Towards Aligning Domain Ontologies with the Building Topology Ontology

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Abstract. The ontology-modelling approach has been recognised as one possible remedy to address the prevalent heterogeneity in information exchange in the Architecture, Construction, Engineering and Facility Management (AEC/FM) industry. A plethora of domain ontologies exist, each designed to fulfil the specific information requirements of a certain use case within the AEC/FM domain. Recent published work proposes a central ontology termed Building Topology Ontology (BOT) which aims at capturing frequently occurring design patterns in domain ontologies. This paper presents a work in progress towards proposing alignments of this central ontology to five domain ontologies from AEC/FM domain. The proposed alignments are evaluated in terms of consistency of the resulting ontology. Finally conclusions are drawn on how a possible redesign of the BOT ontology could stipulate further reuse.

Keywords: Ontology, Alignment, BOT, SAREF, ifcOWL, BRICK, DogOnt, ThinkHome

1 Introduction

For the successful design, construction and operation of buildings data and information needs to be exchanged seamlessly between stakeholders over the full life cycle. Usually a building is in use for several decades. Often this data and information is distributed across various formats and information sources. To address this prevalent heterogeneity a paradigm shift takes placed towards the deployment of the Building Information Modelling (BIM) [6] method to enable model-based information exchange among stakeholders in the AEC/FM industry.

Ontological modelling and the related Semantic Web technologies [2] seem to be a promising path towards further improving and facilitating information exchange among stakeholders through adding additionally formal semantics [4, 5, 12, 17].

In the past a number of domain ontologies have been proposed (see reviews in [5, 12, 14]). A partial overlap between domain ontologies has been recently identified [14]. To enable ontology reuse and to stipulate further adoption of the technology in industry, a central ontology (Building Topology Ontology (BOT)) is proposed [14]. The authors aim at condensing the most often reoccurring concepts into one ontology. To achieve a high maintainability and only a limited set of core classes to work with the authors propose five concepts and seven object properties.

Rassmussen et al. [14] discuss possible methods towards aligning to BOT, however, no alignment to existing domain ontologies is defined and evaluated. This paper presents a work in progress towards filling this gap by defining alignments between AEC/FM domain ontologies to BOT. The alignment of domain ontologies to BOT serves as an enabler for querying and reasoning across different domain ontologies as well as an evaluation of the modelling of BOT. In essence BOT may serve as a catalyst in ontology-based modelling in the AEC/FM domain paving the way for a modular approach with a set of well defined domain ontologies all interlinked by BOT.

In Section 2 explicit alignments are presented for aligning SAREF4BLDG [13], BRICK [1], ThinkHome [16], DogOnt [3] and ifcOWL4_Add2 [11] to BOT. The proposed alignments are evaluated towards semantic consistency and type. Section 3 summarises the findings made and formulates requirements for a possible redesign of BOT.

2 Definition of Alignments

This section summarises the defined alignments of domain ontologies to BOT. The most recent status of the alignment is published on the GitHub-page of the W3C Linked Building Data on the Web Community Group `https://github.com/w3c-lbd-cg/bot/`. The prefixes used in this document are displayed in Table 1.

Table 1. Namespaces and prefixes used in this work.

Prefix	Value
rdf	`http://www.w3.org/1999/02/22-rdf-syntax-ns#`
rdfs	`http://www.w3.org/2000/01/rdf-schema#`
owl	`http://www.w3.org/2002/07/owl#`
bot	`https://w3id.org/bot#`
s4bldg	`https://w3id.org/def/saref4bldg#`
dogont	`http://elite.polito.it/ontologies/dogont.owl#`
th	`https://www.auto.tuwien.ac.at/downloads/thinkhome/ontology/BuildingOntology.owl#`
ifc	`http://www.buildingsmart-tech.org/ifcOWL/IFC4_ADD2#`
brick	`https://brickschema.org/schema/1.0.2/Brick#`

2.1 SAREF Extension for Building Devices

The SAREF extension for building devices (S4BLDG) ontology [13] is an extension of the Smart Appliances REFerences ontology (SAREF) [5] based on the Industry Foundation Classes (IFC) [9]. The extension is proposed to separate building specific information from the generic domain of SAREF, i.e. smart appliances.

The defined alignments from S4BLDG to BOT are presented in Table 2. In total five alignments are made. Three `owl:equivalentClass` statements to `saref4bldg:Building`, `saref4bldg:PhysicalObject` and `saref4bldg:BuildingSpace` are defined reflecting the exact similar semantics. `saref4bldg:hasSpace` is defined only as `rdfs:subPropertyOf` reflecting the absence of an equivalent concept of `bot:Storey` which is defined as the domain of `bot:hasSpace`. Finally equivalence is defined for `bot:containsElement` and `saref4bldg:contains`. It may be noted that this fits the previously defined alignments for `bot:Space` and `bot:Element` as these are the domain and range of `bot:containsElement`.

