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Towards ontology-driven information exchange at Waternet: Developing open-source transformations from knowledge graph to Building Information Modelling standards bSDD and IDS

Sander STOLK [a,b], Anouk VAN OTTERLO [a,c] Quint NETTEN [c] Alexander WORP [a] and Arjan TOET [a]

[a] *Waternet, Amsterdam, the Netherlands*
[b] *Semmtech, Hoofddorp, the Netherlands*
[c] *Based, Tilburg, the Netherlands*
ORCiD ID: Sander Stolk https://orcid.org/0000-0003-2254-6613

Abstract.
This paper researches the technical feasibility of a new approach for exchanging and verifying asset information between clients and contractors in a Building Information Modelling context. The approach hinges on the dissemination of knowledge from ontologies in formats closer to their application and with which contractors tend to be more familiar, i.e., the new open standards buildingSMART Data Dictionary (bSDD) and Information Delivery Specification (IDS). With ontological information available in the bSDD, authoring tools commonly used in the Architecture, Engineering, and Construction industry should be able to access this information for users, who can then apply it to the corresponding geometric elements.

The main software components not yet available in order to realise this approach, on a technical level, were available transformations from ontologies to the bSDD and IDS standards. This paper discusses the transformation tools developed for this purpose, which enable sharing the required terminology and, through newly available software plugins, capturing asset information that can be successfully shared, verified, and subsequently incorporated into the client's asset management systems. We discuss the small transformation tools, *onto2bsdd* and *onto2ids*, developed specifically for this purpose and released under an open-source license. The approach, incorporating the transformations, is evaluated through a case study at Waternet, the major water infrastructure organisation in the region of Amsterdam.

Keywords. ontology, IFC, bSDD, IDS, information needs, transformation, verification, onto2bsdd, onto2ids, interoperability

1. Introduction

Building Information Modelling (or BIM) requires sharing of information on physical objects in a built environment (cf. ISO 19650 [1]), for which a shared understanding is paramount. In order to share the same terminology to capture alphanumeric data on infrastructure assets (e.g., classes and properties that describe physical objects) – regardless of whether the perspective adopted by these parties are geospatial, BIM, Systems Engineering, or otherwise – a number of asset owning organisations have developed ontologies that are published as Linked Data [2,3]. Not all parties in the AEC industry (i.e., Architecture, Engineering, Construction) may be as familiar with this data form, however, and currently used software on projects often do not fully align with Linked Data principles for incorporating existing ontological knowledge [4]. On projects at TenneT, exchanges using Linked Data were achieved by means of long-term partnerships and investments by both asset owner and its contractors [2]. With the goal of facilitating communication in a BIM context, this paper researches an alternative approach: the dissemination of Linked Data ontologies through transformations to openBIM standards buildingSMART Data Dictionary (bSDD) and Information Delivery Specification (IDS). The openBIM standards are associated more closely with the applications that contractors use. The clear advantage in being able to automatically generate bSDD and IDS formats based on knowledge in an ontology is that the same knowledge can be more easily adopted in various contexts. The AEC industry has not yet bridged the technical gap between ontologies on the one side and the bSDD and IDS formats on the other. Automating this process constitutes the contribution of this research. The transformation tools developed for this purpose, *onto2bsdd* and *onto2ids*, have been made available open source.

This research employs a case study for two purposes: firstly, to elicit the information requirements for the transformation tools that were to be developed; secondly, to evaluate the approach that incorporates these new transformation tools. The case at hand is information exchanges on BIM projects at Waternet, the major water infrastructure organisation in the region of Amsterdam, The Netherlands. Their core activities cover the whole water cycle: drinking water, sewage water and water management [5]. The design, construction, maintenance, and decommissioning of assets intended for water management by Waternet often occur in projects specific for these tasks, in which Waternet employs contractors to execute these activities. In recent years, Waternet has opted to develop and employ their own ontology, the Waternet Object Type Library [6], in order to express terminology on their infrastructure assets in a consistent manner, across all their software databases and, more recently, in communication with other parties – regardless of whether the perspective adopted by these parties are geospatial, BIM, Systems Engineering, or otherwise. It is this ontology that is pivotal in our case study.

The remainder of this paper is laid out as follows. Section 2 provides an overview of related work and the open standards and the technologies involved. Section 3 details the methodology. Section 4 describes the aforementioned case study. Section 5 discusses the work towards an ontology-derived dictionary in the bSDD format; section 6 concerns the transformation from an ontology to the verification format IDS. Section 7 discusses the results of both transformations in the Waternet case study. Before concluding, we evaluate our approach in section 8.

