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INTEGRATING BIM AND PRODUCT MANUFACTURER DATA USING THE SEMANTIC WEB TECHNOLOGIES

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SUMMARY*: Building Information Modeling (BIM) technologies enable the AEC-FM industry to create a shared virtual model of a project. BIM not only includes 3D geometry information but also information assigned as parameters to BIM elements. However, the information stored in BIM model elements is not comprehensive. For example, a chiller manufacturer provides a large volume of product data in pdf file format that is not included in the BIM model. It is possible to attach PDF files to BIM elements; the problem with an attached PDF is that its content cannot be interpreted by a computer. Automated retrieval and integration of distributed sources of data requires data in a machine-processable format. One way to solve this problem is to manually add additional data as element properties to a BIM model. However, manually inputting data to BIM platforms (e.g. Autodesk Revit) is a very time consuming and error-prone task. In this article, the authors present the Semantic Web technology as a new solution to integrating building product manufacturers' data with BIM information. The authors convert both BIM data and building product data to RDF/OWL format. Data stored in RDF/OWL format can be easily processed by machines and integrated with RDF/OWL formatted data from other sources over the Internet. The authors use Semantic Web Services to handle data communication between a BIM knowledge base and the product manufacturers' knowledge bases. The authors compare manual entry of manufacturer data to a BIM model to the semantics-based data integration presented in the paper. Results show that the authors' approach improves productivity.*

KEYWORDS: *Building Information Modeling, BIM, Facility management, Semantic Web, RDF, OWL, Ontology*

REFERENCE: *Mehrdad Niknam, Farzad Jalaei, Saeed Karshenas (2019). Integrating BIM and product manufacturer data using the semantic web technologies. Journal of Information Technology in Construction (ITcon), Vol. 24, pg. 424-439, http://www.itcon.org/2019/22*

1. INTRODUCTION

The advent of Building Information Modeling (BIM) technologies has made it possible to create a virtual model of a building that includes not only a 3D geometry but also some physical and functional information about the building elements. A 3D geometry is an important part of the BIM model because it allows engineers perform several essential activities such as clash detection, visualization and walkthrough as well as high-quality rendering. The element properties included in the BIM model may be used for engineering tasks such as cost estimating, energy analysis, and 4D scheduling, to name a few. Building element information is also useful during the service life of a building for maintenance and repair of building products such as mechanical or electrical equipment.

Several domain experts are involved during design, construction, operation, and maintenance stages of a building. Each domain expert generates specialized information for the building elements. For example, designers define design properties, schedulers determine the construction schedule, and cost estimators provide cost information for the building elements. Although BIM platforms such as Autodesk Revit (https://www.autodesk.com) have the capability to store certain building element properties, usually a vast volume of building-related information is not included in the BIM model (Costa and Madrazo, 2015). Most manufacturers provide specifications, data sheets, and user manuals for their products. For example, when a chiller manufacturer creates a product, it provides a large volume of information about its features, benefits, applications, controls, electrical and mechanical properties, dimensions, weight, design options, and the recommended maintenance frequency. This type of information is usually published in a digital file format such as pdf. In this paper building product data that are published by a product manufacturer but are not normally included in the BIM model will be referred to as manufacturer's product data.

Although it is possible to attach pdf files of the manufacturers' product data to the BIM model elements, computers would not be able to interpret the data contained in a pdf document and use them for computational or decision-making purposes. Ideally, data should be added to the BIM model elements as parameters. However, since BIM models usually include many elements, manual addition of new element parameters to a BIM model is a time consuming and prohibitively expensive task. Moreover, adding a lot of element information to a BIM model can impact the performance of the BIM platform.

This paper is about on demand integration of the building product data from a manufacturer's web server with the BIM model data for automated decision making. For example, an automated chiller maintenance scheduling software can gather the necessary product data from the chiller manufacturer's web server, order the necessary parts, and schedule the maintenance work. Although one may be able to develop a system for this purpose using Extensible Markup Language (XML) (https://www.w3.org/XML/), there are some real issues with such an approach in the AEC industry. XML addresses structural and syntactic issues but not the semantics of the data. A software program to read an XML file requires a specific code for the XML file (Cambridge, 2019). This usually does not create serious issues for companies that work with each other for a long time. However, the building construction industry is different because: (1) many products are used in a building project and (2) there is not a standard XML schema for representing building product data. This means one program may not work with all product manufacturer's XML data files.

If both BIM and a product's data are modeled using the Semantic Web technology, the data integration process would be a straight forward task. The Semantic Web technology formats information using Resource Description Framework (RDF) (https://www.w3.org/RDF/) and Web Ontology Language (OWL) (https://www.w3.org/OWL/). Data in RDF/OWL format are modeled as a graph of data where nodes are instance data that are connected to each other with object properties. When information is modeled in a graph format, it is easy to merge data from different sources (e.g., the BIM and the manufacturers' data).

Semantic Web Services are designed to allow different organizations exchange information over the Internet. They allow software agents from various organizations find each other over the Internet and directly communicate and exchange information with very little human involvement. Eliminating human involvement in repetitive and time-consuming tasks, such as manual data entry, significantly improves efficiency and accuracy.

This article presents a new approach for integrating manufacturers' product data with information stored in a BIM model. This approach requires that the BIM and the product manufacturers' data be semantically defined. The following sections briefly discuss publishing information as Semantic Web Services for online information exchange. As a case study, the authors show how a chiller manufacturer can convert and save its product data in RDF/OWL format and make the data accessible using Semantic Web Services. To demonstrate the efficiency achieved using the Semantic technology, the authors compare the performance of the proposed method with a manual data retrieval and entry method.

2. LITERATURE REVIEW

Building Information Modeling (BIM) has significantly impacted how architecture, engineering, construction, and facility management (AEC-FM) tasks are conducted. BIM provides the opportunity to digitally model building information and make the information available to project participants. However, BIM is still facing the information interoperability issue (Pauwels et al., 2017). Many individuals or organizations with different specialties are involved in the AEC-FM industry but so far it has not been possible to merge all documents and data generated in the building process in a single database or establish links among different specialty databases.

The AEC-FM industry is a document-intensive industry. Despite the widespread adoption of BIM in the building process, a large amount of information is still stored and communicated using documents in various static file formats (Deshpande et al, 2014). These types of document are designed for human consumption; for example, the data contained in a pdf document can only be interpreted and utilized by a person. The AEC-FM industry can significantly improve its productivity if the latest digital technology is used to format the building process documents (McKinsey, 2017).

The Semantic Web technology can provide the infrastructure for structuring a project's documents to facilitate the interoperability and machine-processability issues. Semantic Web is designed to (Allemang and Hendler, 2011):

- Enable creating tools and solutions to support interoperability
- Allow machines to exchange data over the Internet
- Enable machines to process data that is created in other domains
- Merge graphs of data from different sources and create an integrated knowledge base.

Several studies have investigated the potential of the Semantic Web technologies in the AEC-FM industry. Pauwels et al. (2017) performed an intensive literature review focused on the applications of the Semantic Web technologies in the AEC industry. The following literature review will focus only on the studies related to semantic definition of building information, building product data, and the applications of the Semantic Web Services for improving interoperability among various building knowledge bases.

Application of the Semantic Web requires designing an ontology which is defined as "a specification of a conceptualization" (Gruber, 1992). Building a domain ontology involves defining the main concepts in the domain, the relationships among the concepts, and the constraints on their use. The combination of a domain ontology and project-specific assertions are referred to in this paper as the project knowledge base.

