BIM-Linked Data Integration for Asset Management

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Abstract

Purpose: This study investigates the transfer of information from the BIM models to either conventional or advanced asset management platforms using Linked Data. To achieve this aim, a process for generating Linked Data in the asset management context and its integration with BIM data is presented.

Methodology: The research design employs a participatory action research (PAR) approach. The PAR approach utilised two qualitative data collection methods namely; focus group and interviews to identify and evaluate the required standards for the mapping of different domains. Also prototyping which is an approach of Software Development Methodology (SDM) is utilized to develop the ontologies and Linked Data.

Findings: The proposed process offers a comprehensive description of the required standards and classifications in construction domain, related vocabularies and object-oriented links to ensure the effective data integration between different domains. Also the proposed process demonstrates the different stages, tools, best practices and guidelines to develop Linked Data, armed with a comprehensive use case Linked Data generation about building assets that consume energy.

Originality/value: The Linked Data generation and publications in the domain of AECO is still in its infancy and it also needs methodological guidelines to support its evolution towards maturity in its processes and applications. This research concentrates on the Linked Data applications with BIM to link across domains where few studies have been conducted.

Keywords: Linked Data, Asset Management, Building Information Modelling, Ontologies.

1. Introduction

In the last decade, Building Information Modelling (BIM) has been recognized as an evolving technological innovation which can facilitate the transformation of the construction industry (Li et al., 2017) and create several opportunities to exchange data between different stakeholders (Zadeh et al., 2017). BIM data functions as "back-end data" in the Computer Aided Facility Management (CAFM) systems for activities such as space management and maintenance management (Kučera and Pitner, 2018). Therefore, private and public owners are interested in the application of BIM in the built environment in general and in the asset management domain in particular(Becerik-Gerber et al., 2012, Teicholz, 2013). In order to facilitate asset management, the delivered building information BIM models in the handover stage have to contain accurate information related to the building assets for better operation and maintenance (Zadeh et al., 2017). To achieve this aim, it has been argued that effective syntactic and semantic interoperability between building information models and different assets database has to be achieved (Ibrahim et al., 2016). Pärn et al. (2017) critiqued that semantic interoperability is the single most important interoperability challenge to overcome in the integration of BIM data with other systems including AM platforms. Despite the different classifications and long lists of diverse required information have been developed by academics and industry professionals to improve the BIM implementation in asset management, it has been argued that still there is a lack of interoperability between building information models and different data domains prevents the cross-domain use of data at an enterprise level in the Operation and Maintenance (O&M) industry (Corry et al., 2014). Hu et al. (2018) argued an ontology is required to cross-link building performance with other building information and Linked Data offers a mechanism to facilitate meaningful sharing of cross-domain building information. Therefore, providing object-oriented cross-domain linking instead of identifying the required information can be more efficient and adequate solution to achieve semantic interoperability between BIM and asset management (Kim et al., 2018).

Linked Data generation and publication is a comprehensive process which requires a pursuit and implementation sequential tasks to ensure effective linking of different datasets. To this end, several guidelines and best practices have been developed and being advocated. However, it has been argued that general guidelines alone cannot provide the required level of detail and adequate process maps including all the different tasks. This is mainly due to the general guidelines not taking into consideration specific characteristics and vocabularies of particular domains (Villazon-Terrazas et al., 2012). As Linked Data application is still in its infancy in the AECO domain (Radulovic et al., 2015), a specific process map for Linked Data generation and publication is required. The main aim of this research is to address the suggested gap by providing a structured process map for linking data between building information models and different information stored in silos related to building assets. This process can improve the data exchange from the building information BIM models to asset management systems during handover stage and consequently improve asset management during the operation and maintenance stage. Achieving the set aim would allow a series of different ontological sources to talk to each other and also enhance compatibility with present and future versions of platforms and databases adapting the selected ontological sources. The proposed process offers a comprehensive description of the required standards and classifications in construction and operation domains, related vocabularies and their link to each other. Also the proposed process presents the different stages, tools, best practices and guidelines to develop Linked Data, armed with a complete example on the generation and publication of Linked Data concerning assets that consume energy in buildings. The selection of assets that consume energy was underpinned by the UK strong environmental and economical mandates to improve the existing buildings energy performance and to ensure new constructions ensure sustainable performance during the whole building lifecycle.

2. Linked Data

Linked Data aims to define a process to publish and share machine readable inter-linked data on the web, based on a set of design principles. Semantic Web term has been coined before Linked Data term by Sir Tim Berners-Lee "the inventor of the Web" at WWW (World Wide Web) in 1994 and documented in a scientific American article in 2001 (Berners-Lee et al., 2001). The semantic web is "Web of actionable information—information derived from data through a semantic theory for interpreting the symbols" (Shadbolt et al., 2006). The semantic web is an extension to the current web where information (Data and documents) are well-defined to ensure better cooperation between computers and humans. The semantic web purpose is to achieve data universality and data linking with any other data. However, Bernes-Lee (2006) noticed that some semantic data published on the web are not linked to other outside semantic data. Therefore Bernes-Lee outlaid four principles that need to be adopted to obtain truly Linked Data. In 2010, Bernes-Lee suggested a five star deployment schema for Linked Data based on the four Linked Data principles. The semantic web of data, unlike the document web, requires standards to ensure a highly interconnected network where the huge amount of heterogeneous data has been given a well-defined meaning. Therefore, an ecosystem of standards, named Semantic Web Stack, to support LOD has been developed by the World Wide Web Consortium (W3C) team.