2. Background and Related Work

The subject of interoperability in the AEC industry has gained attention in recent years [7]. Data interoperability is said to be crucial to enhance efficiency and effectiveness, especially with slowing productivity growth and the imperative to maximize output with limited resources [8]. Although crucial, the diverse information landscape within the industry introduces challenges to achieving interoperability. Barriers include differences in formatting and structures but also semantic differences, where different projects use distinct names for the same concept or employ identical names with different meanings. Clear and linked semantics, i.e., by means of ontologies and alignments between ontologies, are indicated as key factors in overcoming these barriers and their disadvantages [9]. It is such issues of semantic interoperability for which this paper introduces a solution in the context of BIM projects specifically, by developing small transformation tools, applied to a case study.

2.1. Ontologies and Linked Data in AEC

The AEC industry has shown increased interest in the use of ontologies and Linked Data in recent years [10]. This interest can be observed on a broad scale, ranging from standardization initiatives to implementation in practice [11]. To illustrate, a national norm (NEN 2660) has been published in the Netherlands that specifies how to structure ontologies for the built environment and their use in information exchange on the basis of Linked Data [12]. Part of this norm has also been adopted in a European context (CEN 17632-1) [13], for which an expansion is currently in the final stages of the review and acceptance process [14]. Instances of Linked Data exchange supported by an ontology can be found at various large organizations, including TenneT and Schiphol [2,3]. Waternet has also adopted this approach in order to benefit from software-neutral communication according to clearly specified semantics – an essential pillar in their asset information management [6]. As mentioned earlier, the data exchanges at organisations such as TenneT require the Linked Data format to be adopted directly [2]. In contrast, the method researched in this paper requests data in a form adhering to openBIM standards, but adopting terminology from a knowledge graph that encompasses a Linked Data ontology and an alignment to buildingSMART's Industry Foundation Classes (IFC) to improve consistent use of terminology.

2.2. buildingSMART standards

Working with open standards in information exchanges allows information deliveries to be be uniform and standardized, improving interoperability and communication between all parties involved. For BIM contexts, buildingSMART International (bSI) is focusing on improving the exchange of data and information between different software solutions in the construction industry [15]. bSI develops its own data standards for openBIM, of which IFC is the most commonly used. IFC models, which typically contain geometry of building elements along with alphanumeric information on those elements, can be enriched by using classes and properties published as dictionaries in the buildingSMART Data Dictionary platform. The bSDD platform is a web-based service for publishing and consolidating of ontologies based on ISO 12006-3 [15]. Since 2020, developers have started to integrate the bSDD platform into their BIM software or plug-ins by the API in order to access data dictionaries hosted there.[1] In addition to access through its API, the bSDD can also be accessed through a website.[2] Although research has been undertaken to transform dictionaries in the bSDD to Linked Data ontologies, the reverse has, to our knowledge, not yet been undertaken [16].

To standardize manifestations of BIM requirements, buildingSMART has developed the IDS.[3] This standard enables authoring software to convey alphanumeric requirements and for verification software to check an IFC file on compliance to those same requirements. Some first efforts to apply this new standard have been made, but still rely on manual specification of the IDS [17]. This paper approach aims to speed up the creation of such an IDS based on information already available in the form of an ontology and, for alignments with other standards and for requirements on top of that ontology, a larger knowledge graph that incorporates that ontology.

3. Methodology

In researching the technical viability of a new approach for exchanging asset information between clients and contractors in a BIM context, based on ontological information and the recent openBIM standards bSDD and IDS, we have sketched the architecture and the various components in Figure 1. The architecture hinges on the dissemination of knowledge from ontologies (depicted at the top) in formats closer to their application and with which contractors tend to be more familiar, i.e., bSDD and IDS (depicted in the middle). With ontological information available in the bSDD, authoring tools commonly used in the AEC industry (depicted at the bottom left) should be able to access this information for users, who can then apply it to the corresponding geometric elements and verify it using checking tools (depicted at the bottom right).