The ISO standard for building information modeling (ISO16739, 2013) is the Industry Foundation Class (IFC) schema (buildingSMART). Several IFC-based ontologies, referred to as ifcOWL, have been developed by direct translation of the EXPRESS representation of IFC schema to OWL representation; examples include ontologies developed by Beetz et al (2009), Pauwels and Terkaj (2016), and the Link Data Working Group at buildingSMART (LDWG 2019) International. However, according to Pauwels and Roxin (2016), ifcOWL does not deliver the highly demanded simple models to AEC practitioners. The direct mapping of IFC EXPRESS schema to OWL has resulted in complex and unintuitive constructs in ifcOWL ontology and large and complex instance graphs in the knowledge base (Pauwels and Roxin, 2016). A number of research efforts have tried to simplify ifcOWL ontology either by making it more modular (Terkaj and Pauwels, 2017), or generating simpler knowledge bases (Mendes de Farias et al., 2015; Pauwels and Roxin, 2016; and Zhang et al., 2018).

Niknam and Karshenas (2015a, and 2017) approached the semantic modeling of building information with a clean slate. Their objective was to develop a modular and intuitive ontology that can be easily extended by experts in various AEC-FM domains. The W3C Linked Building Data (LBD) Community Group (https://www.w3.org/community/lbd/) has also concentrated its efforts on developing ontologies that represent building information without any direct connection to IFC. The W3C LBD ontology is named Building Topology Ontology (BOT) (https://w3c-lbd-cg.github.io/bot/).

The architecture of the ontology developed by Niknam and Karshenas (2017) includes a small core or shared ontology called BIMSO that includes the vocabulary common among all AEC-FM domains. Various AEC-FM domain experts would build their domain ontologies by extending BIMSO. Therefore, BIMSO acts as a semantic bridge between all AEC-FM domains, facilitating interoperability. BIMSO uses the building elements defined in

Uniformat II classification system (http://www.uniformat.com). UNIFORMAT II is an ASTM standard (http://www.astm.org/Standards/E1557.htm) that is commonly used by building professionals in North America and several other countries. OMNICLASS construction classification system (http://beta.omniclass.org/) also has incorporated UNIFORMAT II as the basis of its Element Table. The fact that most building professionals in several countries are familiar with and use the UNIFORMAT II classification system makes BIMSO intuitive and easy to understand by practitioners.

The BOT ontology developed by W3C LBD includes some of the concepts included in BIMSO such as Floor, Space, and Element. However, BOT ontology does not use UNIFORMAT II elements. The W3C LBD is also working on ways to more effectively represent building products and element properties.

In a number of studies, Niknam and Karshenas have demonstrated the use of BIMSO in various AEC-FM applications such as a virtual social networking application for the participants in an AEC project (Niknam and Karshenas, 2014), sustainable design of buildings (Niknam and Karshenas, 2015b), construction project cost estimating (Niknam and Karshenas, 2013, Niknam and Karshenas, 2015a, Niknam, 2015), and construction scheduling (Niknam and Karshenas, 2016). In this article, BIMSO is extended to building product data published by manufacturers. Currently, product data are mostly published in pdf format and require a human being to read and interpret the data. To convert the data to RDF/OWL knowledge bases, a product data ontology must be created that defines the vocabulary used in manufacturer's product data files. The ontology developed herein for building product data is referred to as BIMMO. A building product ontology makes it possible to develop RDF/OWL knowledge bases for the manufacturers' product data and thus facilitate the integration of the BIM knowledge bases with the product manufacturers' knowledge bases.

Niknam and Karshenas (2013, 2015a) used Semantic Web Services to facilitate data communication between material suppliers' knowledge bases and a construction cost estimating application. Semantic Web Services allow software programs to find each other over the Internet, exchange data without human intervention, and without the need to write customized code for each service. For example, a cost estimating application would send a product's specifications to project material suppliers' Semantic Web Services and receive the latest cost information for the product, thus making the cost estimating process more efficient by eliminating human involvement in the repetitive and time-consuming process of obtaining the latest material prices and manually updating cost estimating databases. This makes the cost estimating process not only faster but also more accurate by eliminating the potential for human error in manual data entry.

In this study, the authors have used Semantic Web Services to facilitate the communication between a BIM knowledge base and a product manufacturer knowledge base over the Internet. The BIM knowledge base would send a product model number to the product manufacturer's Semantic Web Service and receive the requested product data from the manufacturer web service.

3. INTEGRATING BIM DATA WITH PRODUCT MANUFACTURER DATA USING SEMANTIC WEB SERVICES

Architectural, structural, mechanical, electrical, and plumbing designers create 2D drawings for their views of a project. BIM experts convert the 2D drawings to 3D BIM models and integrate different design drawings. A BIM model includes not only a 3D model of the building but also element information assigned as parameters to the building elements. The information assigned as parameters to BIM elements is not comprehensive. To integrate all the relevant data about an element from its manufacturer over the Internet, new technologies are needed. RDF/OWL is the common framework and language used in the Semantic Web for data modeling and storage. The Semantic Web is designed to: facilitate the information exchange over the Internet, process information, and integrate distributed sources of information about an object (Segaran et al., 2009; Allemang and Hendler, 2011; Hebeler et al., 2011).

Fig. 1 shows a schematic view of the process of combining the BIM properties of an element with the additional information provided by the manufacturer of the element. The BIM model is converted to an RDF/OWL semantic knowledge base, also referred to as a BIM knowledge base. The BIM knowledge base may be modified during construction to reflect the changes made in building elements. The edited BIM knowledge base at the end of the construction process is referred to as as-built BIM knowledge base. The as-built BIM knowledge base is used by facility managers for planning and performing maintenance and repair operations.

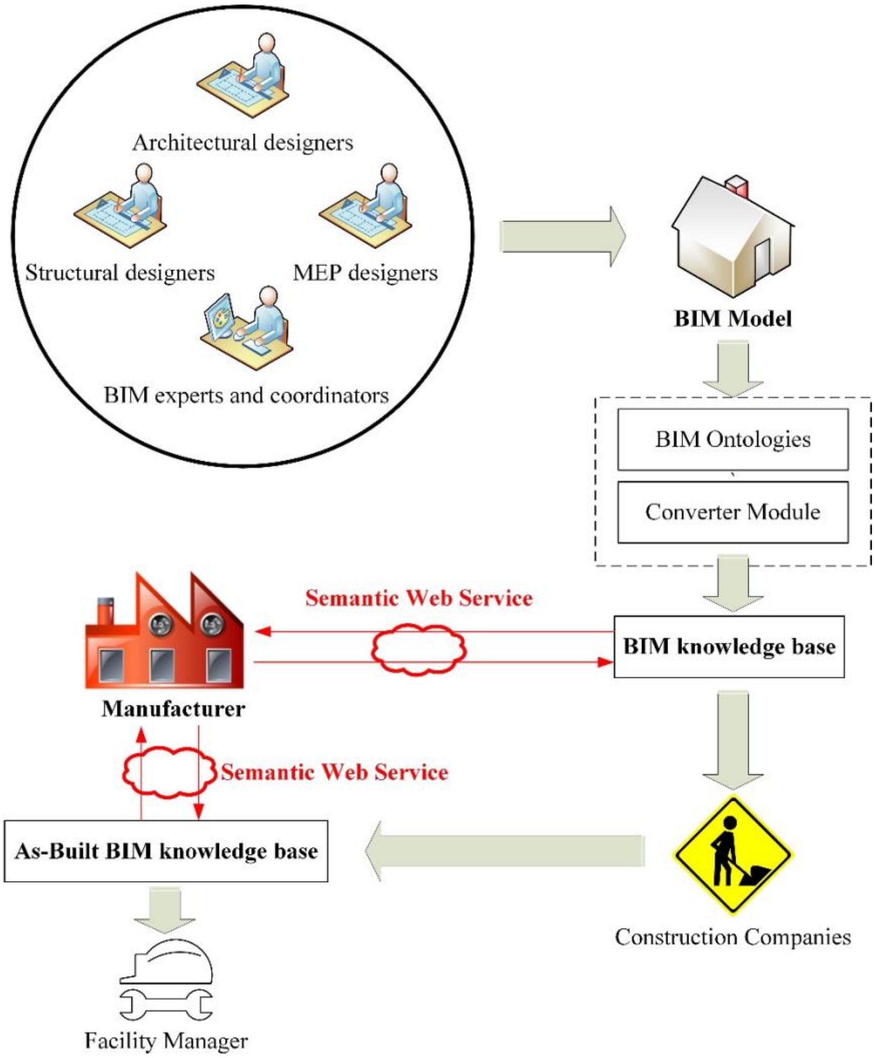

FIG. 1: Using Semantic Web Services (SWS) to integrate manufacturer product data with the BIM data.

