Smart Buildings: Semantic Web Technology for Building Information Model and Building Management System

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***Abstract*—Smart Building is a trend towards the Buildings Automation paradigm. Smart Building aims to autonomously control devices and systems in given environment. These devices and systems are nevertheless supervised by facility management. The facility management normally is aided by heterogeneous systems and applications. Due to multifarious data of the systems, applications, and missing integration of data in building automation, the data is manually collected by facility management, for analysis and decision making. Therefore, such a system is required to integrate the multi-form data of various systems and applications. Hence, Semantic Web technology is proposed in this paper to integrate data and to implement front end. Therefore, Semantic Web technology not only provide base for analysis and decision making for facility management, but also facilitate developers to focus on front-end of application. The aim is to structure the data, where active devices cannot only be located in a building but also identify according to its connected systems and subsystems. This also supports and maintains historical data for future analysis.**

I. INTRODUCTION

Necessity of each organization is to ensure various aspects of its operation that are not directly involved in its primary goal, i.e. providing service to customer or selling products. Facility management (FM) covers the aspects, such as space management, help desk & service desk, maintenance or energy monitoring. International Facility Management Association (IFMA) defines FM that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology.

FM distinguishes several systems and data sources that support and simplify tasks of FM. Widely used Computer Aided Facility Management (CAFM) systems cover most areas of FM. CAFM software serves as repository and user interface for operational data, for example assigning employees to rooms, log of maintenance plans, requests & tasks, energy consumption data, and many more. This CAFM is used by facility managers in FM. The Building Information Model (BIM) is a data source that contains spatial information about building constructions, locations and devices installed in them. Data from the BIM database serve as an input for CAFM systems. Finally, the task of FM is tightly connected to modern "intelligent buildings". These facilities incorporate a wide scale of automated systems, such as security system, access control system, fire alarm system or building automation systems that controls Heating, Ventilation, Air Conditioning (HVAC) devices. Building Management System (BMS) facilitates remote monitoring and controlling of the building operations. The detailed description of CAFM and BMS software can be found in [1], [2].

Currently the integration of BMS data with CAFM and BIM is simplified, which is not effectively queried because the integration is missing. The integration between them is impossible, without semantic structure because BMS data is determined by network topology. The semantic structure is required for the advanced analytical features of CAFM software, which are currently not integrated with BMS data. The missing integration between CAFM, BMS and BIM does not affect small sites with less installation, as long as data collection and analysis are performed manually. However, for large sites (i.e. installation of hundreds of devices, thousands of sensors), manual data collection prevents effective gathering of required information. Despite of large sites, BMS contains large amount of accurate, up-to-date and detailed data which is valuable for building operation analysis. This data cannot be collected by any other way, other than semantic structure (i.e. designing Ontology Model).

Development of analytical systems for building operations requires expertise in fields of building automation protocols and building technologies, which is not common among commercial IT experts. Vendors of building automation systems focus on development of the hardware. Software, which is provided by vendors with the hardware, is used for management and programming the building technologies system in everyday operations, rather than for analytical operations. Developing the complex systems for analytical operations is commercially unprofitable in large sites; therefore, development of such systems is rare in current time. Comparing to small sites, data analysis is performed by simple approaches such as defining manual reports, exporting raw data (an ad-hoc analysis is performed by end users) or using purely financial data (i.e. invoices) for operation analysis.

Overcoming the issue of analytical system complexity, the goal of this research proposal is to define a middleware layer. The middleware layer will simplify development of advanced applications in the field of building operation analysis. It is worth to note, that the aim of the work is not to provide tools for building operations analysis, but to develop a middleware layer. The development of middleware tools, models, methods and standardized interfaces will allow skilled software developers to apply their knowledge and skills in the field of building

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operation analysis. These skills cannot be applied now, because expertise in the field of building automation is required.

One of the main parts of the middleware layer is a Semantic Model. The Semantic Model stores additional information about BMS data, which allows meaningful and efficient querying mechanism. This paper aims to present Ontology repository implemented for Semantic Model of BMS data. The paper explains related work in section 2. Overview of Semantic based Smart Building and Ontological Model is explained in detail in section 3. Section 4 and 5 explains use case scenarios and provided solutions to scenarios using Ontology model, respectively.

II. Related Work

Information technology plays an important role in intelligent buildings, as an increasingly sophisticated demand [3], [4], from decades for comfort living and requirement of increased occupant control. Indeed, much of the work in regard to building automated systems was done, but still integration is lacking between the data for analysis.

Various devices communicate and interact, without direct human intervention. Coordination between devices act as supervisors, these devices are devoted to manage available resources to meet defined requirements. Building management and automation systems are still far from this vision [5]. Scenarios are defined during implementation but no dynamic changes occurred. Currently, automatic information management systems are quite limited.