Most components depicted in the architecture of Figure 1 are already available at the time of writing. Although not depicted here, many software pieces exist to create ontologies and to share them as RDF in so-called triplestores.[4] AEC software for modelling in a BIM context, such as Revit, have recently had open-source plugins made available for them that can access terminology from the bSDD platform.[5] Software that can verify information models, through the IDS standard, exist too. One such piece of software is the usBIM IFC Checker from ACCA software.[6] For the architecture proposed, therefore, the main challenge is the development of transformations from ontologies (and, larger, knowledge graphs) to the bSDD and IDS standards. In Figure 1, these transformations are shown right below the knowledge graph, as components *onto2bsdd* and *onto2ids* that facilitate the information to appear as bSDD and IDS. Development of these transformations should allow for sharing the required terminology

[1] Examples are open-source bSDD plugins for Revit, SketchUp, and Trimble Connect, being developed by Digibase in collaboration with BuildingSMART, Ketenstandard, ILS O&E, Semmtech, and DigiGo. See footnote 6.

[2] `https://search.bsdd.buildingsmart.org/`

[3] `https://github.com/buildingSMART/IDS/`

[4] To illustrate, the software used by Waternet for maintaining their ontology is the Laces suite (`https://laceshub.com`).

[5] `https://github.com/buildingsmart-community/bSDD-Revit-plugin`

[6] `https://www.accasoftware.com/en/ifc-checker`

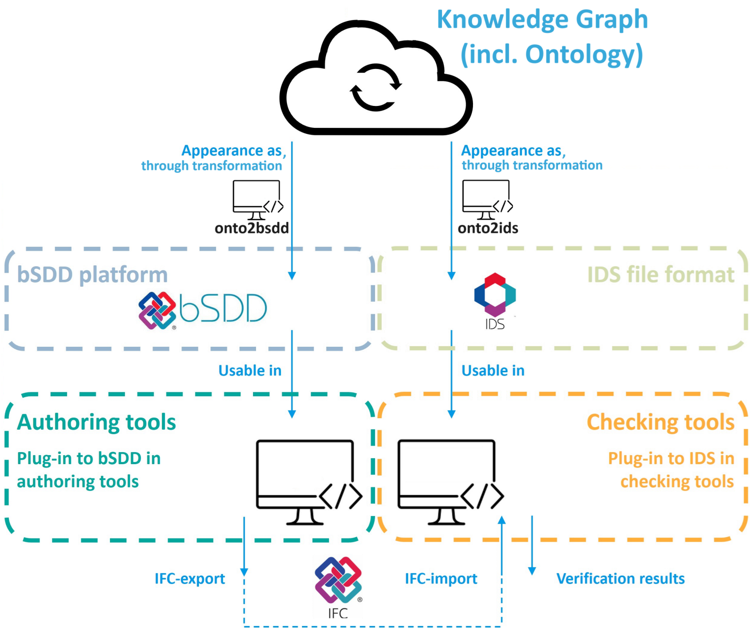

Figure 1. Architecture of information exchange in a BIM context

and, through the aforementioned plugins, capturing asset information that can be successfully shared, verified, and subsequently incorporated into the client's asset management systems.

This research employs a case study in which requirements for the transformation tools are elicited from asset information management experts at Waternet (see sections 5.1 and 6.1). Once the necessary transformations have been developed, we will evaluate the solution in its capability to carry over and verify the asset information in a BIM context, using Revit and the open-source bSDD plugin for modelling and the IFC Checker from ACCA for verifying. For this evaluation, too, we will incorporate feedback from those same experts. A more thorough evaluation, e.g., through pilot projects, is to follow in the future. In the next section, we will detail the case study which will be used in evaluation of both the transformations and the technical viability of the architecture.

4. Case study: Waternet and the W-OTL ontology

Waternet is the major water infrastructure organisation in the region of Amsterdam, The Netherlands. The organisation works for the regional public water authority Amstel, Gooi and Vecht and for the municipality of Amsterdam. Their core activities cover the whole water cycle: drinking water, sewage water and water management [5]. The organisation is facing significant challenges ranging from ageing infrastructure to an increase in demand (more inhabitants and in more locations) and stricter requirements concerning aspects such as water quality and protection against current and future sea levels. In order to face challenges such as these, digitization and robust, future-proof information management is essential. To face these challenges information is often needed to provide clear and better understandings into today's problems and make the best decisions for the future.

One of the key areas in which information management is being improved at Waternet is in the manner of information exchange between parties. Such exchanges necessitate clear specifications on what information is to be delivered, when, and how; and a manner in which the delivered information can be verified effectively and efficiently (e.g., for the delivery of the right information at the end of a project). To this end, Waternet is in the process of assessing which improvements can be made in the manner in which information on their water management assets is exchanged.