2.1. Linked Data and Semantic Web in AECO Domain

Linked Data application has enjoyed great popularity in other domains including biology, medical records, accounting and social media (Schmachtenberg et al., 2014). These success stories encourage the implementation of semantic web and Linked Data in AECO domain (Radulovic et al., 2015). Several researchers have illustrated the different benefits can be acquired by the implementation of Linked Data in the built environment domain, also the barriers to overcome the integration of data through the building lifecycle phases. Abanda et al. (2013) categorized semantic web implementation studies in the built environment domain based on area of application. While Pauwels et al. (2017) categorized the works differently to three main categories based on aims and barriers to overcome.

Curry et al. (2013) proposed the use of Linked Data in order to manage and operate building assets holistically. They argued that Linked Data can provide a cross domain integration between building silo systems in a homogenous format. Based on that, O'Donnell et al. (2013) combined Linked Data and complex event processing technologies to enhance the efficiency of building energy management activities. Several silo domains such as human resources source, architecture source which are represented in 3D models, inventory source, legislation source and Building Energy Performance (BEP) source can be cross-mapped and integrated through the use of Linked Data. They argued that this approach can reduce the time required by building managers to analyse and optimize building energy performance. Corry et al. (2014) demonstrated several examples of integration and publishing of building related data following semantic web rules to improve the building performance. One of the examples was the cross-domain integration of the scheduling data with the building operation strategy. They linked the data from Building Management Systems (BMS), the room booking system, Human Resources Management (HRM) systems and building information model based on the room entity. Lee et al. (2016) proposed a framework for sharing construction defect information through the applicability of BIM and Linked Data. For creating the ontology, they adapted OmniClass classification's taxonomy to build the classes and properties. Kim et al. (2018) proposed a method to link the IFC objects with the FM work information. They developed a semantic relation between the classes of IFC, COBie and historical maintenance work concepts. They argued that the proposed approach can enable facility managers to semantically link the BIM objects to the maintenance records in the Semantic Web during the O&M phase in order to provide a BIM environment without the specific BIM authoring application.

Despite the available studies, the Linked Data generation and publications in the domain of AECO is still in its infancy and it also needs methodological guidelines to support its evolution towards maturity in its processes and applications (Radulovic et al., 2015). Pauwels et al. (2017) argued that highest number of use cases in the construction industry lies under linking across domains because of the limited number of involved technologies and the simpler approaches. This research concentrates on the Linked Data applications with BIM to link across domains where few studies have been conducted. The following section - section 3 - represents the research methods adopted for the study and the proceeding section - section 4 - presents the proposed process for generating Linked Data in the context of asset management and its integration with BIM data. Finally, the last section - section 5 -provides some concluding remarks and suggests future lines of work.

3. Methodology

Research design is the map for the research process to achieve its aims and objectives. Figure 1 illustrates a diagrammatic representation for the research design of this research.