Table 2. Proposed alignment of BOT [14] and SAREF4Building [13].

Subject	Predicate	Object
bot:Building	owl:equivalentClass	saref4bldg:Building
bot:Element	owl:equivalentClass	saref4bldg:PhysicalObject
bot:Space	owl:equivalentClass	saref4bldg:BuildingSpace
bot:hasSpace	rdfs:subPropertyOf	saref4bldg:hasSpace
bot:containsElement	owl:equivalentProperty	saref4bldg:contains

2.2 BRICK Uniform Schema for Representing Metadata in Buildings

The BRICK ontology [1] sets out towards defining a uniform schema for representing building data with a specific emphasis on building operation. This is reflected also by its top-level concepts which constitute `brick:Location`, `brick:Point`, `brick:Equipment` and `brick:Measurement`.

Alignments from BRICK to BOT have been found and are presented in Table 3. Two equivalences may be manifested when considering `brick:Building` and `brick:Storey` with exactly the same semantics. The remaining defined alignments use `rdfs:subClassOf` to place `bot:Space` into a suitable relationship to `brick:Location` which is an abstract definition of an building environment and its subclasses. No object property alignments have been found.

Table 3. Proposed alignment of BOT [14] and BRICK [1].

Subject	**Predicate**	**Object**
bot:Building	owl:equivalentClass	brick:Building
bot:Storey	owl:equivalentClass	brick:Floor
bot:Space	rdfs:subClassOf	brick:Location
brick:Basement	rdfs:subClassOf	bot:Space
brick:Outside	rdfs:subClassOf	bot:Space
brick:Room	rdfs:subClassOf	bot:Space
brick:Space	rdfs:subClassOf	bot:Space
brick:Wing	rdfs:subClassOf	bot:Space
brick:Zone	rdfs:subClassOf	bot:Space
brick:Equipment	rdfs:subClassOf	bot:Element
brick:Point	rdfs:subClassOf	bot:Element

2.3 DogOnt - Ontology Modeling for Intelligent Domotic Environments

DogOnt [3] may be considered as one of the first domain ontologies for smart homes and related appliances. It is under active development and most recent releases may be obtained from a GitHub repository (`https://github.com/iot-ontologies/dogont`).

The defined alignments from DogOnt to BOT are summarised in Table 4. Equivalence may be asserted for `dogont:Storey` and `dogont:Building`. However, similar to BRICK ontology defining alignments to `bot:Space` needs to be done using `rdfs:subClassOf` as DogOnt defines a general concept `dogont:-BuildingEnvironment` for generic enclosements in a building. `dogont:Device`, `dogont:UnControllable`, `dogont:Controllable` and `dogont:TechnicalSystem` may be declared as `rdfs:subClassOf` `bot:Element` in a straightforward manner. No possible object property alignments have been found.

2.4 ThinkHome Ontology

ThinkHome ontologies [16] comprises a family of ontologies formalising the wider range of the buildings domain, smart homes and adjacent domains of energy and smart grid. A use case is to enable intelligent demand side management of utilities on the electrical grid.

The defined alignments from ThinkHome building domain ontology to BOT are presented in Table 5. Equivalences may be asserted for `th:Campus`, `th:Building` and `th:BuildingStorey` without violating the semantics. To represent the generic nature of `bot:Space`, `th:Zone` and `th:Space` are defined as subclasses arising from their definitions. Subsumption applies for a number of concepts from the ontology. No object property alignments are found.

Table 4. Proposed alignment of BOT [14] and DogOnt [3].

Subject	**Predicate**	**Object**
bot:Building	owl:equivalentClass	dogont:Building
dogont:Flat	rdfs:subClassOf	bot:Building
bot:Storey	owl:equivalentClass	dogont:Storey
bot:Space	rdfs:subClassOf	dogont:BuildingEnvironment
dogont:Room	rdfs:subClassOf	bot:Space
dogont:Garage	rdfs:subClassOf	bot:Space
dogont:Garden	rdfs:subClassOf	bot:Space
dogont:Controllable	rdfs:subClassOf	bot:Element
dogont:Device	rdfs:subClassOf	bot:Element
dogont:UnControllable	rdfs:subClassOf	bot:Element
dogont:TechnicalSystem	rdfs:subClassOf	bot:Element

Table 5. Proposed alignment of BOT [14] and ThinkHome [16].

Subject	**Predicate**	**Object**
bot:Site	owl:equivalentClass	th:Campus
bot:Building	owl:equivalentClass	th:Building
bot:Storey	owl:equivalentClass	th:BuildingStorey
th:Zone	rdfs:subClassOf	bot:Space
th:Space	rdfs:subClassOf	bot:Space
th:Equipment	rdfs:subClassOf	bot:Element
th:Construction	rdfs:subClassOf	bot:Element
th:Layer	rdfs:subClassOf	bot:Element
th:Material	rdfs:subClassOf	bot:Element
th:Opening	rdfs:subClassOf	bot:Element
th:Surface	rdfs:subClassOf	bot:Element

2.5 Industry Foundation Classes 4 Addendum 2

The Industry Foundation Classes (IFC) are a well known and accepted standard in the domain of BIM and it covers in comparison to the aforementioned ontologies a much wider domain including for example detailed geometry. It has been translated to OWL [11].