When BIM experts create a BIM model, they either use predefined element families or create their own families. Sometimes, BIM experts download families from websites such as the National BIM Library (https://www.nationalbimlibrary.com/en/) and bimobject (https://www.bimobject.com/en-us). Although families include parametric and element property information, they are not comprehensive (Costa and Madrazo, 2015). The product manufacturers usually provide a large amount of information in pdf or printed formats for their products that are not included in the BIM families but would be useful during construction or service life phases of the building. It would be very time consuming and inefficient to manually add the data to BIM elements or BIM knowledge bases. The purpose of this study is to allow computers directly access and retrieve the necessary information from the manufacturers' web servers and update a BIM knowledge base. The authors use Semantic Web Services (SWS) for this purpose as shown in Fig. 1. As Fig. 1 shows, the BIM knowledge base has a communication module that locates a manufacturer's SWS, submits a product's model number, receives the necessary product data from the manufacturer knowledge base, and integrates the data with the information in the BIM knowledge base.

Fig. 2 shows the communication process in more details. The communication system developed in this study requires the following steps:

1. Ontologies are needed to model product data in RDF/OWL format. In this study, the BIMSO ontology developed by Niknam and Karshenas (2017) is used as a semantic bridge between the BIM knowledge base and a product manufacturer knowledge base. The building product manufacturer ontology, BIMMO, is discussed in section 4 of this article.

2. OWL-S ontology is used to provide semantic descriptions for the web services.
3. A product manufacturer creates semantic knowledge bases in RDF/OWL format for its products using the BIMMO ontology.
4. The manufacturer presents its web service in a way that its inputs and outputs are defined according to the BIMSO and BIMMO ontologies.
5. A converter module reads the service WSDL description, the product ontology, and the OWL-S ontology and creates an OWL-S description for the service.
6. The OWL-S descriptions of the web service is added to the manufacturer server.
7. Manufacturer server provider agent sends OWL-S descriptions of the web service to the BIM knowledge base requester agent.
8. Using the OWL-S descriptions of the web service, the BIM knowledge base requester agent sends a product model number to the manufacturer's web service as a SOAP message.
9. The manufacturer web service queries its knowledge base for the requested product information.
10. The manufacturer's knowledge base sends the query results to the manufacturer's web service.
11. The manufacturer's web service sends product specifications to the BIM knowledge base.

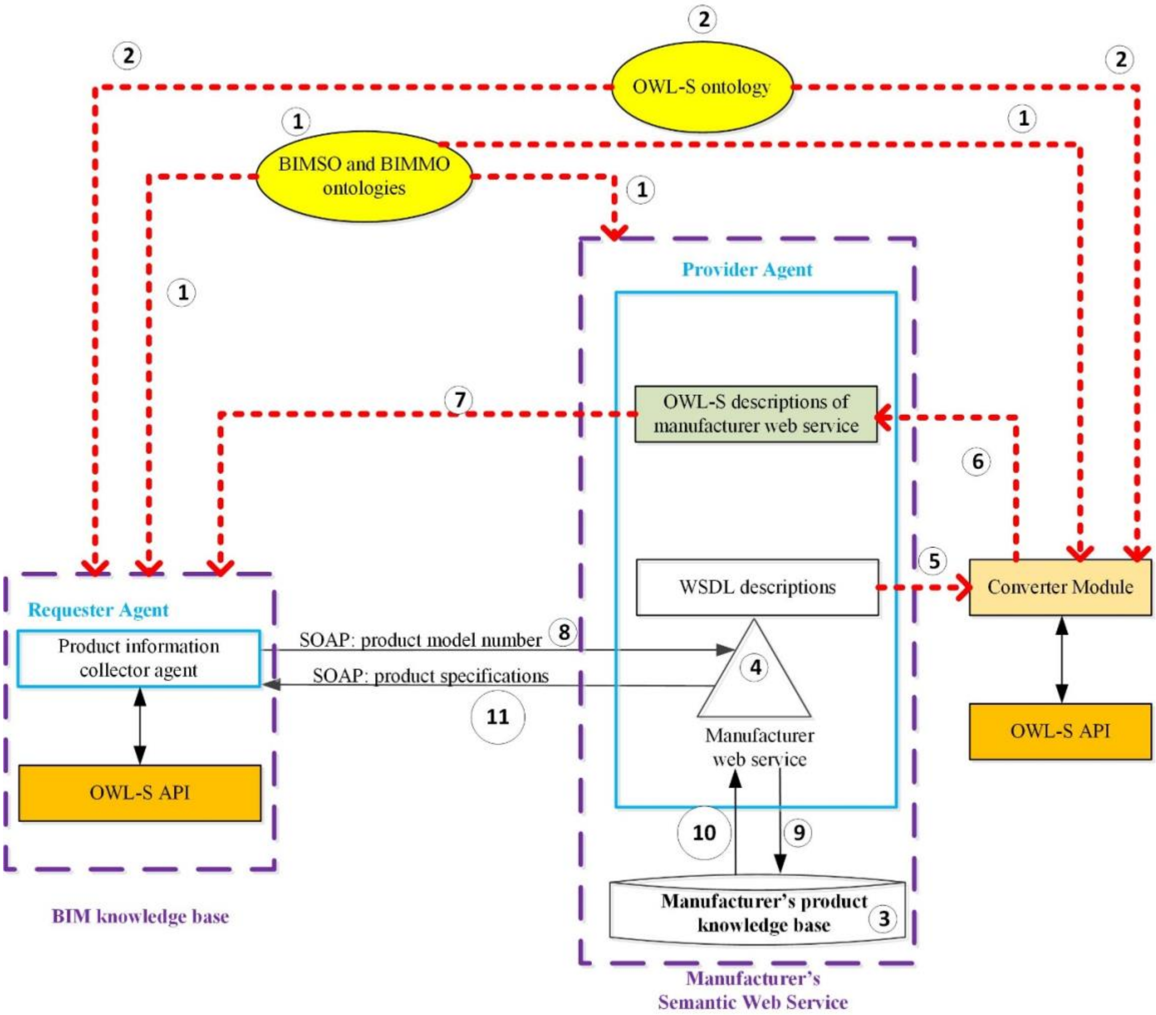

FIG. 2: A schematic view of the Communication between a BIM knowledge base and a manufacturer Semantic Web Service (SWS)

The product data received from a manufacturer's semantic web service can be easily merged with the information already in the BIM knowledge base. Fig. 3 shows RDF/OWL data graphs for the building element X with model number 123 in two different domains. The properties defined for element X in two graphs can be merged into one graph by overlapping the nodes labeled X from the two domains to create a single data graph for element X.