Moving towards more explicit and standardized ways in capturing and conveying which information is needed, and for what purpose in its asset management processes, the water management organisation aims to improve interoperability and the communication between all parties that carry out information exchanges with them. In recent years, Waternet has opted to develop and employ their own ontology, the Waternet Object Type Library [6]. This W-OTL is developed for expressing terminology on their infrastructure assets in a consistent manner, across all their software databases and, more recently, in communication with other parties – regardless of whether the perspective adopted by these parties are geospatial, BIM, Systems Engineering, or otherwise. The W-OTL is expressed in the open standard Linked Data and contains (1) a taxonomy of classes expressing physical objects, spatial objects, and documents; (2) relations between these classes; and (3) properties relevant for each class, including possible values.

As not all delivering parties in a BIM context are used to working with Linked Data, Waternet has hitherto mostly asked contractors to supply the desired alphanumeric data, to be expressed according to the W-OTL, by means of Excel spreadsheets. This paper instead opts for a different approach that allows contractors to capture the necessary data directly in the BIM model, in a standardized manner and alongside of the geometry.

Before continuing in the next sections with outlining the development of tooling that can automate the production of an ontology-derived dictionary in bSDD (section 5) and an ontology-derived IDS to verify alphanumeric data in the field of BIM (section 6), we should note that, for the purpose of this case study, the W-OTL has been expanded with an alignment to the IFC schema. Thus, a pump according to W-OTL is known to be a pump according to IFC. This alignment, limited in scope to the current case study, has been modelled to ensure classifications between the W-OTL and IFC can be verified for consistency; an object in a BIM model that ought to be classified as a W-OTL pump should not also be classified as an IFC door. The understandings captured in this alignment, published as Linked Data, need to be available to contractors alongside the W-OTL terminology. The W-OTL and the alignment, and more Linked Datasets besides, are managed and published using the Laces software.[7] Managing the alignment as a separate dataset from the terminology it maps is, in the context of Waternet certainly, advantageous. This practice allows for different teams to work separately from each other in their own workspaces, whilst Linked Data technology enables retaining proper links between the datasets where relevant.

[7] https://laceshub.com

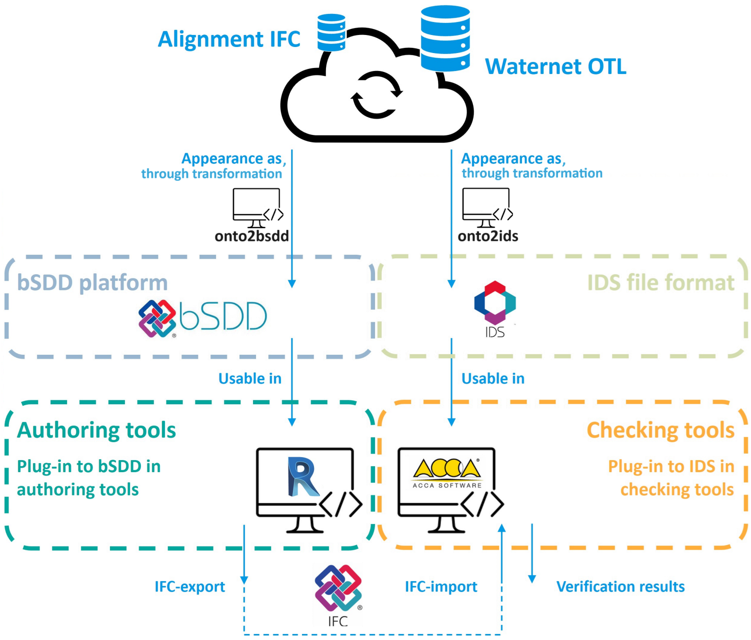

Figure 2. Case study with bSDD and IDS

5. Developing *onto2bsdd*: tooling to obtain an ontology-derived dictionary in bSDD

5.1. Information requirements

The information requirements obtained from asset information experts at Waternet were as follows. To be accessible, understood, and applied consistently on BIM projects through the bSDD platform, ontology classes and properties need to be disseminated via the bSDD platform along with their unique identification (i.e., URIs), preferred names, and definitions. Ontology properties need to be registered with this same information, but also have to include their datatype and, in the case of enumerations, any values that these properties are allowed to have. Additionally, every class registered in the bSDD has to indicate which properties are relevant and, if one exists, which IFC entity corresponds to that class.