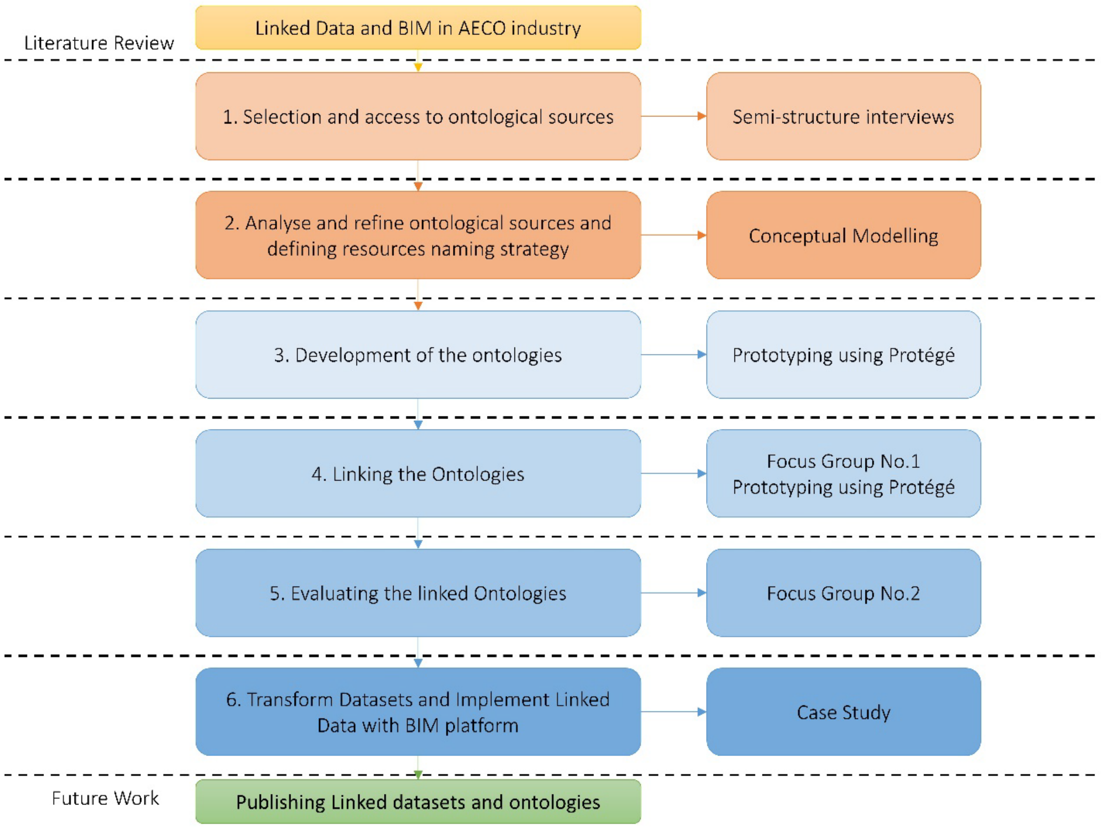

Figure 1: Research design of this research

Each phase in the research design requires different research methods to enrich the ontologies with the required information. The first phase includes the engagement of experts to identify the required standards for the mapping of different domains. Four semi-structured interviews with facility managers were conducted in the first phase for that purpose. Once the ontological sources such as: NRM (New Rules of Measurement) 1 & 3, Uniclass2, SFG20, Industry Foundation Classes (IFC) and finally Revit as a BIM Platform are identified, the different sources were accessed. Phase two requires analysing and refining the ontological sources to be suitable for the research scope. Conceptual modelling approach has been adapted to build the required conceptual frameworks. Conceptual framework has been constructed from combining different paradigms and concepts based on the literature review and conducted interviews with the research goal and objectives. The main sources of the developed datasets are previous researches, applicable theories, researcher's own experience knowledge and research's thought experience (Maxwell, 2008). Phase three has been achieved through prototyping which is an approach of Software Development Methodology (SDM). The prototype model is selected as the approach in this research as it is a top-down, iterative approach that continues until the user's requirements are accomplished. The fourth phase includes the involvement of experts from the AECO industry to define the link between classes in different ontologies. As cross domain integration of assets' data and data from building information models are relatively new and no enough information around that topic, focus groups is conducted in this research as the qualitative data collection method. This interaction between participants in focus groups may produce spontaneous responses and more cognitive views. The focus group was conducted with eight experts in the construction and/or operation industry. The expertise for eligibility to participate in the focus group was determined based on different criteria namely; five years' experience in BIM and/or asset management and mechanical or electrical engineer. The focus group started with high level of involvement of the interviewer, by giving an introduction to the different classifications for the building assets and brief introduction to Linked Data and ontologies. The first question is then enquired, leading to an unstructured discussion about the potential answers. During discussion, the interviewer level of involvement was low, then moved to high by concluding the discussion and then moving to the next question. Another focus group was conducted with the same participants in the first focus group in phase five. The second focus group has been lead to evaluate and validate the mapping developed between all the different ontologies for each individual asset that consumes energy during the development of ontologies stage. The interviewer showed the developed mapping between the different standards for each asset and consequently the participants interact to agree/disagree/refine the developed mapping. The focus group's discussion was whether the abstracted concepts were precise and accurate or not. Finally, a case study has been conducted for a new extension of an educational building in phase six to evaluate the implementation of the proposed mapping between the different ontological sources.

4. Linked Data Development

Figure 2 represents an overview of whole process of Linked Data development and its relevant tasks. The sequential relations between the tasks are represented with full lines, while the outputs from each task are represented with continuous lines. The process also is represented by other four main phases namely; Data, Information, Knowledge and finally wisdom. These phases have been adapted from the Big Data domain. Following, each task of the Linked Data development process is discussed in details.