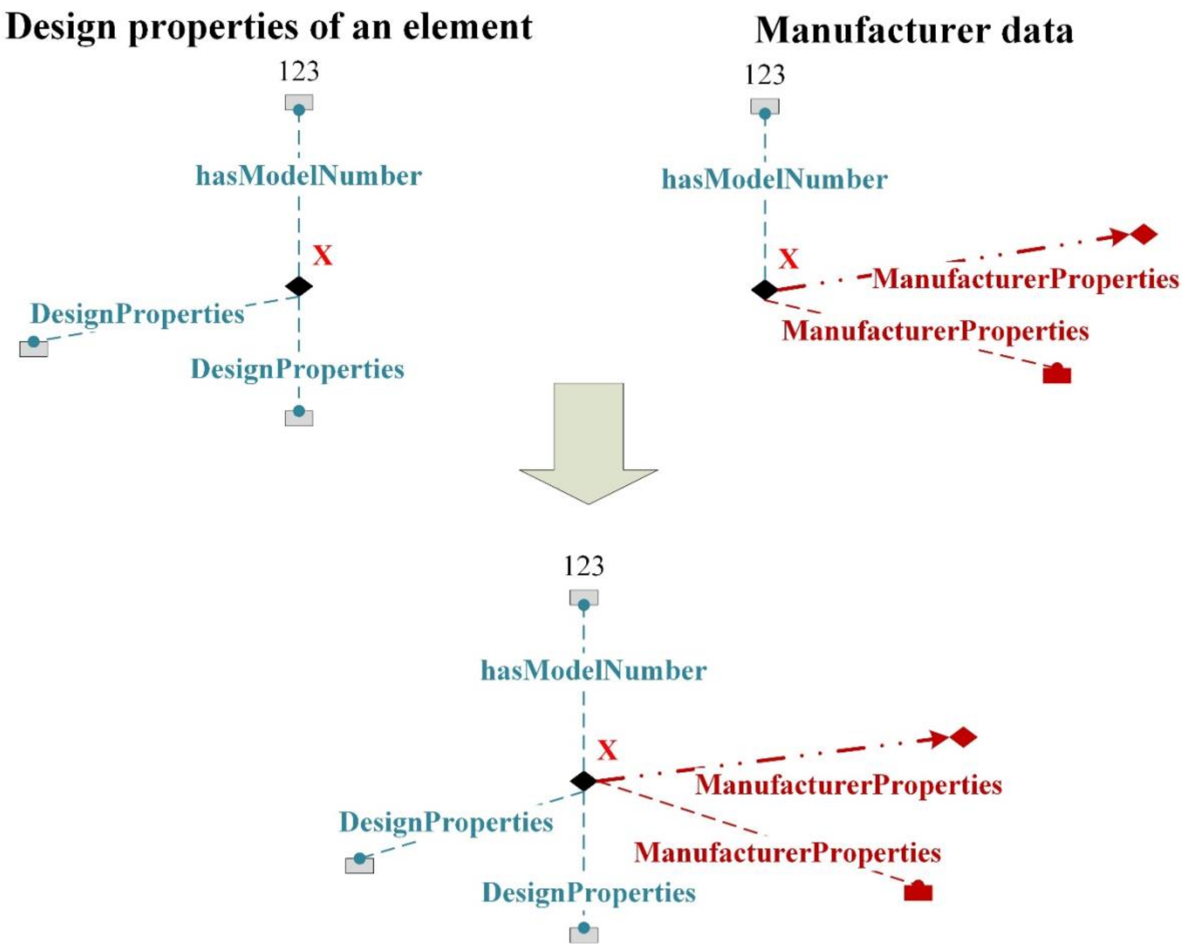

FIG. 3: Merging graphs of RDF/OWL data

A domain ontology is needed for converting the domain's data into a RDF/OWL knowledge base. An ontology organizes data by grouping (classifying) data and establishing links (connections) between different classes of data. The required ontologies for converting BIM data to the RDF/OWL format are explained in an earlier study (Niknam and Karshenas, 2017). Th ontology developed for manufacturers' product data, referred to as BIMMO is explained in the following section.

4. BIM MANUFACTURER ONTOLOGY (BIMMO)

As explained above, the communication between a BIM knowledge base and a manufacturer's SWS requires a common vocabulary. BIMSO ontology (Niknam and Karshenas, 2017) would provide the common vocabulary between different domains and acts as a semantic bridge for data integration among various domains if each domain ontology is created by extending BIMSO. Fig. 4 shows a BIM manufacturer ontology (BIMMO) that is an extension of BIMSO.

In Fig. 4, BIMSO:D30301101180 represents a building product. D30301101180 is the Uniformat II code for a chiller element with a fan coil. In Fig. 4, BIMMO is the prefix that the authors assigned to the manufacturer ontology; it's string representation is BIM_Manufacturer_Ontology#. The org:Organization ontology (https://www.w3.org/TR/vocab-org/) defines a manufacturer's organization. BIMMO:hasProperty property has several sub-properties such as hasLength, hasHeight, and hasOperatingWeight for defining a product's physical properties. In a similar way, BIMMO:hasIdentity property defines several sub-properties such as hasDescription and hasID to describe the identity of a product. If a building product includes several parts, BIMMO:hasPart property is used to define its parts. Each part can have its own properties.

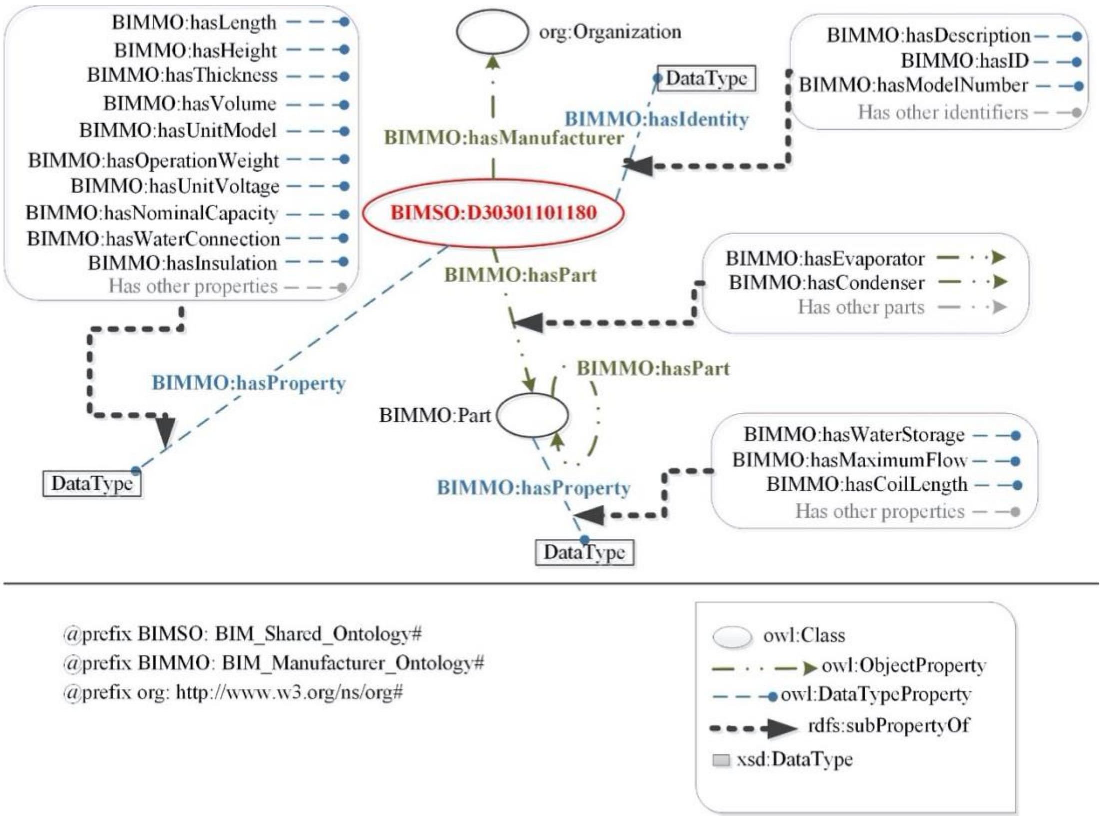

FIG. 4: BIM manufacturer ontology (BIMMO)

5. CASE STUDY: A CHILLER MANUFACTURER KNOWLEDGE BASE

Manufacturers can create semantic knowledge bases for their products based on the ontology shown in Fig. 4. As a case study, the authors converted the specifications for a chiller to RDF/OWL format. The resulting knowledge base graph is very large and cannot be shown in one piece. Fig. 5 to Fig. 15 show different sections of the chiller's knowledge base.

