An evaluation of the strict meaning of owl:sameAs in the field of BIM GIS Integration

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Abstract. Linking heterogeneous information models from the domains Building Information Modelling (BIM) and Geospatial Information Systems (GIS) enables synergetic effects between these domains. A common approach to define links between corresponding objects are identity relation like *owl:sameAs* from the Web Ontology Language (OWL). Identity relations suggests that everything stated about one entity hold for the corresponding entity (i.e., they share all of their properties). However, this kind of semantics is too strict for linking objects from heterogeneous information models. This paper shows the issue of the strict semantics of identity relations for linking building elements of heterogeneous information models like Industry Foundation Classes (IFC) and CityGML. In more detail, related literature about heterogeneities and links between IFC and CityGML are reviewed. Afterwards, the issue caused by the strict semantics of identity links for linking IFC and CityGML models is illustrated and alternative approaches to identity links are discussed. As a result, identity links are prone to be misleading for linking building elements represented in Industry Foundation Classes (IFC) and CityGML models. However, alternative linking approaches have the short coming that they generally rely on the correct interpretation of the user.

Keywords: BIM GIS Integration, Linked Data, Semantic Web Technologies, owl:sameAs, Identity links.

1 Introduction

Linking heterogeneous information models across the domains Building Information Modeling (BIM) and Geospatial Information Systems (GIS) aims to improve the communication among different disciplines and support decision-making during the life cycle of a construction project [1–4]. In particular, the information models Industry Foundation Classes (IFC) and CityGML are promising for synergies between the domains BIM and GIS due to both their overlapping and distinct representation scope [5, 6]. While IFC is mainly intended to represent information about building assets for design purposes, CityGML is intended to represent information about various buildings and their surroundings for spatial analysis purposes. The consequent heterogeneity between IFC and CityGML caused by the distinct underlying perspectives and purposes impede a seamless one-to-one mapping between corresponding objects of these information models [7–11].

Matching of corresponding objects results in a set of correspondences, which is called alignment [12, 13] or link model [14]. The resulting correspondences are made explicit and shareable by means of alignment languages like Web Ontology Language

(OWL) [15]. In OWL, the links between corresponding objects at instance-level are commonly represented by means of the expression *owl:sameAs* which states that the linked objects “have the same identity” [15]. However, the meaning of *same identity* is not further specified such that it is generally interpreted in terms of logical equality.

A common description of logical equality follows the concept of identity according to Leibniz’ principles of identity of indiscernibles [16]. Roughly spoken, Leibniz’ principles of identity of indiscernibles state that two objects sharing the same identity implies that they share all of their properties and vice versa. Thus, two objects linked through *owl:sameAs* are generally interpreted in terms that the properties of one object holds for the other. Current research has shown that this meaning of *owl:sameAs* is often too strict since the linked objects do not necessarily share all of their properties: Is a ship before the replacement of some components the same as the ship after this replacement [17]? Is Tim Berners-Lee as child the same as Tim Berners-Lee as adult [18]? Is drug A the same as drug B when having the same structure but different vendors [19]? To the best of the authors knowledge, the applicability of *owl:sameAs* is not discussed with respect to BIM and GIS, even though the lack of seamless one-to-one mappings between objects of IFC- and CityGML-models seams to conflict with the strict meaning of *owl:sameAs*.

In this paper, related literature about the strict meaning of *owl:sameAs* and the alignment of heterogeneous information models from the domains BIM and GIS is investigated. Afterwards, the information models IFC, CityGML and the alignment language OWL are described. In the fourth chapter, the meaning of identity links like *owl:sameAs* is discussed and different types of properties for which Leibniz’ laws holds/ does not hold are introduced. In the subsequent chapter, two examples illustrate difficulties accompanying the usage of identity links for linking IFC and CityGML. Last, these difficulties are summarized and conclusions for the usage of identity links like *owl:sameAs* for linking heterogenous information models from the domains BIM and GIS are provided.