5.2. Generating bSDD dictionary from a knowledge graph

We have developed *onto2bsdd*, a small Web application that generates a bSDD dictionary based on the W-OTL – or in fact any other ontology published as Linked Data. The source code is available under an open license.[8] *onto2bsdd* uses JavaScript to parse the results of a SPARQL query [18] and transform that knowledge to a bSDD JSON import model.[9]

[8] `https://github.com/ssstolk/onto2bsdd`
[9] `https://github.com/buildingSMART/bSDD/blob/master/Documentation/bSDD%20JSON%20import%20model.md`

The logic used in the application is straightforward: header information, which can be adjusted in the *onto2bsdd* user interface, is combined with the results of a SPARQL query (in CSV) executed on the SPARQL endpoint of the ontology in question (see Table 1). These sources are used together to fill out a JSON object with classes and properties intended to be part of the dictionary in the bSDD. Table 2 shows the mapping from ontology query variables to the bSDD import data model. URIs used to identify classes and properties in the source ontology are, in order to retain information on the origins, registered in the bSDD JSON import object alongside their generated counterpart bSDD entities and properties. Links to IFC entities are, whenever present in the query results, included as part of the same JSON object.

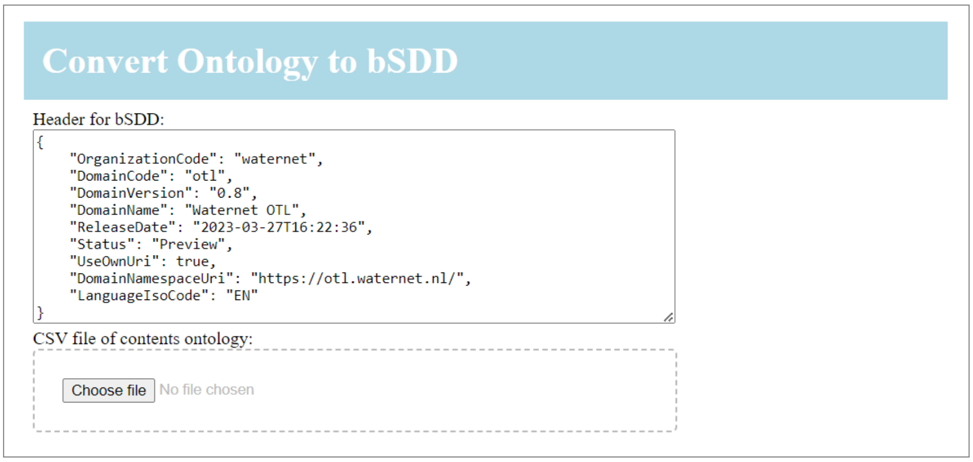

Figure 3. Web interface of *onto2bsdd*

variable	description
ontoClassPrefLabel	human-readable name for an ontology class
ontoClassURI	unique resource identifier for the ontology class
ontoClassDefinition	definition for the ontology class
ifcClassLabel	counterpart IFC entity (e.g. IfcDoor)
ifcClassURI	unique resource identifier for the IFC entity
ontoParentClassPrefLabel	human-readable name for the parent ontology class (hypernym)
ontoParentClassURI	unique resource identifier for the parent ontology class
ontoPropertyPrefLabel	human-readable name for a property relevant for the class
ontoPropertyURI	unique resource identifier for the ontology property
ontoPropertyDefinition	definition for the ontology property
ontoPropertyDatatype	datatype
ontoPropertyDatatypeLabel	datatype label
ontoPropertyEnumValues	possible enumeration values

Table 1. SPARQL variables used by *onto2bsdd*.

W-OTL (ontology)	bSDD	comment
all objects	*all objects*	
onto...URI	OwnedUri	URL to uniquely identify the term
onto...URI	Code	localname of URI is used
onto...PrefLabel	Name	
onto...Definition	Definition	
ontoClass	Class	
ontoParentClassURI	ParentClassCode	localname of URI is used
ifcClassLabel	RelatedIfcEntityNamesList	
(Property path)	ClassProperties	is left implied in query results
ontoProperty	Property	
ontoPropertyDatatype	DataType	
ontoPropertyEnumValues	AllowedValues	
Property path	ClassProperty	
ontoPropertyURI	PropertyURI	
ontoPropertyURI	PropertyCode	
onto{Class&Property}URI	OwnedUri	concatenation of the two URIs
ontoName	PropertySet	from header, e.g. "Waternet OTL"

Table 2. Mapping between query results on a Linked Data ontology and the bSDD import data model.