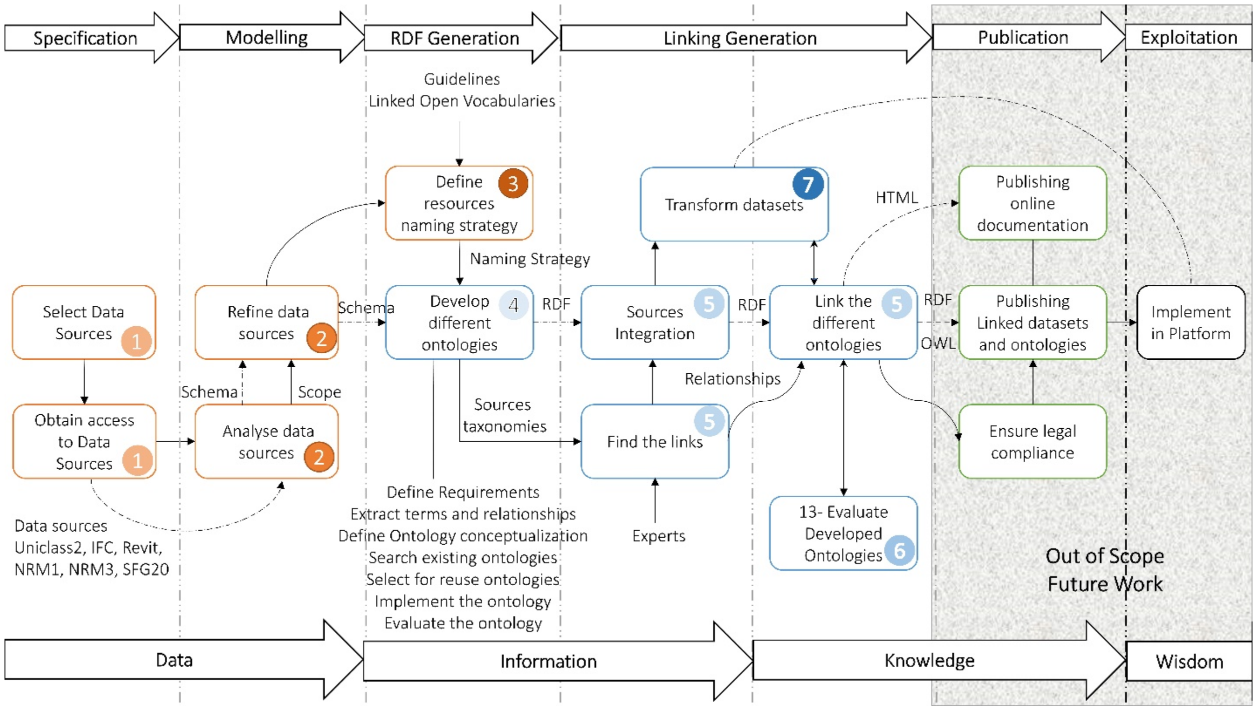

Figure 2: Process of generation and publication of Linked Data (adapted from (Radulovic et al. 2015))

4.1. Selection and access to ontological sources

The first two tasks in Linked Data generation process are the selection of the required ontological sources and obtaining access for the selected ontological sources respectively. Different ontological sources were selected in the research to achieve the required goal such as: NRM 1, NRM 3, Uniclass2, SFG20, Industry Foundation Classes (IFC) and finally Revit as a BIM Platform. All these ontological sources achieved the specified requirements explicitly; to include data/classification or vocabularies about assets in buildings, to be available to use, standards and/or guidelines related to the best practice in UK and finally to be presented in a structured way to be easily adopted.

NRM is a suite of documents issued by the Royal Institution of Chartered Surveyors (RICS) group. NRM1 has been published to provide a standard and guideline on the quantification of building works for cost estimate purpose based on the UK practice. While, NRM3 has been written to provide a standard and guideline for the quantification and description of the maintenance works for cost estimate purpose during building phases. NRM1 and NRM3 together present the basis of life cycle cost management of capital buildings works and maintenance. Both NRM1 and NRM3 have been selected for the proposed Linked Data as they are understandable by all stakeholders involved in the project and associated elemental classifications can aid the communication between the project team and the employer (RICS, 2012). The data source of the NRM1 and NRM3 dataset are available in the public domain from the rics.org.uk webpage (RICS, 2012) and is provided in PDF format as tables.

IFC provides the benchmark for sharing of information of any built environment asset through its lifecycle between all the stakeholders, notwithstanding of the used software application. The data source of IFC dataset and vocabulary is available on BuildSMART website and is provided in .ifcXML and .OWL formats. SFG20 provides the benchmark for optimum maintenance, avoiding over or under maintaining of assets and the backbone to building engineering services maintenance industry. Although SFG20 is not specified in PAS 1192, it can be easily figured out as it is aligned with NRM3. The authors accessed the SFG20 through a free trial request where the standard is provided in a tree online taxonomy.

Uniclass2 is the new UK implementation of the international framework for construction information. Uniclass2 was been developed to form a structured classification which is endorsed by all construction and property bodies and professional institutions. The data source of Uniclass2 dataset and vocabulary is available as structured tables on the NBS BIM toolkit website and is provided in PDF and xls formats. Finally Revit is one of the most popular BIM platforms. It is important to take in consideration the classification of Revit to be able to link all the different standards with the Revit elements. Revit is accessed through the university computers.

4.2. Analyse and refine ontological sources

Once the ontological sources are selected and access is obtained, the next step is to analyse the data in order to observe how much the data is structured and organized, understand the structure/schema of the data and the relationships between them and finally define the required datasets to form the classes and concepts for an ontology. Subsequently, the next step is to refine the data by correcting errors in the schema and creating mapping between columns and rows if the schema is SQL based.

As mentioned before in the introduction section, this research concentrates on assets that consume energy. Therefore, all datasets related to assets that consume energy are used to develop the ontologies in the next stages. The developed taxonomy by Farghaly et al. (2018) was chosen for the refinement of the datasets. The taxonomy classified the assets consume energy to nine main categories namely; water heating, ventilation, refrigeration, lighting, electronics, kitchen, computers, space cooling/heating and others. Each category contains the related assets (Farghaly et al., 2018).