2 Related Literature

2.1 Heterogeneities between IFC and CityGML

The literature review about heterogeneities between IFC and CityGML models indicates and explains mismatches between the two kinds of information models. In summary, there are three different approaches which describe heterogeneity between IFC and CityGML at both instance- and schema level. The first approach lists particular differences from a rather general perspective [3, 4, 20–23]. In contrast to that, another approach describes heterogeneities by means of defined structures like interoperability models [3]. The third approach compares entities of IFC and CityGML at schema-level [7, 10, 11]. Regarding instance-level heterogeneities, there are two major aspects that are relevant for the discourse of the paper: First, the instantiation is often based on different types of data acquisition. While IFC models are often modelled manually in the design phase (prescriptive), CityGML models are often created based on surveying, remote sensing or photogrammetry (descriptive) [8, 20, 24]. Therefore, IFC models often cover idealized geometrical descriptions, while CityGML models often represent visible geometries in analogy to the real-world asset. Second, the underlying modelling paradigm differs due to different purposes and types of data acquisition [8, 20, 24]. Building elements in CityGML are geometrically represented by means of boundary representations, while building elements in IFC are generally described as solids created by means of explicit or implicit geometrical representations.

2.2 Instance-level links between IFC and CityGML

There a variety approaches in research to link instance-level information from IFC and CityGML models: For instance, Hijazi et al. [25] use a relation table representing GMLIDs of CityGML buildings and the related subproject of an IFC model. Hor et al. [26] map corresponding objects of IFC and CityGML models based on Semantic Web Technologies using the link predicates *Equivalent*, *As-is*, and *Has an attribute*. Huang et al. [27] relate window objects represented as ifcOWL/BOT and CityGML use the link predicate *skos:exactMatch* from the SKOS vocabulary. Vilgertshofer et al. [28] map the globalID of an IFC element to the gml:id of CityGML element using Semantic Web Technologies without explicitly mentioning any link predicate. Stepien et al. [29] make use of topological relationships to link several different models like city models and cadastral maps to an infrastructure alignment of a tunnel using Semantic Web technologies.

3 Information Models and Alignment Languages

The information model Industry Foundation Classes (IFC) supports the vendor-neutral information exchange throughout the life cycle of building assets and is associated with the domain BIM [30]. Its development is primarily supported by buildingSMART. The instance information can be represented through different formats like Standard Presentation Format (SPF) (ISO 10303-21). The schema of IFC was translated to the ifcOWL to make it accessible in the field of Semantic Web [31]. However, ifcOWL is conceived as inadequate for linking information following the idea of Semantic Web, e.g. due to its complexity and size [32]. Instead, the Building Topology Ontology (BOT) was developed to overcome these drawbacks [32]. On the other side, CityGML [33, 34] aims to support modelling, storage, and exchange of city models and refers to the domain GIS. It is based on Geographic Markup Language (GML) (ISO 19136) and primarily developed by Open Geospatial Consortium (OGC).

Alignment languages are intended to represent sets of correspondences between entities of information models at either or both levels instance and schema. Examples for alignment languages are OWL [15], Expressive and Declarative Ontology Alignment Language (EDOAL) [35], Semantic Web Rule Language (SWRL) [36] and Context-OWL (C-OWL) [37]. Among others, alignment languages differ regarding their expressivity and compatibility to formal languages [12]. In this paper, the alignment language OWL is discussed due to its prevalence use in the field of Semantic Web. OWL is based on Resource Description Framework (RDF) such that linking of IFC and CityGML requires the syntactical translation from their native format to RDF [31, 38]. OWL is a logic-based language and its current version OWL 2 was developed by World Wide Web Consortiums (W3C) [37]. OWL Description Logic (DL) is a prominent form of OWL and allows to link entities at schema- and instance-level following subset of first order logic *SHOIN(D)*.