6. Developing *onto2ids*: tooling to obtain an ontology-derived IDS

6.1. Information requirements

To ensure the data quality of (enriched) IFC models, verification steps should employ an IDS file that adheres to the same ontology terminology as made available via the bSDD. When a BIM model object is categorized using ontological terminology, it is necessary to check for corresponding properties in the Pset associated with the ontology. Additionally, in order to ensure that all elements of the IFC model are classified according to (the bSDD publication of) the ontology, the IDS should contain a specific requirement to verify this condition by means of the following pattern: for each modelled object, a classification must be present according to the ontological classification system. For verifying the properties used, the IDS should include separate specifications for every ontology class in which the applicability is set to that class. These requirements are constructed based on the properties associated with the object classification, indicating that these properties must be used and are part of the Pset associated with the ontology.

6.2. Generating IDS from a knowledge graph

In a similar approach to *onto2bsdd*, we have developed *onto2ids*.[10] This Web application uses JavaScript to parse the results of a SPARQL query (see Table 3 for the variables used) and transform that knowledge to an IDS shaped as described in the preceding section. The user interface of *onto2ids* requires information on the bSDD dictionary concerned, the IDS that is to be generated, and the results of a SPARQL query (in CSV)

[10] `https://github.com/ssstolk/onto2ids`

executed on the SPARQL endpoint of the ontology in question. These three sources are consulted by the application to fill out a template that adheres to the IDS schema for XML. A download of the resulting IDS is initiated automatically after its generation.

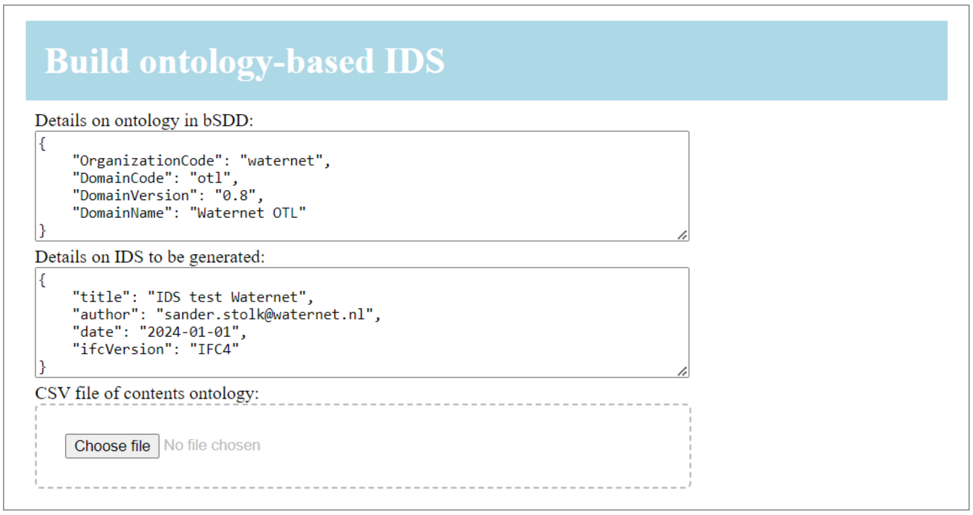

Figure 4. Web interface of *onto2ids*

variable	description
ontoClassPrefLabel	human-readable name for an ontology class
ontoClassURI	unique resource identifier for the ontology class
ifcClassLabel	counterpart IFC entity (e.g. IfcDoor)
ontoPropertyPrefLabel	human-readable name for a property relevant for the class
ontoPropertyURI	unique resource identifier for the ontology property
ontoPropertyDatatype	property requirements: datatype
ontoPropertyEnumValues	property requirements: enumeration values
ontoPropertyCardinalityMin	property requirements: min cardinality
ontoPropertyCardinalityMax	property requirements: max cardinality

Table 3. SPARQL variables used by *onto2ids*.

7. Results

We have used both *onto2bsdd* and *onto2ids* in the context of the Waternet case study. With each, their SPARQL query was executed on the two different Linked Data datasets in conjunction: the W-OTL and the alignment between that ontology and IFC. For generating the IDS, not all desired information is present in these datasets, however. Currently, the W-OTL lacks information to provide the IDS with minimum cardinalities for properties in information deliveries. We have therefore opted to incorporate this as a recommendation for future work and, as a temporary work-around to test the technical viability, let the SPARQL query return that each property is required minimally once per element. The results, a JSON file generated by *onto2bsdd* and an IDS file generated by *onto2ids*, can be found in the Github repositories for these Web-based tools.[11] The JSON file containing information for bSDD has been uploaded to the bSDD platform (see Figure 5).[12] From here, the bSDD Revit plugin should be able to access it, as we will see in our evaluation.