4.3. Define resources naming strategy

The vocabularies used to represent data are a key to form Linked Data. Meanwhile, one of main principles of Linked Data states that URIs must be used for naming resources such as vocabularies and terms. In this section, the strategy to define the URIs for generating resources are discussed.

There are two main forms of URI namely; slash URI and hash URI. In slash URIs, the resource is accessed as individual or group. While the hash URIs contain a fragment which separates the normal URI and fragment identifier by a hash character ('#'). Most known available domains are semantic web, DBpedia and RDF-ized version of Wikipedia (Heath and Bizer, 2011).

Accordingly and armed with the tips provided by Heath and Bizer (2011), as the data set will contain a significant amount of data and it can grow in the future, slash URIs are adopted for data sets. However, smaller amount of data are entered in the development of ontologies, therefore, the hash URIs are used. The ontologies will have the path form /ontology/<ontologyName>#<className> for classes and /ontology/<ontologyName>#<propertyName>. The domain of semanticweb.org is selected to adapt the developed ontologies and the naming conventions of the classes are written as the selected construction standards and classifications.

4.4. Development of ontologies

The ontology is developed through seven different steps (Noy and McGuinness, 2001). The first step is to define the requirements that have to be fulfilled by the ontology. As mentioned before, the research concentrates only on assets that consume energy. Therefore, the developed ontologies will only cover these assets. Since the datasets for that scope is small and the speed of processing is not an issue, the Turtle serialization was selected because it is easy to read by humans. Most of data sets are available in PDF format, therefore the ontologies have been created from scratch using Protégé 5.2 as ontology editor.

The second step is to consider reusing existing ontologies. Abanda et al. (2017) developed an ontology based on NRM1 concepts to facilitate the cost estimation process in AEC industry. Pauwels and Terkaj (2016) developed an ontology based on IFC EXPRESS schema to allow the conversion of IFC instance files into equivalent RDF graphs. The reuse of these existing ontologies has been taken in consideration in the ontologies development by referencing them, instead of by importing the existing ontologies as a whole. It has been observed that developing ontologies with the required classes for the research scope is simpler and quicker than importing all the existing ontologies.

The third step is to enumerate important terms in the ontology. In this step, terms are extracted to form a list of concepts (classes, relationships and slots) from the data schema regardless any overlap between concepts they represent. The names of the selected terms have followed the resource naming strategy.

The fourth step is to define the classes and develop the class hierarchy. Several approaches can be used for developing class hierarchy namely; top-down, bottom-up and combination. In this research, the top-down approach was adapted in the development of the class hierarchy in the different proposed ontologies. For example, as the schema of the NRM1 and NRM3 are available in a tabular format in PDF documents. The ontology concepts were extracted manually from the elemental work breakdown structure (WSP) illustrated in the NRM documents. The WSP includes eight different classes/concepts namely; Group 1: Substructure; Group 2: Superstructure; Group 3: Internal Finishes; Group 4: Fittings, Furnishes and Equipment; Group 5: Services; Group 6: Prefabricated Buildings and Building Units; Group 7: Work to Existing Buildings, and Group 8: External Works. Concepts were categorized into four hierarchical levels. The top (first) level concepts adopted are Substructure; Superstructure; Internal Finishes; Fittings, Furnishes and Equipment; Services; Prefabricated Buildings and Building Units; Work to Existing Buildings and External Works. The second level concepts were obtained from the immediate breakdown of first level concepts as in the NRMs. The third and fourth concepts were obtained from the first and fourth columns respectively from the tables under each second level concept. Columns four and five in the NRM1 and NRM3 tables represent the included and excluded elements respectively.

The fifth and sixth steps are closely interconnected and usually are done together. The fifth step is to define properties of classes (slots). The definition of classes alone will not provide enough information to answer competency questions asked in step 1. Slots describe the internal structure of concepts in ontology and they have to be attached to the most general class that can have these properties. While the sixth step is to define the facets of the slots. The values of slots are described in different facets such as; value type, allowed values, cardinality and other facet features. The value type facet can be described in different value types such as; string, number, Boolean and enumerated. Allowed values facets defines the range of slot and cardinality facets defines how many values the slot can have. In this research, the properties attached to the classes and subclasses described value type facet and the string and number value types are used for defining most of the slots. Finally the seventh step is to create the instance of classes in the hierarchy. This step consists requires 3 tasks respectively which are choosing the class, creating the instance of that class and finally filling in the slots values. Figure 3 represents a screenshot for the developed ontologies using Protégé 5.2.0.