Fig. 5 shows the first part of the knowledge base graph. In the Semantic Web every object must have a unique identification.

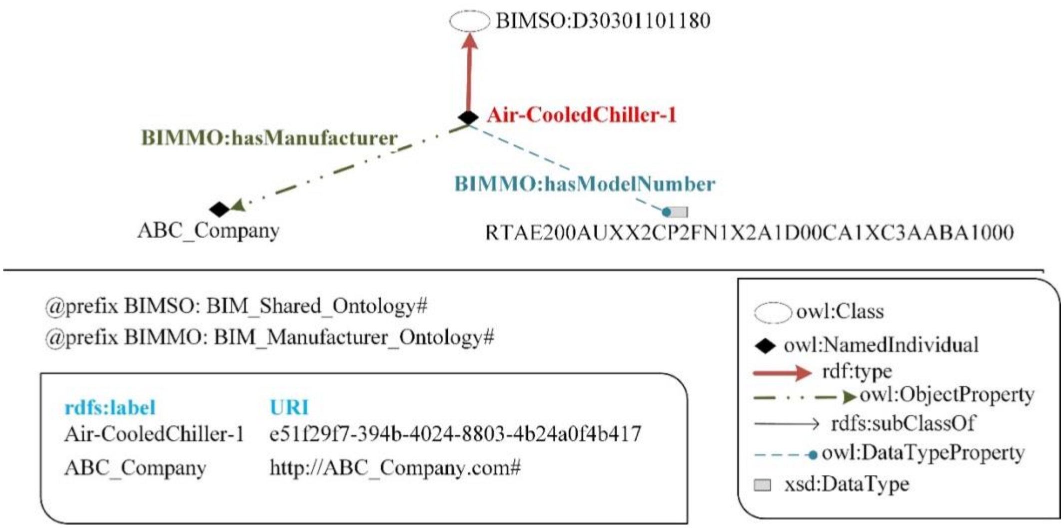

FIG. 5: A chiller's manufacturer and model number

The 32-bit code e51f29f7-394b-4024-8803-4b24a0f4b417 is a unique ID assigned to the chiller element. The 32-bit code is for machine use. To make the graph human-readable, the authors have assigned the label Air-CooledChiller-1 to the product. The manufacturer and model number of the chiller are shown with BIMMO:hasManufacturer and BIMMO:hasModelNumber properties. The manufacturer is ABC_Company with URI http://ABC_Company.com# and the model number is RTAE200AUXX2CP2FN1X2A1D00CA1XC3AABA1000 assigned to the product by the manufacturer.

The authors used BIMMO:hasUnitType and BIMMO:hasUnitModel properties to indicate that the unit type of the chiller is Air-cooled and its unit model is rotary chiller as shown in Fig. 6.

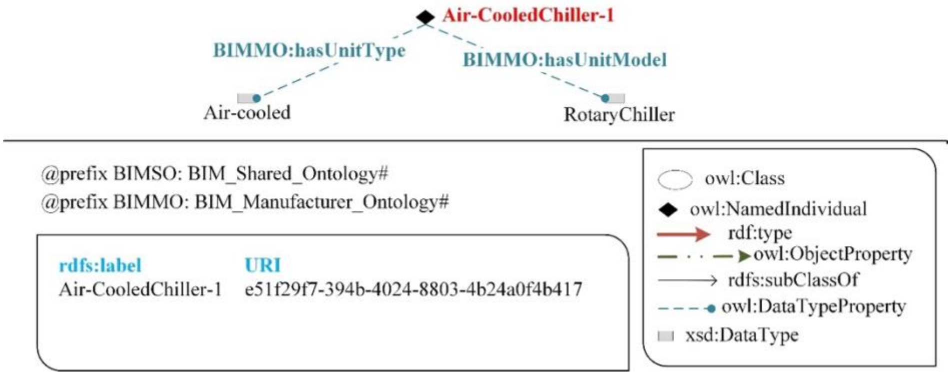

FIG. 6: A chiller's type and model

Fig. 7 shows the properties that the authors have defined and used to represent the product's voltage, nominal capacity, sound package, agency listing, and pressure vessel code. To represent a unit of measurement for a property, the authors had two choices: (1) using a multivalued property as used by Niknam and Karshenas (2017), or (2) making the unit of measurement part of the property. In this paper, the authors have used the second approach. For example, the property for the nominal capacity is defined as BIMMO:hasNominalCapacity(Tons) which includes the unit of measurement. As Fig. 7 shows the chiller has the following properties:

- 200/60/3-unit voltage
- 200 tons nominal capacity
- InvisiSound superior sound package
- European safety standard
- European pressure vessel code

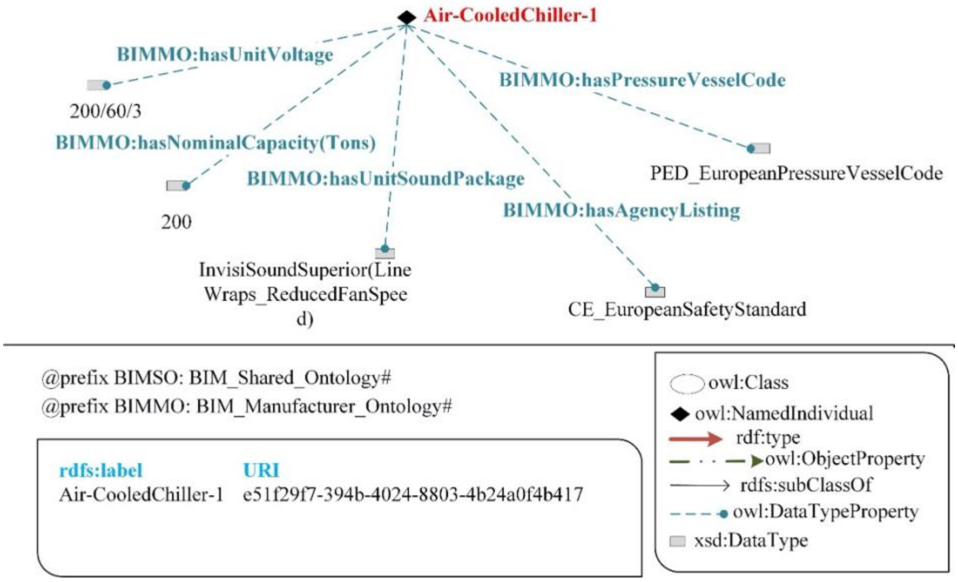

FIG. 7: A chiller's unit voltage, nominal capacity, unit sound package, agency listing, and pressure vessel code

Fig. 8 shows that the chiller's factory charge is nitrogen, includes a 2 pass evaporator for standard cooling between 5.5℃ to 20℃ with the fluid type water, and has grooved pipes for water connection.