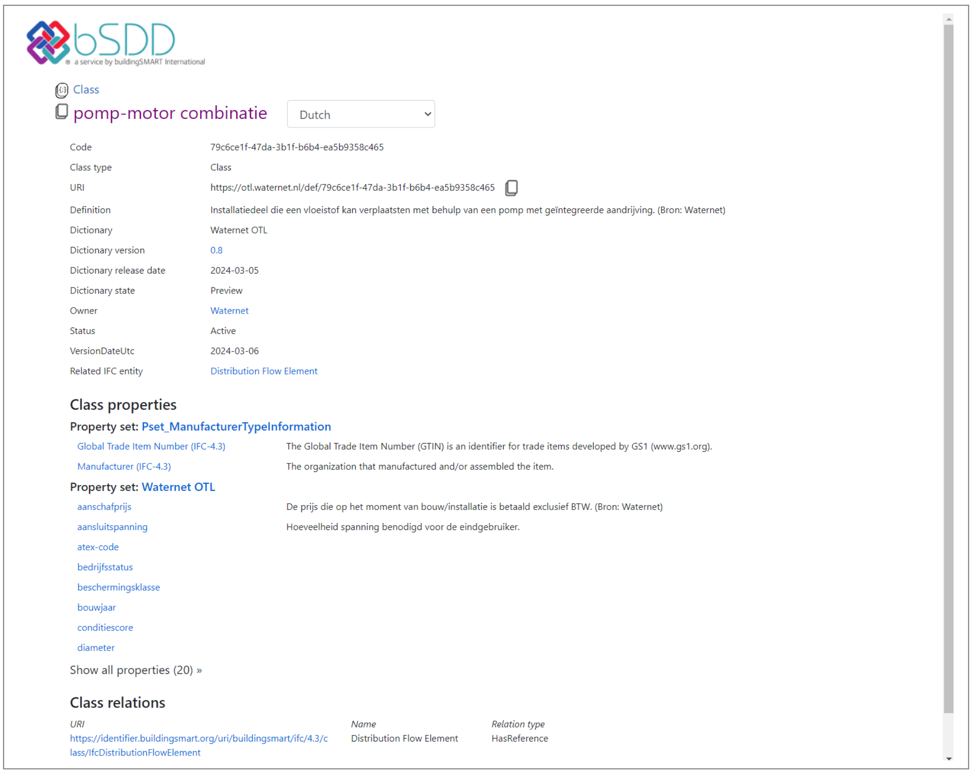

Figure 5. The W-OTL class 'pump-engine combination' in bSDD.

8. Evaluation

To evaluate whether the bSDD publication and IDS export are usable for asset owning organisations, both parts of the case study – i.e., enriching a BIM model with classes and properties via the bSDD and verifying it using IDS – were tested with a supplied model of a physical asset that Waternet maintains. Figures 6 and 7 show screenshots taken from ACCA Software usBIM[13], in which an IFC model was enriched with classifications to

[11] `https://github.com/ssstolk/onto2bsdd/blob/main/onto/waternet/ontology-bsdd.json` and `https://github.com/ssstolk/onto2ids/blob/main/onto/waternet/IDS%20test%20Waternet.ids`
[12] `https://search.bsdd.buildingsmart.org/class/137886`
[13] `https://www.accasoftware.com/en/`

W-OTL classes and with W-OTL properties, both served from the bSDD, on geometric elements selected for the evaluation. The enriched IFC model was verified against the IDS generated. In an initial test, no violated requirements were found for those geometric elements that were within scope of the evaluation. After manually adjusting the IFC model by removing filled in values for required properties, the verification process based on IDS proved effective in discovering the violated requirements in the captured asset information. The team of asset information experts at Waternet who were consulted, confirmed that the IFC model indeed contains the structure necessary for extracting alphanumeric information that is based on the W-OTL in order to ingest that information into their asset management platform (as per the information requirements stated in sections 5.1 and 6.1). Moreover, they indicated that the ability to the view the fulfilled and unfulfilled information requirements as part of the BIM model, enhanced their insight and understanding of areas of attention and are thought to facilitate communication between client and contractor. A more thorough evaluation, e.g., through pilot projects, is to follow in the future.