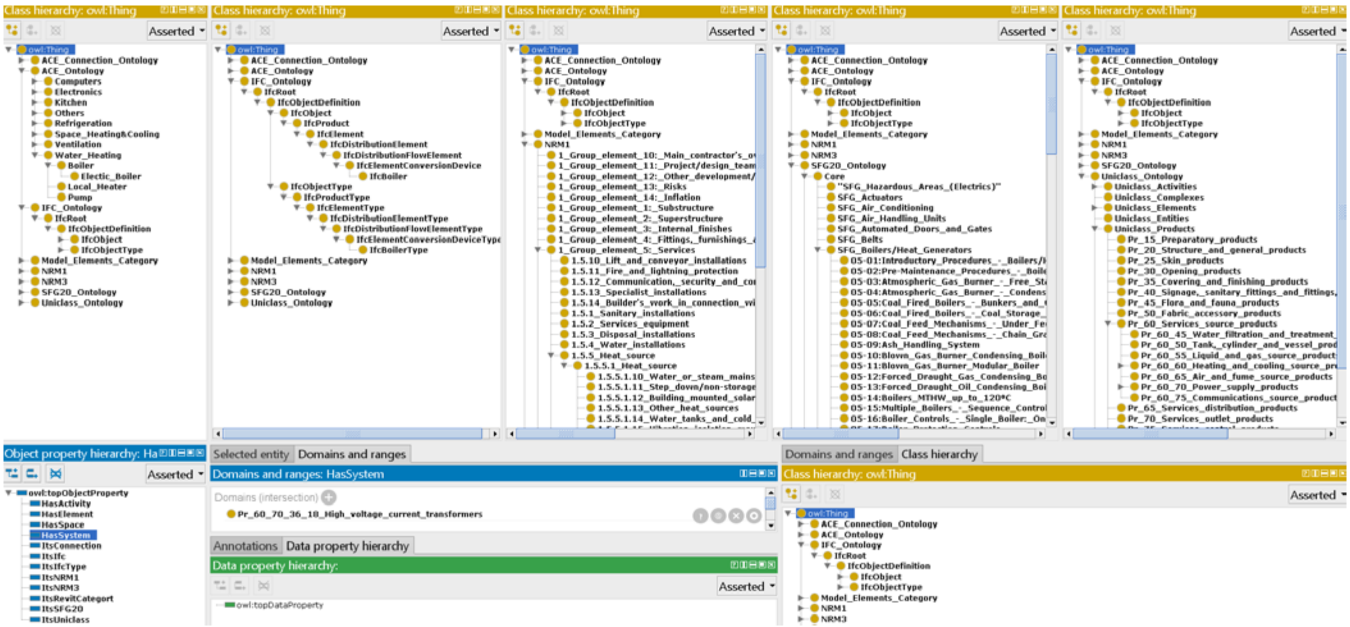

Figure 3: Screenshot from Protégé 5.2.0 for the developed ontologies

4.5. Link the ontologies

Linked Data relies on setting RDF links between URI aliases in order to be able to track the different information providers refer to the same asset. This stage aims to make visible indicators that have not been previously harvested such as: the interconnections, incoming and outgoing links between vocabularies/classifications. In the end of the first focus group, the link between the classes of the different classifications has been documented. Figure 4 illustrate the link and mapping between the different ontological sources for a specific asset (Boiler). The hierarchical sequence for each standard is represented to reach the class to symbolise electrical boiler. The different relationships are color-coded depicted in the bottom left of Figure 4.