4 Semantics of Identity Links

The expressivity of *SHOIN(D)* allows to relate individuals by means of an identity relation, noted in OWL as "owl:sameAs" and is further expressed by the symbol "=". Logical identity is only valid between a thing and itself. Thus, two things cannot be considered as identical from logical perspective even though referring to the same real-world object. An approach to formalize identity is provided by Leibniz' principle 'The indiscernibility of identicals' and its counterpart 'The identity of indiscernibles' [16]. The former states that $x = y$ implies that x and y have all the same properties, described in eq. (1). Vice versa, the latter principle states that x and y have all the same properties implies $x = y$, described in eq. (2). The combination of both principles is circular [19], since x and y are identical if and only if the objects have all the same properties. In summary, the Leibniz' principles supports rather the identification of non-identical objects since the differences between the respective properties imply that the identity relations cannot be established [19].

$$\forall \mathrm{x}\, \forall \mathrm{y}\, [\mathrm{x} = \mathrm{y} \;\rightarrow\; \forall \mathrm{F}\, (Fx \;\leftrightarrow\; Fy)] \quad (1)$$

$$\forall \mathrm{x}\, \forall \mathrm{y}\, [\; \forall \mathrm{F}\, (Fx \;\leftrightarrow\; Fy) \rightarrow\; \mathrm{x} = \mathrm{y}] \quad (2)$$

For the following discourse about the applicability of identity relation for linking IFC and CityGML models, three different sets of properties are introduced:

- Ψ: Set of properties for which the first principle (1) is valid. In other words, Ψ covers properties for which propagation is allowed.
- Φ: Set of properties for which the first principle is invalid.
- Π: Set of properties for which a less strict meaning of the second principle (2) is valid. The notion "less strict" means that two properties might indicate a match (are element of Π) even though the properties are not exactly the same. Roughly spoken, Π refers to properties on which basis the matching is carried out.

Notably, a property must be element of either Ψ or Φ but can be element of Π. These sets of properties are similar to those defined by Idrissou et al. [39] except of the aspect that the first principle of Leibniz' law is not necessarily valid for properties of element of Π. This is because, properties might be sufficient for matching (Π) but not considered as valid for the corresponding object (Φ), e.g. the length values of two objects might indicate a match but differ such that they are not necessarily valid for the respective corresponding object.

5 Identity Links across IFC and CityGML

5.1 Overview

The discourse about identity links across IFC and CityGML models is illustrated by two examples. In these examples, a fictive building (FZK House), is represented as IFC[1] and CityGML[2] model. The CityGML model provided by KIT was subsequently modified such that only visible surfaces are represented. The reduction of the model to visible surfaces simulates acquisitions methods, like laser scanning or photogrammetry. The different kinds of data acquisition and different underlying modeling paradigms result in differences concerning geometrical dimensions (section 2.1) of a beam (Example A) and walls (Example B). Notably, the geometric dimensions (e.g. length and width) are not explicitly available in CityGML but can be calculated based on the available information.

5.2 Example A: Beam

In Example A, the length of beam object in the IFC model (*IfcBeam*) and the corresponding beam object in the CityGML (*BuildingInstallation*) model differs (Fig. 1). While the length of the *IfcBeam* refers to the true length, the length of the BuildingInstallation refers to the visible length of the same real-world beam. Furthermore, also the visible length values of both objects differ due to different data acquisition methods. Similar to the length of the *BuildingInstallation*, the visible length of the *IfcBeam* is not stored explicitly in the model but can be calculated.

The assignment of the properties concerning the length to Ψ/ Φ is not clear since it is questionable whether the properties can be considered as valid for the corresponding object. Is the property describing the true length of the *IfcBeam* valid for the *BuildingInstallation*, even though the true length is not addressed by BuildingInstallation? Is the visible length of the *IfcBeam* valid for the *BuildingInstallation*, even though its value differs from the value of the visible length of the BuildingInstallation? Thus, depending on the perspective, which relies on the underlaying purpose, it might be assumed that the length values are part of either Ψ or Φ.