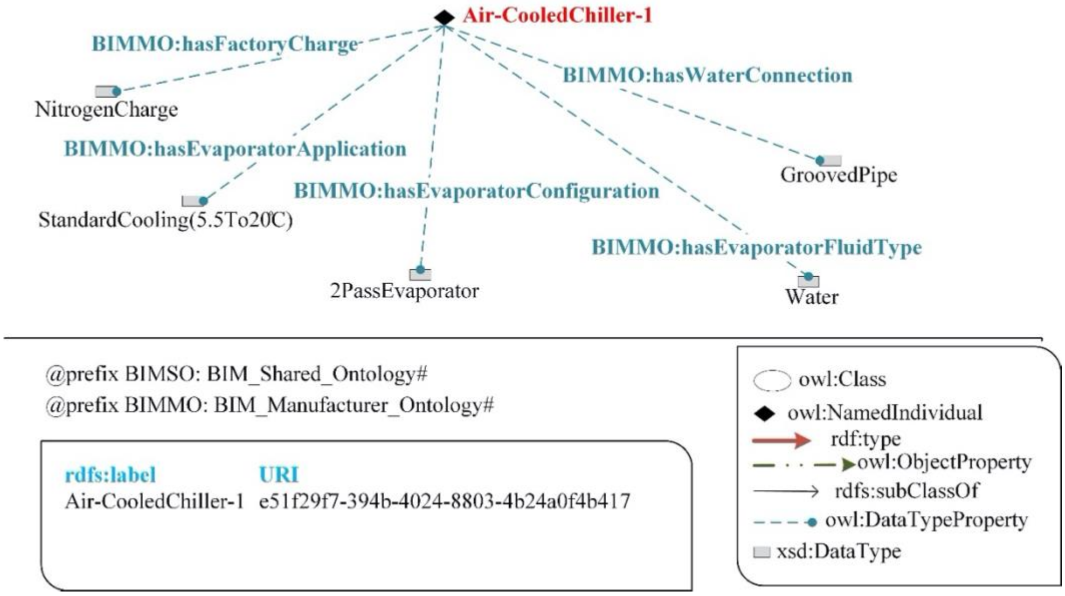

FIG. 8: A chiller's factory charge, evaporator application, evaporator configuration, evaporator fluid type, and water connection

Fig. 9 shows that the chiller element has the following options:

- Factory installed water switch
- 0.75" insulation for all cold parts
- Standard ambient from 0 to 40.6℃
- Complete coat epoxy fin for condenser
- Circuit breaker

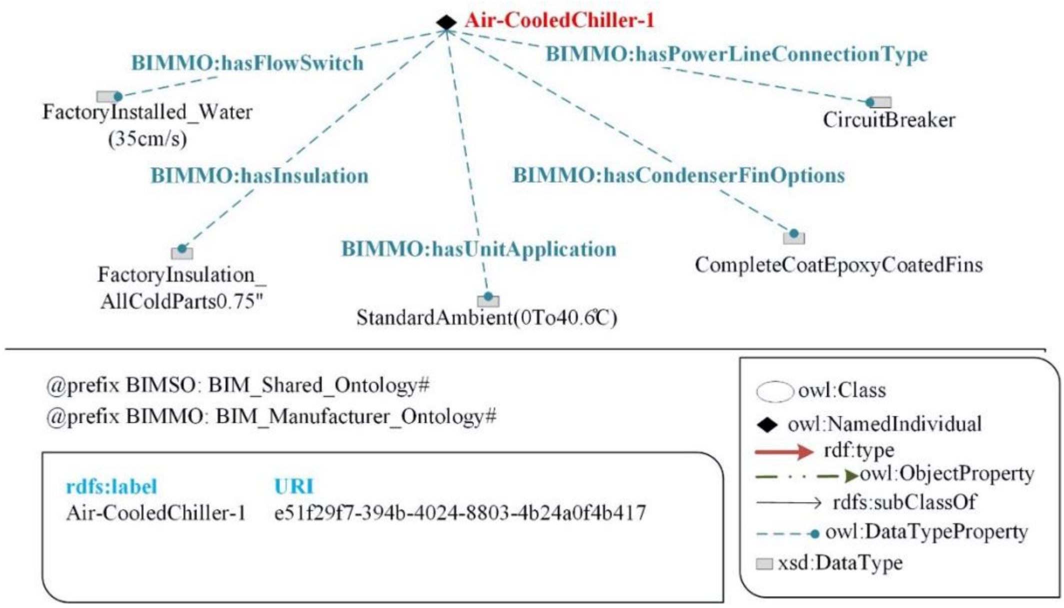

FIG. 9: A chiller's flow switch, insulation, unit application, condenser fin options, and power line connection type

Fig. 10 shows that the chiller has:

- Short circuit current rating A
- Factory installed transformer
- Line reactors
- 15A, 115V convenience outlet (Type B)
- Modbus interface remote communicator

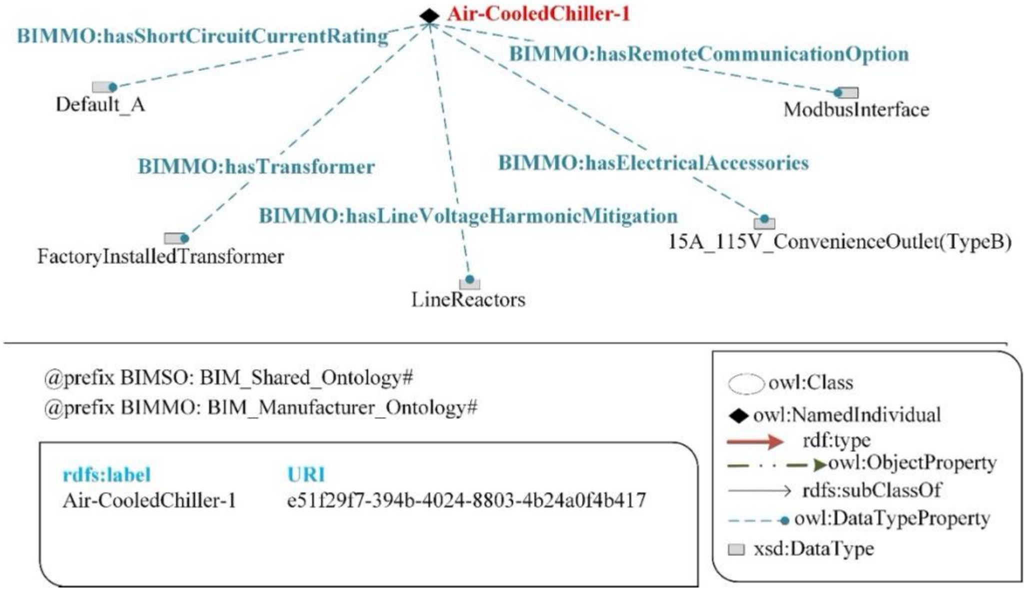

FIG. 10: A chiller's short circuit current rating, transformer, voltage mitigation, electrical accessories, and remote communication

Fig. 11 shows that the chiller element has:

- Hardwired bundle communication
- Seismic structural design according to International Building Code (IBC)
- Architectural louvered panels appearance
- Elastomeric isolators

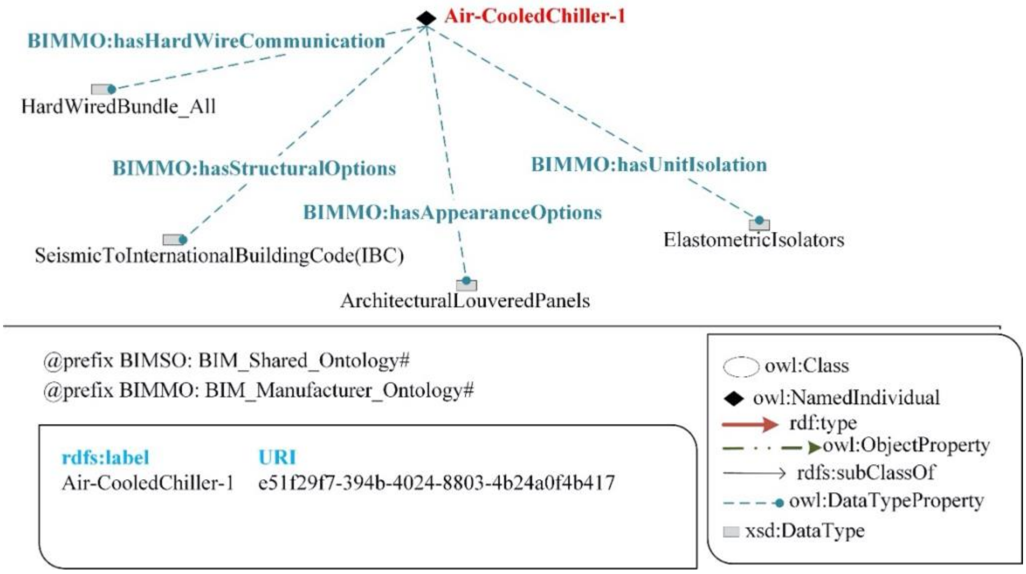

FIG. 11: A chiller hardwire communication, structural option, appearance, and unit isolation