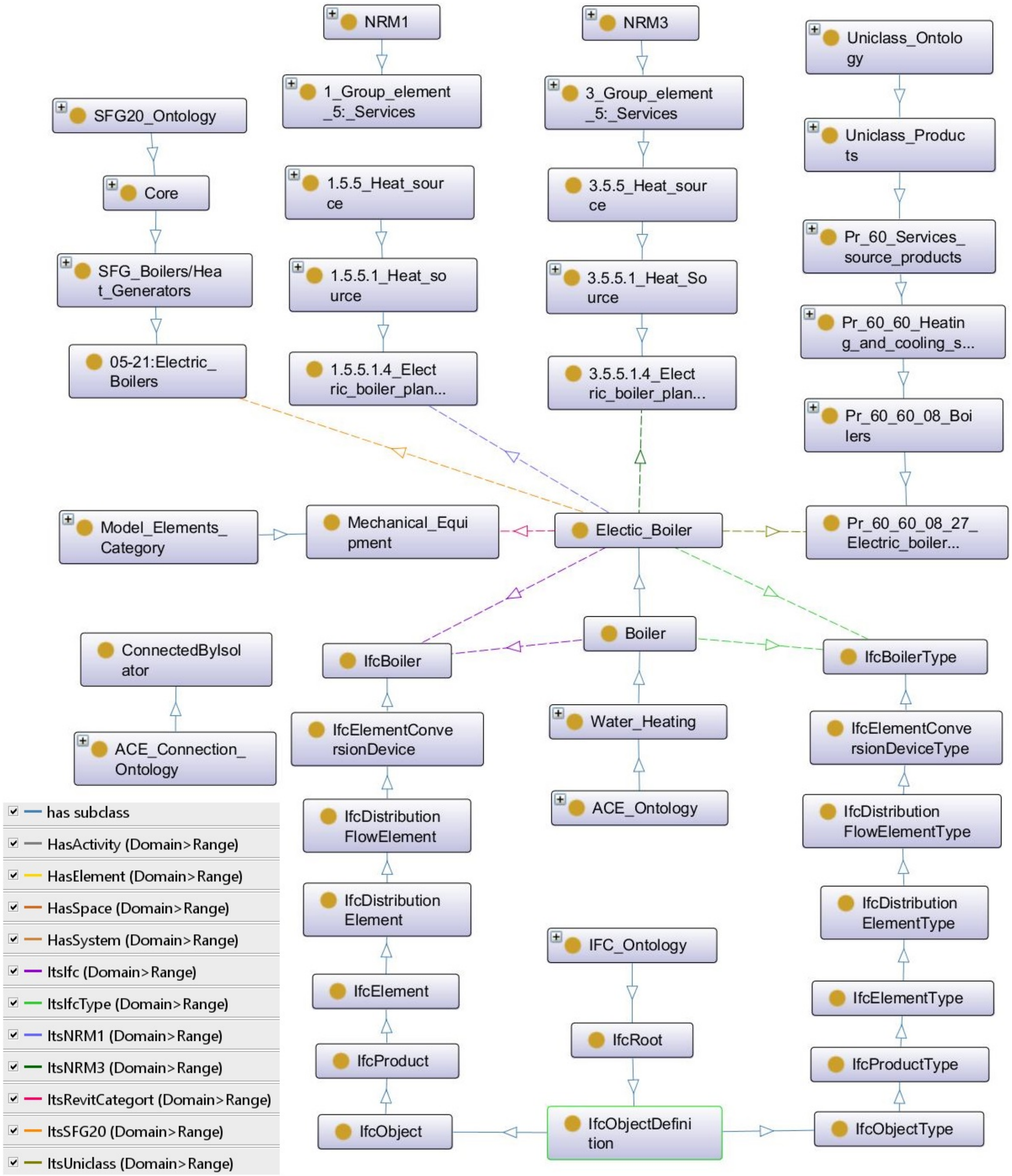

Figure 4: Example of linked classifications for an electrical boiler

4.6. Evaluate the ontologies

Ontology evaluation is vital activity to assure that what is developed meets the application requirement (Gomez-Perez et al., 2006). In this step, syntactic and semantic correctness of the developed ontologies and also the mapping between the different ontologies have to be verified. Also the developed ontology has to be evaluated against the purpose of development. Logical based approach is adapted for syntactic evaluation. Several SPARQL queries are executed to observe the credibility of obtained results and HermiT reasoner was used to validate the consistency with the used ontologies. HermiT is reasoner for ontologies written using the Web Ontology Language (OWL) and it is preinstalled Protégé plug-in. Meanwhile, Manchester OWL syntax validator was used to evaluate the OWL syntax compliance for the developed ontologies. After the syntactic evaluation, the ontology has been revised and the final version deemed to reflect practice was semantically correct. Feature based approach is adapted for semantic evaluation of the developed ontologies. Feature based approach evaluate the ontologies quality by engaging users and expertise. In the final revision, a new ontology is added which represents the connection of the asset to electricity. The subclasses of this ontology are socket, diffuser, isolator, control panel and battery. Respectively, an object property was added to map the connection to electricity ontology and the main ACE ontology. Also during the focus group, several challenges and gaps have been discussed between the author and the expertise which need to overcome to achieve appropriate cross linking between different sources. The first challenge highlighted was that the export option of IFC in Revit cannot fulfil the required link by expertise. By default, Revit exports building elements to an IFC file based on the categories (and subcategories) to which the elements belong based on the mapping defined by International Alliance for Interoperability (IAI) data exchange standards. However, it is required to map with Revit families instead. The authors highlighted it the participants that: on the Autodesk knowledge network website, a solution is proposed to overcome that challenge. The solution requires adding two shared parameters named IFCExportAs and IFCExportType where the Revit user needs to fulfil with the class of IFC for each family. The second challenge is exporting the whole model is timing consuming and not required. One of the participants suggested to add two parameters for the Revit elements. The first parameter identifies firstly if the asset is maintainable or not, while the second parameter classifies the asset's importance from the operation point of view. The asset importance parameter was suggested to be a Camel Case string type. Using the two parameters, we can distinguish which assets required to be exported and consequently develop an MVD to achieve the purpose. The third highlighted point is linking the different tables of uniclass2 to each other's.

4.7. Transform Datasets

The developed ontologies and the defined resource naming strategy are used in the transformation process of data into RDF format. Figure 5 illustrates the proposed framework for data transformation in this research. Three different data sources were selected for our case study namely; the BIM models, the operations and maintenance schedules and the procurement documents. The Turtle serialization was selected as the research RDF serialization. Turtle serialization is easily readable by humans and the research datasets is small which would not affect the speed of processing. Since the data are available in the CSV and XML format, OpenRefine with the RDF extension for transforming the data into RDF is selected. The OpenRefine tool is widely known in the community and it is easy to use. To achieve the transformation, a mapping between the data and the ontology has to be defined taking in consideration the defined resource naming strategy. This has been achieved in several tasks, firstly initial transformations to the data made in order to correct errors. Secondly, mappings between the columns and rows in the table and the ontology and specifying the pattern for naming instances according to the resource naming strategy. Consequently, the RDF syntax are chosen and the datasets are generated and evaluated semantically and syntactically.