5.3 Example B: Wall

In the second example, IFC- and CityGML objects referring to the same real-world wall shall be related (Fig. 2). In the IFC model, two walls in top of each other are expressed through two *IfcWall* objects. In contrast to that, the corresponding object in CityGML describe the visible surfaces of the walls by means of the objects *InteriorWallSurface* and *OuterWallSurface*. The *OuterWallSurface* of the CityGML corresponds to *IfcWall* objects and the *InteriorWallSurfaces* correspond to the respective wall objects of the IFC model.

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1 https://www.ifcwiki.org/index.php?title=KIT_IFC_Examples (last access on 16th of May)

2 https://www.citygmlwiki.org/index.php?title=FZK_Haus (last access on 16th of May)

Similar to the previous example, the geometric values differ due to modeling paradigm and types of data acquisition. Again, the deviating geometric values means that the properties cannot be clearly assigned to a specific set of properties. Moreover, the described identity relations between the IFC and CityGML models allow to infer that the lower *IfcWall_1* is the same as the upper *InteriorWallSurface_2*. For sure, this relation is misleading for several properties like the height of *IfcWall_1* (Φ) but might be true for other properties like the width of the *IfcWall_1* (Ψ).

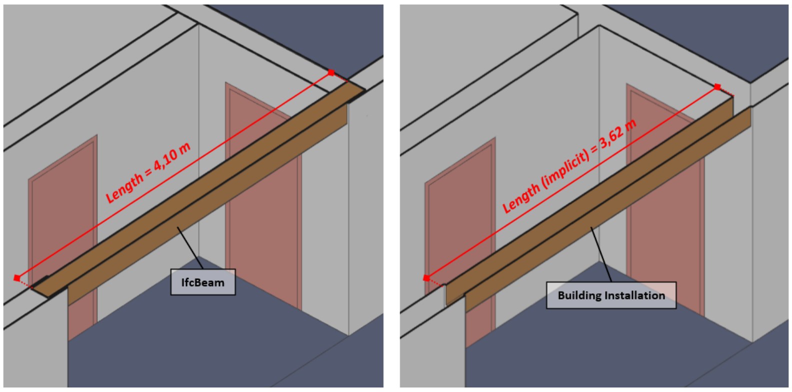

Fig. 1. Beam object in IFC (left) and CityGML (right) with different length values caused by different modeling paradigms and data acquisition methods

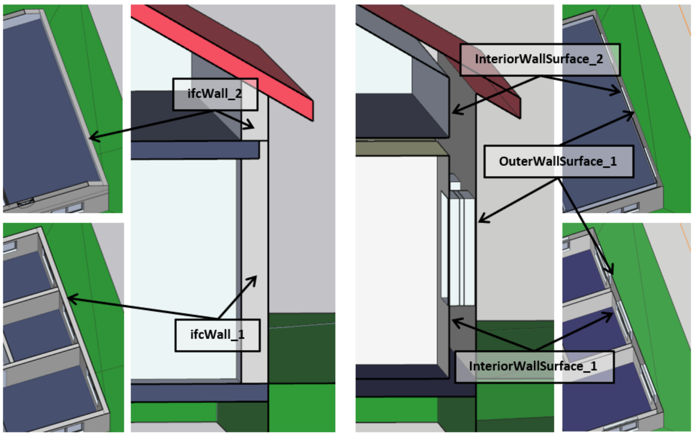

Fig. 2. Wall objects in IFC (left) and CityGML (right) with different dimensions caused by different modeling paradigms and data acquisition methods

6 Alternative approaches

The problem concerning the strict meaning of *owl:sameAs* is a well-known issue in the field of Semantic Web Technologies [40] and several approaches were investigated to overcome this issue. In summary, there are three different approaches aiming to specify the links between entities:

- First, some approaches introduce alternative vocabulary to owl:sameAs. For instance, the link predicate *rdfs:seeAlso* does not suggest full identity between the linked entities but indicate that the related entity provide additional information. Furthermore, Simple Knowledge Organization System (SKOS) [41], Context-OWL (C-OWL) [37], and Similarity Ontology (SO) provide vocabulary which is less strict compared to "owl:sameAs". As an example. C-OWL covers five different relation types, namely disjoint, equivalence, overlap, general and more specific. Further alternative vocabularies are topological relationships as they are covered by Geo-SPARQL and BimSPARQL [42]. Overall, these kinds of approaches have in common that their semantics is rather too weak than too strict: What does it mean when two building objects are *related*? Too which degree do two building objects *intersect*? Thus, making conclusions following these links require deep knowledge about the linked information.
- Second, another approach focuses on the classification of properties to ensure identity according to Leibniz' law. For instance, Raad et al. [43] and Beek et al. [19, 43] reduce an RDF-graph such that Leibniz' laws holds in the context of the resulting subgraph [19, 43]. As mentioned previously, Idrissou et al. [39] propose to distinguish between three set of properties that are relevant for the meaning of an identity link: Properties for which both principles of Leibniz' laws hold, properties for which only the second principle hold and properties for which none of the principles is valid. To the best of the authors knowledge, the idea of Idrissou et al. [39] is conceptual but has never been implemented. The approaches following the classification of properties have to deal with several issues: For instance, whether a principle of Leibniz' law hold for a property depends on the perspective of the user. Does the length value of the IFC beam hold for the CityGML beam even though their values differ due to different data acquisition methods? Furthermore, these approaches are limited to the comparison of properties of the corresponding objects, while other information like topological information might be also relevant for the semantics of links. Last, the category to which a property belongs needs to be explicit what result in a large number of additional triples.
- Third, some approaches aim to enhance specific links or sets of links through additional data. For instance, the alignment language Expressive and Declarative Ontology Alignment Language (EDOAL) [35] specifies patterns for correspondences (called *cells*), where the correspondences can be enriched by additional data. Similar to *cells*, C-OWL make use of so-called *bridge rules*. Furthermore, VoID [44] provides vocabulary for adding meta data to a set of links (like matching algorithms, or authorship). Further examplary approaches aiming to enrich links with meta data are SingletonProperty [45], Named graphs [46], and RDF* [47]. As an example, Guha

[10] and McCarthy [15] propose graph-context pairs to state that the graph holds only in a specific context. Idrissou et al. [39] use Singleton Properties and VoID to enrich links with information about matching algorithms to provide more meaningful links. Furthermore, Aljalbout et al. [48] propose OWL^C and enrich links with contextual information to limit the validity scope of these links. However, following this approach the information relevant for the semantics of the links must be explicitly defined what is a challenging task.

In summary, these approaches have in common that they do not exhaustively define the semantics of the links. Instead, the semantics of the links is left to the interpretation by the user. What does it mean when two objects are *related* (first approach)? In which context are properties assigned to Leibniz' second principle of identity of indiscernibles (second approach)? How is the semantics of the link affected when it is enriched with information about its matching algorithm (third approach)? In short, alternative linking approaches have the shortcoming that they rely on the correct interpretation by the user.

7 Conclusion

The discourse about identity relations like *owl:sameAs* for linking building elements of heterogeneous instance models has shown that these kinds of relations are prone to be misleading. This is because identity links suggest that the corresponding objects are exactly the same thing what means that everything stated about one object hold for the corresponding object. Roughly spoken, both objects must share all of their properties. However, the properties describing objects like building elements differ due to several reasons. Most obvious, they differ regarding some meta data like authorship or time of creation. Furthermore, the properties of corresponding building elements differ due to different types of data acquisition, and modelling paradigms as illustrated in the previous examples. Consequently, alternative approaches for linking building elements of heterogeneous instance models need to be utilized to overcome the misleading character of identity relations.

In the field of Semantic Web, there are three different approaches aiming to overcome the misleading character of identity relations: alternative vocabularies, categorizing information, and enriching links with meta- or contextual data. However, these approaches do not exhaustively define the semantics of the links but leave the semantics of links as a matter of interpretation.

Conclusively, the semantics of links relating heterogeneous information models from the domains BIM and GIS needs to be exploited in more detail in future research investigations. A more detailed understanding of these kinds of links would support the development of methods aiming to link heterogenous information models from the domains BIM and GIS in a more efficient manner.

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