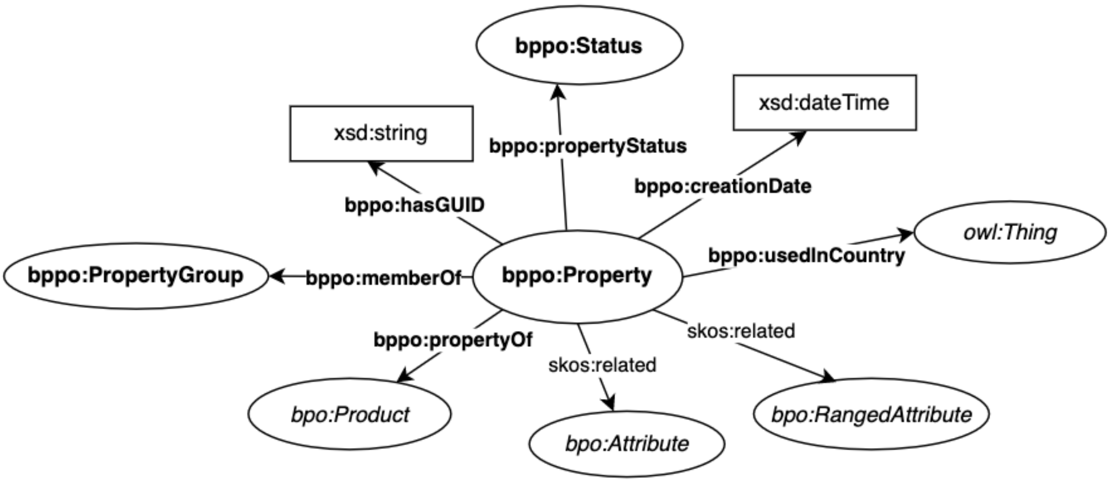

Figure 3: A fragment of the BPPO

Table 1 — Mechanical properties

GUID	ID	Name	Description	Symbol	Format, Unit	Value set	Examples
2GZ1YB8enFVhDHOKgLc$BU	01-0001	overall diameter	Overall diameter of the housing of the luminaire or sensing device.		1E0, mm	n.a.	
19Z9XKYDT4p8HR0ZbD$wO_	01-0002	height	Height of the housing of the luminaire or sensing device. Corresponds to z-axis, gamma angle 180° and 180° vertical of the light distribution curve. This definition is regardless of orientation of luminaires. See Figure 1.		1E0, mm	n.a.	
...							
1LrBLaYtnCARKperF_2Ykh	01-0017	glow wire resistance	The glow wire test for fire hazard (see EN 60695-2-10) to test electrical products, assemblies or individual components.		1E0, °C	550°C, 650°C, 750°C, 850°C, 960°C	

Figure 4: Example properties specified in SIS-CEN/TS 17623:2021

given the transformation rule, the optional attributes currently are not represented in the BPPO. This was suggested by the domain expert. The standard SIS-CEN/TS 17623:2021 also shows that the optional attributes are not used.

In the second step, the development of the property ontology for a particular category of products is guided by the top-domain ontology BPPO. In this work an ontology for representing the lighting product properties is developed. During the development, SIS-CEN/TS 17623:2021, a standard for "BIM Properties for lighting – Luminaires and sensing devices" is *the non-ontological resource* used to gain the knowledge. Currently, standards are being developed for different categories of products. One of the product categories where this work have come rather far is luminaires and sensing devices. Fig. 4 shows the example mechanical properties of lighting product. Each row in the table records one property. 6 attributes defined in EN ISO 23386:2020