The defined alignments from BOT to IFC4_Add2 are presented in Table 6. Equivalence is defined for all top level concepts of BOT. No object property alignments are defined as IFC utilises objectified relationships. Hence alignments require more complex statements, e.g. through SWRL [8] notation.

Table 6. Proposed alignment of BOT [14] and ifcOWL4_Add2 [11].

Subject	Predicate	Object
bot:Site	owl:equivalentClass	ifc:IfcSite
bot:Building	owl:equivalentClass	ifc:IfcBuilding
bot:Storey	owl:equivalentClass	ifc:IfcBuildingStorey
bot:Space	owl:equivalentClass	ifc:IfcSpace
bot:Element	owl:equivalentClass	ifc:IfcElement

3 Evaluation and Discussion

The defined alignments have been implemented using the Protégé ontology editor [10] and are serialised into a separate ontology file each. There the BOT ontology as well as its respective counterpart are imported and alignments are defined. The resulting alignments are loaded in Protégé and consistency is evaluated by invoking the HermiT [7] reasoner upon.

The results of the study are presented in Table 7. Analysing the defined alignments it becomes apparent that most alignments have been defined on class level. Only for one ontology an alignment on the object property level has been found.

The main difficulty discovered when analysing domain ontologies to define alignments is the different granularity observed in the different domains. BOT distinguishes `bot:Site`, `bot:Building`, `bot:Storey` etc. with associated definition of object properties. However, in the respective domain ontologies it may only be `brick:Location` or `dogont:BuildingEnvironment`. Thus, the following requirements regarding a possible revision of BOT may be defined:

- Introduction of a concept `bot:*Enclosing` as a superclass of `bot:Site`, `bot:Building`, `bot:Storey` and `bot:Space`;
- Provide high-level mereological relationship (hasPart, isPartOf) relationship between `bot:*Enclosing` and `bot:Element` as well as between two `bot:-*Enclosings`;

Table 7. Evaluation of defined alignments, No. of Alignments - Total number of alignment triples. Consistency - Invoking HermiT [7] reasoner on the alignment ontology did not return any faults; Concept level - Alignments defined on concept level, Object Property level - Alignments defined on object property level.

Domain Ontology	**No. of Alignments**	**Consistency**	**Concept level**	**Object Property level**
S4BLDG [13]	5	yes	yes	yes
BRICK [1]	11	yes	yes	no
DogOnt [3]	11	yes	yes	no
ThinkHome [16]	11	yes	yes	no
ifcOWL [11]	5	yes	yes	no

– Provide high-level topological relationship (isConnectedTo/ isAdjacentTo) relationship between `bot:*Enclosing` and `bot:Element` as well as between two `bot:*Enclosing`s.

4 Conclusion

This work fills a gap by proposing alignments of domain ontologies from the AEC/FM domain to a central ontology termed Building Topology Ontology (BOT) [14]. Alignments to five domain ontologies originating from building automation domain, i.e. SAREF4BLDG [13], BRICK [1], ThinkHome [16], DogOnt [3] and Building Information Modelling (BIM) domain ifcOWL4_Add2 [11] to BOT are presented. The alignments are implemented as separate ontologies importing BOT and the counterpart into a separate ontology file. All alignment ontologies are found to be consistent when invoking HermiT reasoner upon. The experience gathered through performing this study are summarised into requirements formulated for future revisions for BOT ontology to further stipulate reuse. Some of these requirements are considered through a revision of BOT ontology presented in a companion paper [15].

The proposed alignments mainly consist of equivalences (`owl:equivalentClass`) or subsumption (`rdfs:subClassOf`) on class level. Alignments found on property level are rather limited. A reason for this is the rigid definition of site, building, storey and space in BOT which are not always distinguished in domain ontologies and the domain restrictions of the object properties. For example when using `bot:hasSpace` a reasoner infers that something related to a space is a `bot:Storey`, which might not always be the case.

The proposed alignments need to be further tested and discussed, at best, involving the respective domain ontology designers to develop a commonly agreed on mapping. The ontology files containing the proposed alignments are published for public review and enhancement in a GitHub repository (`https://github.com/w3c-lbd-cg/bot/`). Furthermore, use cases need to be defined where cross-domain information can be integrated and queried across related ontologies.

Future research is required on evaluating possible alignments of BOT to upper level ontologies such as `schema.org` or `dbpedia.org` as well as other domain ontologies in the AEC/FM domain not included in this study.

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