Ontology engineering is a primary concern for defining concepts and relation between them. Therefore, main entities of building according to requirements are used as concepts to design Ontology Model. Hence, relations between concepts facilitate reasoning, which ultimately contributes in analysis. For designing self configuration and self management system, Ambient Intelligent (AmI) system [6] is an example, which uses ontology for interacting within given environment and exploiting knowledge for cognitive processes and autonomously managing its own functions. Likewise Wireless Sensor Network (WSN) is also used in Open Framework Middle-ware [7] for management in Smart buildings. Open Framework Middle-ware diagnoses faults in sensor networks. Therefore rule base knowledge management model is designed. This model facilitates FM applications, such as in energy monitoring, security, water flow control, etc. Additionally, Home and Building Automation (HBA) [5] is another flexible multi-agent system. This system applies knowledge base representation and automated reasoning for resource discovery in building automation.

In Smart Building automation, wireless pervasive computing is introduced to enhance life comfort, and importantly reduce maintenance and consumption cost. The Smart Building automation integrates mobile technology to facilitate maintenance, which deals with monitoring and life safety plans in case of emergency. An ontological model is proposed [8] to switch-off lights when no one is in room, scheduling water valves and pumps accordingly and switching to photovoltaic installation if bright shining sun rises. Besides this, an approach for embedded systems of sensors is used to detect activities of visitors and occupants [9], while interacting with smart building. The focus is to support FM tasks, such as building management, maintenance, inspection and emergency response.

Industry Factory Classes (IFC) are extensively used in construction of BIM in smart buildings. These classes are imported into a Semantic Web Model, where the requirements are analyzed by facility manager according to feasibility of a building construction. Similarly, the Semantic Model is also used to view the 3D building models to visualize data. Therefore, an approach [10], based on both semantic architecture (named as CDMF) and IFC 2x3 is used for 3D geometries of a building. In project *DRUM/PRE* [11], IFC classes are used for data maintenance & connections, and are linked through Semantic Web Technology to allow required queries. The IFC classes are also used to define policies for Energy-Efficient smart buildings, i.e. in *Think Home* project [12]. The proposed Semantic Model, in this paper, gathered BIM information from Spatial database. Here, the construction of BIM in Ontology Model facilitates in allocating the active devices, analyzing effects of readings gathered from devices and also helps in decision making of device installation in new buildings. In proposed Ontology Model, BIM is not using IFC for making decisions in selecting construction materials.

With the BIM, BMS is used for construction of the Ontology Model, to cover several aspects of operational analysis in Smart Building. The Ontology Model is designed to connect data used in various heterogeneous systems. Domain knowledge of the Model facilitates in monitoring various devices, provide instant response to concerned end-users and reasoning & analysis for future decision making, as in [5], [13], which reduces cost of energy and leads to efficient building operation. Comparing to [5], [7], [8], the Ontology Model, proposed in this paper, not only identifies device connections with subsequent systems & subsystem, automatic reasoning and focuses to support FM tasks but also to locate the active devices in a building. This is achieved by integrating Spatial and Technology databases. Due to this integration of databases, building operators perform quick response in allocating a device in alarming situations. Even when a device requires replacement or adjustments, this additional feature facilitates immediate time response. Device allocation also supports the analysis and decision making, for example, if various temperature sensors provide different reading in and outside a room, then this feature helps in identifying that which device is more affected by external temperature of the room. The model reduces information load on building operators, as discussed in [14], and also reduces location identification time as compared to a manually locating a device. The proposed Ontology Model is based on existing systems used at our campus, where Spatial database, Technology database and BACnet addresses are already in use for manual analysis and future decision making.

III. Semantic Web Technology & Smart Building

Several concepts are gathered from different systems in analyzing building operation, these systems are BIM, BMS and CAFM. Table I provides overview of concepts used in the systems. For example, temperature in a particular room is a Measured Variable, and is explained as;

- Meaning (physical quantity, ... –> room temperature)
- Source (Location Information and Device Information –> data from BIM database)
- Available data (device, ... –> BMS network addresses

BIM	BACnet Address	Purpose	Environment Var.
Location Information	Device	List of Object Purpose	Physical Quantity List
Device Information	Object Type (Data Point)		Aggregation Type
	Object Instance		Environmental Spec.
			Further Specification

TABLE I: Elements of Building Operation Semantics

for real-time data, historic data and event triggers)

- Relations (which variable is influenced by & what is influenced by a variable)

Detailed description of BMS and BIM is explained below. The Ontology Model is based on practical experience and requirements required for the campus's BMS systems. The BMS at campus integrates over 40 building in one network and uses BACnet as its communication protocol. The BMS contains approximately 1000 devices and hundreds of thousands data points (BACnet objects). The Model is generalized on the abstract concepts that are common for each of the building's operation, monitoring and FM systems. The general architecture of the system is explained in [15].