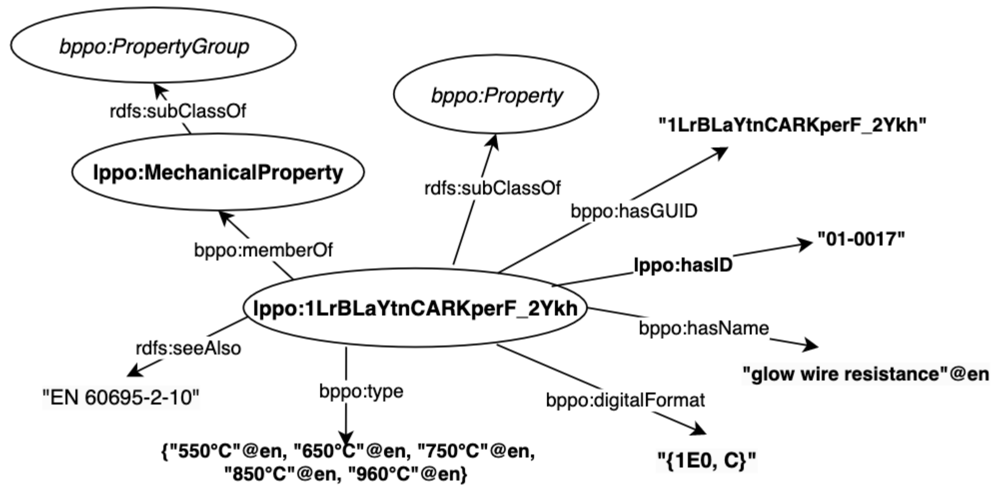

Figure 5: Representation of an electric lighting product property in the LPPO

are used to describe each property in this standard. `ID` and `symbol` are the new attributes introduced in this standard. In total there are 8 tables of which each organizes a set of properties into a group. The ontology has been developed using the concepts and properties defined in the BPPO. Fig. 5 shows a fragment of the LPPO which represent the property *glow wire resistance* described in Fig. 4. The ontology fragment written in the format Turtle is given below.

Availability: The ontologies have the permanent w3id http://w3id.org/ppon/bppo/ and http://w3id.org/ppon/lppo/, and currently are maintained on the gitlab https://github.com/tanhe-git/ppon.

```
:1LrBLaYtnCARKperF_2Ykh rdfs:subClassOf bppo:Property ;
    bppo:memberOf :MechanicalProeprty;
    bppo:hasGUID "1LrBLaYtnCARKperF_2Ykh";
    :hasID "01-0017";
    bppo:hasName "glow wire resistance"@en ;
    bppo:description "The glow wire test for fire hazard (see EN 60695-2-10)
     ↪  to test electrical products, assemblies or individual
     ↪  components."@en ;
    bppo:digitalFormat "(IE0, C)";
    lppo:valueSet :glowWireResisteanceTemperatureValueSet;
    rdfs:seeAlso "EN 60695-2-10".

:glowWireResistanceTemperatureValueSet owl:equivalentClass
   [ rdf:type rdfs:Datatype;
     owl:oneOf (  "550C"^^xsd:string  "650°C"^^xsd:string "750C"^^xsd:string
      ↪  "850C"^^xsd:string "960C^^xsd:string)
   ] .
```

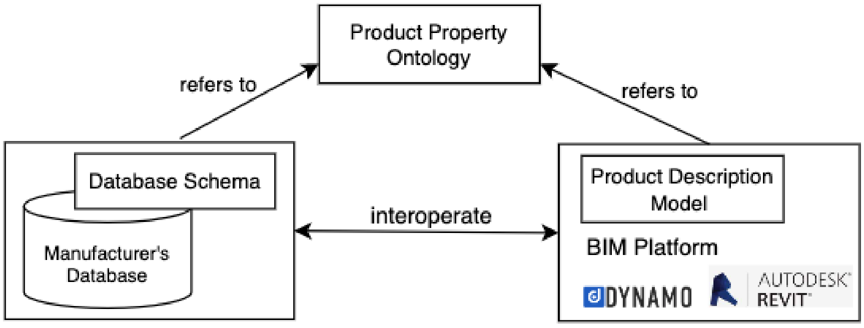

Figure 6: Semantic interoperability using product property ontology

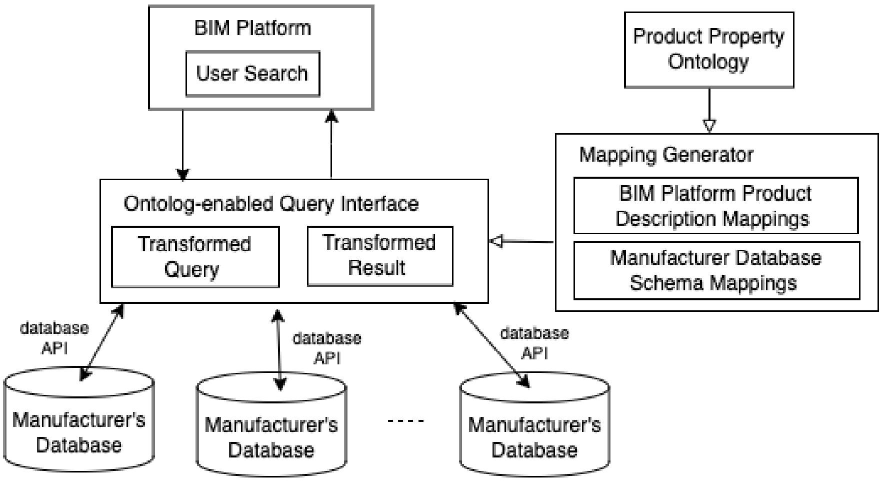

Figure 7: The architecture of using product property ontology to support the interoperability between manufacturer's database and BIM platform