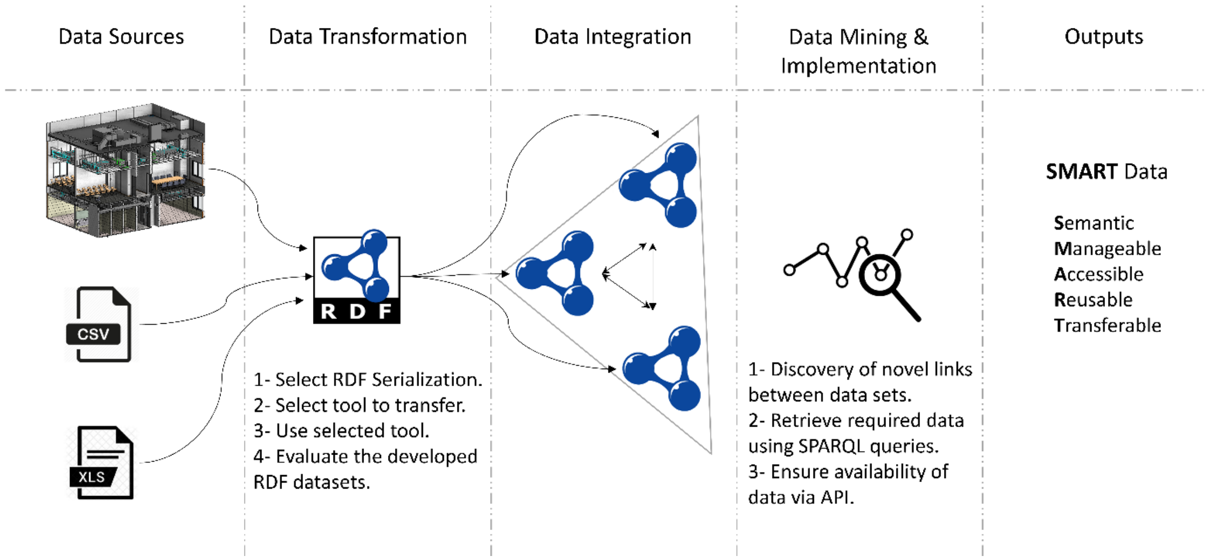

Figure 5: Proposed framework for Data transformation

After the conversion of datasets into RDF formats, they are now machine readable and more interoperable as they are represented using the defined standardized vocabularies. To cross link the different datasets, the authors manually have mapped the different assets to their related information in the several datasets. With the different datasets are interlinked to each other, the discovery of novel links between the data sets and the retrieve of required data are now possible using SPARQL queries. Also, it will provide a potential for the availability of required information in the BIM models using Application Programming Interface (API) to import required data in the BIM platforms. Finally, the proposed framework can provide outputs which are characterized with maximally semantical, manageable, accessible, reusable and transferable data.

5. Conclusion and Further works

The holistic management and maintenance of assets is a multi-domain problem encompassing data from different sources such as BIM models, sensors, asset databases. To effectively conduct AM related activities, required information from these different sources must be clearly defined to systematically manage activities for asset operation and maintenance. However due to the heterogeneity of assets, cross domain integration would be more effective than identifying the required information at an early stage.

Linked Data offers an appropriate technology platform enabling cross domain integration of information related to managing and operating the building assets. Linked Data processed and queried for human and computers consumption using web standards such as RDF in combinations with four basic Linked Data principles and the five stars schema. These Linked Data principles and five stars approach stimulated to develop some guidelines and best practice examples for storing, exposing, sharing and connecting RDF data by dereferenceable URIs in semantic web. However, general guidelines alone cannot provide the required level of details and adequate process map for Linked Data implementation in different domains. Each particular domain requires a guideline for Linked Data generation and publication taking in considerations associated characteristics and vocabularies and proposing the proper tools and techniques to be implemented.

As Linked Data application is still in its infancy in AECO domain, the paper presented a process map for Linked Data generation for building assets to improve asset management. By providing detailed description of all the tasks and related tools and technologies in the generation and publication processes, the proposed process map can help both owners and facility mangers to manage the building assets information from different databases with semantically Linked Data in the Semantic Web. The different developed ontologies reused terms of widely deployed vocabularies in AECO industry such as IFC, NRM1, NRM3 and SFG20. Vocabularies linking, using schema- level constructs of classes and properties, provides a shared knowledge representative conceptual model. The different classes of the ontologies from the selected standards were object/asset based linked and mapped. The proposed process map aims to help researchers and practitioners interested in managing and operating building assets without authorization of BIM platforms and with exploiting Linked Data technologies. Although it is possible to create the same mapping system using traditional SQL based technology, the usage of Linked Data approach can provide a foundation for enabling modularity of new technologies and future extensions for the systems. Once the mapping has been executed, a case study for an educational building has been conducted to evaluate the proposed mapping. The case study had several limitations due to the absence of required sensors and databases to provide information related to different aspects such as the occupant behaviour, rooms temperature and the lectures schedules.

Future work including several use cases will be conducted to ensure the outputs of the proposed processes and corresponding tools and techniques. Authors believe that publishing assets information from the different datasets as RDF along with the developed ontologies can provide both the syntactic and semantic integration of BIM data and other assets ontological sources long as promised by semantic web technologies.

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