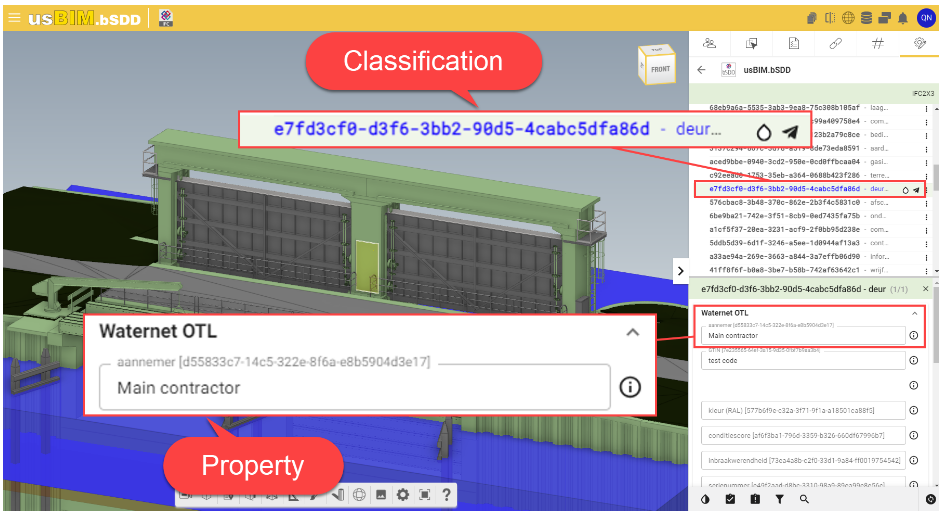

Figure 6. Screenshot of enriching a BIM model by bSDD

9. Conclusion and Future Work

The advantage in being able to automatically generate bSDD and IDS formats based on knowledge in an ontology is that the same knowledge can be more easily adopted in various contexts. In order to truly utilize these mechanics and tooling in an operational setting at Waternet, the findings of this paper will still need to be incorporated into an appropriate governance scheme. Moreover, in addition to information requirements, other functional and non-functional requirements have to be elicited from key users and experts in order to build a solution that is not only viable technically but also operationally. We surmise that the Web applications would benefit from further integration into an automated pipeline (including them using SPARQL directly to retrieve

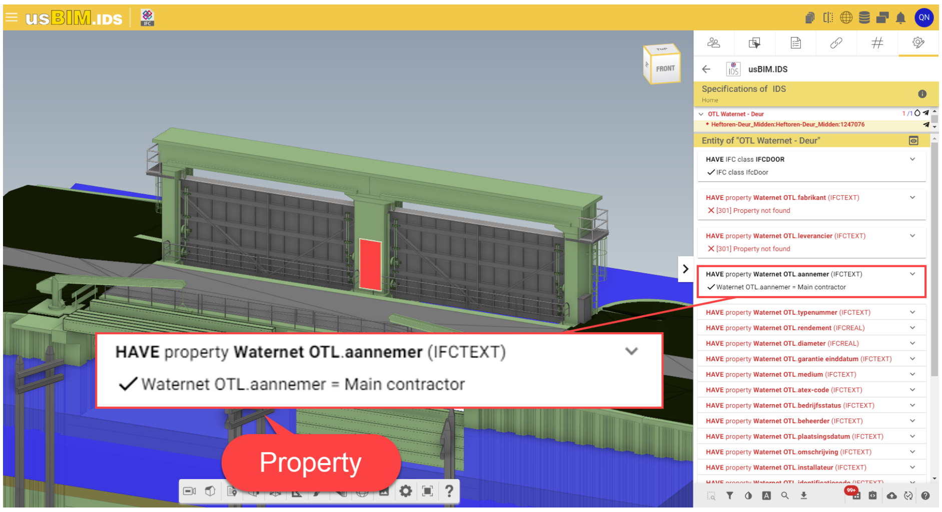

Figure 7. Screenshot of verifying a BIM model by IDS

contents of the ontology, as opposed to them operating on query results in CSV format). Moreover, work is also required at Waternet to expand their ontology with information about which information is required for a specific project phase or use case to generate an IDS with a specific scope.

Beyond the technical components being now available, the main work to be done lies not in the technical department but in adopting and evaluating the new approach with contractors. The goal for clear communication and exchange of information between client and contractor requires both parties to be involved in a thorough assessment of whether the new approach can truly be adopted by all organisations, as changes involve more than only technical aspects. Nevertheless, this paper has taken the first steps towards ontology-driven information exchange at Waternet and confirmed the technical feasibility of the new approach. Clients and contractors in BIM contexts, at Waternet and elsewhere, can build on this research, adopt or improve on the transformations made available open-source, and assess the organisational efforts that remain for adopting such ontology-driven information exchange on their own BIM projects.

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