4. Using the Ontologies to Support Semantic Interoperability

Ontology evaluation has been a challenge in the area of ontology engineering for a long time [32, 33, 34, 35]. In [36, 37], the authors argue that one way to evaluate an ontology is to assess its usability or appicability in the tasks it targets. As described in Section 3, the BPPO is a top domain ontology and serves as a foundational knowledge base to support the development of specific ontologies for particular categories of products or groups of product categories. In Section 3, we have presented this usage when the LPPO ontology is developed based on the BPPO. In this section we will mainly present the usage of the LPPO to support semantic interoperability between product manufactures' database and BIM platform in a real world example application.

As illustrated in Figure 6, product property ontology acts as the reference to establish the semantic relationships between the concepts and terms used in manufacturer's database schema and product description model used in BIM platform. Figure 7 details the architecture for the semantic interoperability using ontology presented in Figure 6. The component `Mapping Generator` in the architecture illustrated in Figure 7 will generate the mappings between manufacturer's database schema and the ontology, and between BIM platform's product description model and the ontology. The component `Ontology-enabled Query Interface` will rewrite the query sent from BIM platform to a query readable and understandable by manufacturer's database API using the mappings, and rewrite the query result sent back from manufacturer's database API to the data model readable and understandable by BIM platform. A prototype of the architecture shown in Fig 7 was implemented and presented in [38]. The prototype aims to enable semantic interoperability between the BIM authoring tool Autodesk Revit [8] and an electric lighting product manufacturer's database. Through this prototype, product manufacturers share their data via the ontology-based query interface, eliminating the need to outsource the data.

Be more specific, the prototype was built to assist designers and architects to gain access to product data that is specific to their use cases at hand regardless of their expertise at managing data, and enables manufacturers to maintain their interest for data autonomy, while still giving designers and architects access to data from their databases. In this prototype the manufacturer's database has been implemented as a RDF triplestore by populating the LPPO ontology. The triplestore was implemented using Stardog [9]. The database query API is a SPARQL endpoint. The mappings are created using the LPPO and implemented as a part of the prototype. The ontology-enabled query interface is implemented using visual programming in Dynamo [10] which is a popular visual programming software packages supported by BIM platforms. Additionally, Dynamo works with Python scripts. The Dynamo program 1) composes SPARQL query given a product data search task, 2) connects to the manufacturer's database, 3) parses the query results and 4) loads the results to a Revit description model. In the steps 1) and 4) the mappings are utilized. The prototype is demonstrated and evaluated in a real world use case in BIM project. It is to support lighting engineer in simulating the number of lighting fixtures needed for a conference room in Revit using lighting product properties. Four participants from the electric lighting product manufacturer and a BIM consulting firm have participated the evaluation and work on the simulation case using the prototype. The application has shown the effeciency of the LPPO ontology to build semantic interoperability between manufacturer' database and BIM platform.

5. Conclusions

In this paper, we presented two ontologies of properties for products used in the construction industry. BPPO is a top domain ontology which represents the attributes standardized in an ISO standard developed by the BIM community for describing properties. This ontology provides the classes and properties to support modeling of the properties for particular categories of products in a standardized manner. The ontology LPPO represents and standardizes the properties that

[8]https://www.autodesk.com/products/revit/
[9]https://www.stardog.com/
[10]https://dynamobim.org/

describe the characteristics of electric lighting products using the classes and properties defined in BPPO. Further, we showed the use of the LPPO to support the interoperability between manufacturer's product database and BIM platform.

As suggested by EN ISO 23386:2020, there is a need to build a network of interconnected data dictionaries to describe, author and maintain properties in the construction industry. Ideally, each data dictionary in the network defines the properties for particular category of products or group of product categories. To address this need, we have followed the suggestion put forth in EN ISO 23386:2020 and developed the top domain ontology BPPO and the domain ontology LPPO. One direction of the future work is on expanding and enhancing the network of product property ontologies to cover a wider range of building product categories.

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