Fig. 12 shows that the chiller has an evaporator part with URI=e055cd1f-1caa-4097-ac9b-0aeaf2cea254 and Evaporator-1 label. The evaporator part has the following properties:

- 90.5 l water storage
- 15.24 cm water connection size
- 14.4 l/s minimum flow
- 52.7 l/s maximum flow

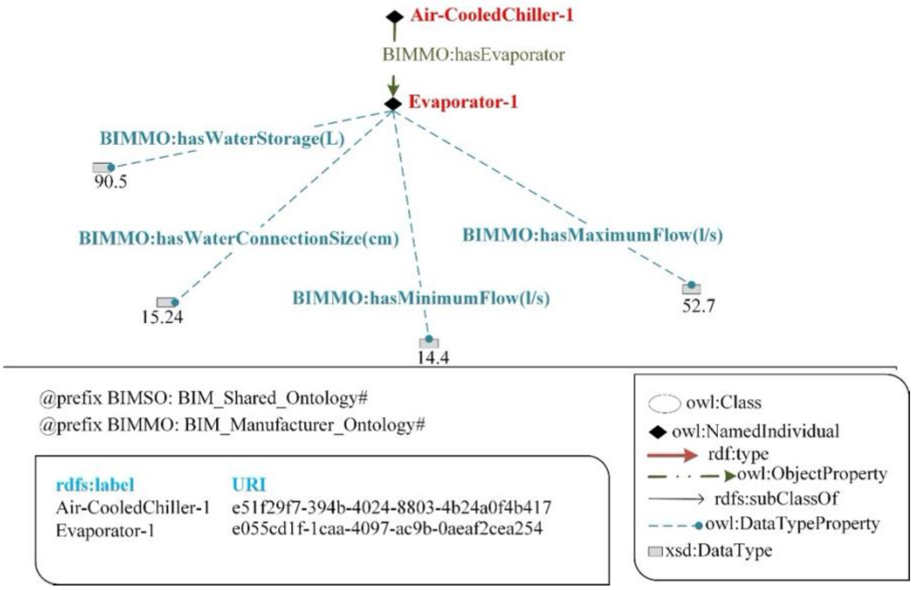

FIG. 12: A chiller's evaporators properties

Fig. 13 shows that the chiller has a condenser part labeled Condenser_1 with the following properties:

- 12 number of coils
- 200 cm coil length
- 127 cm coil height
- 630 Fins/M
- 3 rows

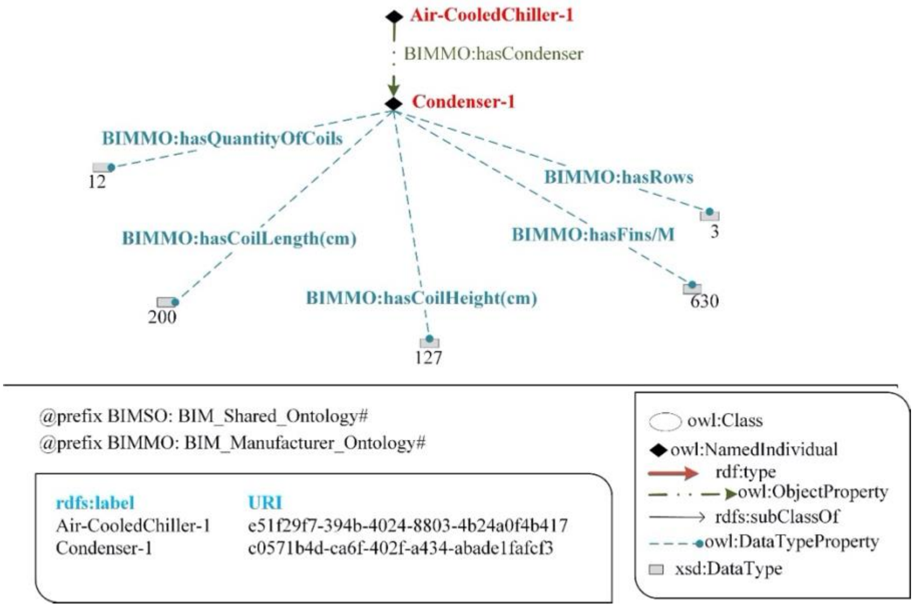

FIG. 13: A chiller's condenser properties

Fig. 14 shows the following properties for the condenser_1's fan:

- 12 number of fans
- 95.3 cm fan diameter
- 273690 m3/hr fan total airflow
- 44.2 m/s fan tip speed

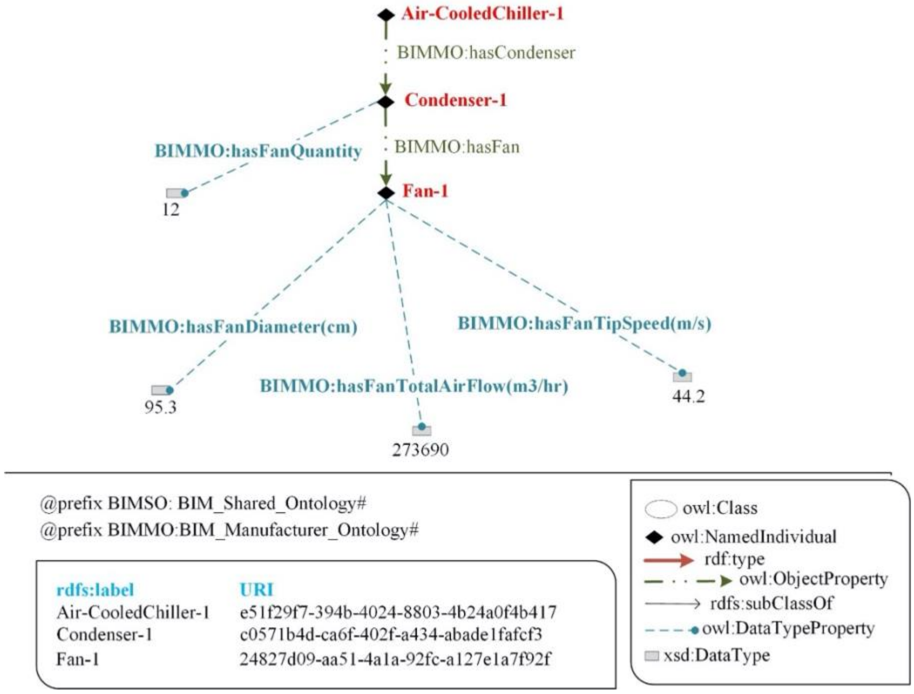

FIG. 14: A chiller's condenser properties

Fig. 15 shows the weight and dimension properties of the chiller:

- 6263 kg shipping weight
- 6354 kg operating weight
- 855 cm length
- 223 cm width
- 243 cm height

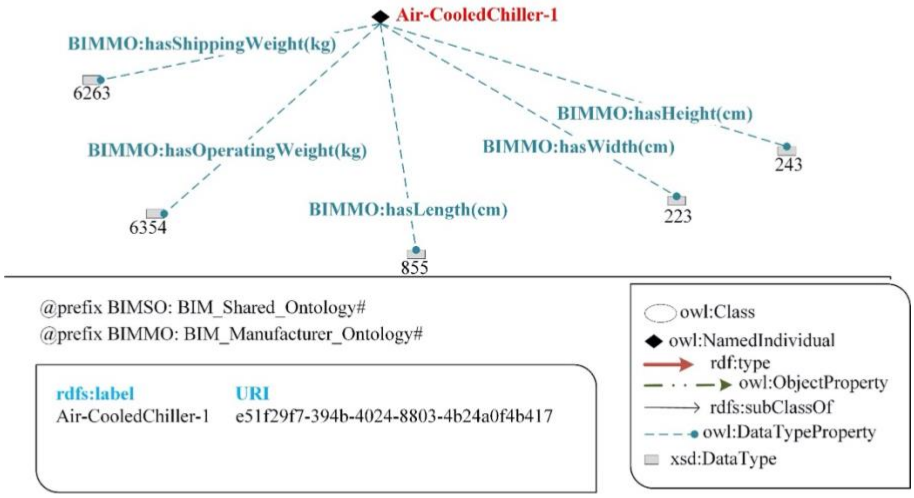

FIG. 15: A chiller's weight and dimensions

In a similar way, other properties of the chiller are modeled in the manufacturer knowledge base. The chiller's RDF/OWL knowledge base was saved in RDF4J datastore (http://rdf4j.org/about/), which is an open source Java framework for parsing, storing, inferencing and querying RDF data. RDF4J supports SPARQL endpoints for querying the knowledge base and creating applications that leverage the power of the Semantic Web.

Using OWL-S, the authors created a chiller manufacturer's Semantic Web Service in order to provide an interface for remote access to its data over the Internet. As explained in Fig. 2, a program is written that sends a product model number to the manufacturer Semantic Web Service and retrieves the corresponding product specifications.

6. ANALYSIS AND DISCUSSION

To demonstrate an application of the developed methodology, a semantic knowledge base for an air-cooled chiller product was developed. The Semantic Web Services technology was used to expose the chiller's data over the Internet in RDF/OWL format and to allow communication between a BIM knowledge base and the manufacturer's product knowledge base. The knowledge bases were stored in RDF4J (http://rdf4j.org/about/) datastore. RDF4J allows parsing, storing, inferencing and querying RDF data. It supports SPARQL query language over RDF data. The required semantic web services were implemented using the Java programming language and OWL-S API (https://www.w3.org/Submission/OWL-S/).

To analyze the performance of the presented approach, the authors used the following two methods to measure the time it takes to merge a building element manufacturer data into the building's BIM knowledge base:

1. User interfaces were developed that allowed users to retrieve data from a server and manually enter the data into the BIM knowledge base.
2. Semantic Web Services, as explained in Fig. 1 and Fig. 2, were used to automatically retrieve and integrate the manufacturer's data into the BIM knowledge base.

In the first approach (the manual approach), 5 civil engineers were asked to read data from a manufacturer server and manually input the data into the BIM knowledge base. According to Nielsen (2000), 5 users provide adequate results for validation and analysis purposes. The 5 civil engineers used for this task were experienced BIM users with good familiarity with graphical user interfaces used in various software for data entry. Only one product, an air-cooled chiller product, was tested. It took on the average 27 minutes with a standard deviation of 2.7 minutes for the users to find the appropriate manufacturer and its product, read product properties, and input the data into a BIM knowledge base. The observed average and standard deviation are for the users performing the same task.

In the second approach, the communication module of software developed by the authors and a Semantic Web Service implemented on a server were used. The process involved finding the element manufacturer based on its URI and retrieving the required product data using the product's model number. This approach does not require human involvement for data retrieval from the web service or data entry into the BIM data base; the process of data retrieval and integration is automatic. The speed of the second approach will dependent on the specifications of the server and client computers as well as the Internet speed. For this test, the following computer hardware were used.

Server specifications:

- HP ProLiant ML 10 Gen 9 Server with Standard Bay
- CPU: Intel Xeon E3-1225 v5 :3.3GHz, 4core, 8MB, 80W
- RAM: HP 8 GB Single Rank x8 DDR4-2133 unbuffered
- Internet upload speed: 20 Mb/s
- Internet download speed: 32 Mb/s

Client specifications:

- CPU: Intel® Core™ i7-7700HQ CPU @ 2.80GHz
- RAM: 16.0 GB
- Internet upload speed: 1 Mb/s
- Internet download speed: 16 Mb/s

For the above-mentioned specifications, it took, on the average, 8 seconds for the client software to connect to the server, send the product model number, retrieve the results and save them in the BIM knowledge base. Since a building includes several components, this approach obviously saves time for data discovery, retrieval, and integration.

The second approach is not only faster but it also eliminates human errors that usually occur in manual data entry operations. A comparison of the results of the above-mentioned two knowledge base updating methods showed that, on the average, in the manual method each user made 17 mistakes with a standard deviation of 7.2; whereas, no errors were observed in the second approach. Although the above numbers are very approximate indicators of the performances of the two methods, they, nevertheless, show that automation of data retrieval and entry improves efficiency and accuracy.

7. SUMMARY AND CONCLUSIONS

Building product manufacturers publish specifications, user manuals, and data sheets that contain valuable information for the key participants in the building process. This type of information is usually published in pdf format and is not included in the BIM model of a building. However, the information is valuable for decision making during various stages of the building process. It is also desirable to store the information in a machine processable format to facilitate automation of some operations.

In this article, the authors presented a new idea for integrating a building product's BIM data with the additional data provided by the product manufacturers using the Semantic Web and the Semantic Web Service technologies. The presented methodology requires that the BIM and the manufacturer's data be semantically defined in RDF/OWL format. In an earlier study (Niknam and Karshenas, 2017), a methodology for semantically defining BIM data was presented. In this study, semantic definition of product manufacturers' data was discussed. Semantic Web Services were used to retrieve the product manufacturer's data and combine it with the BIM data. Since both the BIM and the manufacturer data are modeled in RDF/OWL graph data structure, it is easy to merge the two sources of data and the combined data would be machine processable.

The combined building product data are especially useful during the service life of a building. As an example, a product maintenance process during the service life of a building may include:

1. Determine manufacturer's recommended maintenance frequency and set the next maintenance date (data available in the manufacturer's knowledge base).
2. Determine manufacturer's recommended parts to be replaced and part specifications (data available in the manufacturer's knowledge base).
3. Prepare a maintenance order for facility manager's approval.
4. Order the work to a qualified contractor.

With a few queries to the product manufacturer's knowledge base, the information for steps 1 and 2 can be easily retrieved. However, since the product knowledge base data are machine processable, the whole maintenance scheduling process could be automated. This would require a software agent program to prepare an online maintenance order that includes the date of the next maintenance, a list of the parts to be replaced, and the manufacturer's recommended part specifications (all data retrievable from the product knowledge base). The form is sent to the facility manager for approval. Upon approval, a software agent places the order online."

To investigate the performance of the new approach, the authors measured the time that it took to manually retrieve a product manufacturer's data and integrate them into the BIM data with the automated approach presented in this paper. It took, on the average, 27 minutes to integrate data for an air-cooled chiller element using the manual approach. The same operations took, on the average, 8 seconds using the automated approach discussed in the paper. Since a building includes many products, the authors' approach can significantly reduce the time it takes to integrate distributed sources of building data. The new approach also eliminates human errors in data retrieval and entry. The integrated product data are valuable for decision making during various stages of the building process, especially, for maintenance and repair operations during a project's service life.

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