Environment Variable in BMS – Environment Variable is a value that is measured by BMS, for example room temperature in particular room, energy consumption of specific engine, building energy consumption, etc. No data source exists, in campus, that contains repository for measured variables. However, list of registered Environment Variables, i.e. Physical Quantity, are used for precise specification of value type, for example air temperature in a room, revolutions per minute of exhaust fan, current passing through phase A, etc. To integrate members of quantity register with respective BMS objects and BIM devices, Semantic technology is used according to meaning of measured value, for example measured quantity, location, source device type, network address. Alphanumeric strings are used as identifiers of quantities in the register. The string consists of following parts describing the Quantity (e.g. Energy, Frequency, Temperature, Humidity), Aggregation Type (e.g. Present value, Average, Difference, Sum), Environment Specification (e.g. Air, Water), Further Specification (e.g. Outside, In room, In plumbing).

BACnet in BMS – BACnet defines large numbers of Object Types, and these Object Types serves different purposes. The most common of them are input and output objects. These objects represent values of read or write, which are sent to input or received from output ports of device. The values are from sensors or control signals sent to connected devices; i.e. valves, engines, pumps and relays. Other Object Types include trend logs and object specification. The trend logs are archive data stores, for example Event Definitions, Algorithms (i.e. definitions of programs and loops), Schedule Objects (automatic control of output values according to time), Helper Variables and System Objects. Object specification in BACnet protocol defines set of properties for each Object Type, but the details are omitted because of operation analysis. An object in BACnet protocol is identified by its network address. The address consists of three parts, i.e. Device Address, Object Type and Object Instance. Object Instance is a numerical value, which is unique for each object according to Object Type of a particular Device.

Object Purpose in BMS – Object Purpose describes functionality of objects. As mentioned above, different types of BACnet objects serve various purposes. Some of them are used for expressing "*Present Value*" of variable measured by a sensor, other provide "*Historical Data*", define "*Event Trigger*" or "*Control Algorithm*". In any case, the purpose of a BACnet object cannot be derived from its Object Type for example; object of type "*Analog Variable*" can be used as representation of current sensor data in similar way as "*Analog Input*" object.

Location Information in BIM – Location Information is stored in Spatial database named as "Building Passport". Location is described by its location code. The location code serve as a primary key in Spatial database. Usually, room is represented as a location in a building. In Spatial database location code is a string defining location data as Site Code, Building Number, Floor and Room information; figure 1 elaborates Building Passport.

Device Information in BIM–Device Information is stored in Technology database named as "Technology Passport". In Technology database Device Information represents a device that describes location of the device, its purpose and its connection to a particular system in a building. For example the systems could be building automation system, security system, CCTV, water supply, power lines, etc. In Technology database, Technology Passport is a string consisting of System, Sub-System, Device Type and Device Index; as described in figure 1. The Device Index is used to distinguish similar devices in a room. The "Building Passport (BP)" is integrated, with Ontology Model, with "Technology Passport (TP)" to define a complete code for a device, its connections and its location in a building.

Note that, the object data in BMS are not identical to the devices in BIM, for example, temperature sensors are considered as devices in the BIM, but the sensors values are used in BMS. Therefore, the value of temperature is measured by temperature sensor, which is passed through a particular Programmable Logic Controller (PLC). The temperature sensor value is communicated through a BACnet address in BMS. Therefore, relations are defined between BMS objects and BIM devices to describe the data of original source. The identification codes shown in figure 1 are used as instances in Ontology Model.

A. Semantic Web and Complex Data

The complex data used in BMS and BIM systems, is analyzed to construct Ontology Model. The Ontology Model is constructed in Protege 4.3 tool. BMS and BIM systems are using different conventions for a single device installed in a room. Therefore, each of the related information, used in BMS and BIM, are integrated with each other. The information used for integration are; (i) in BACnet; the Device, Object Instance and Object Type are integrated, (ii) in Environmental Variables; the Physical Quantity, Aggregation type, Environment Specifica-

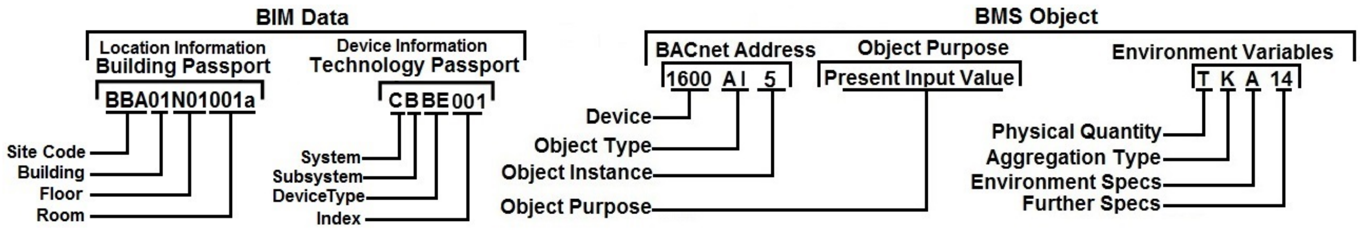

Fig. 1: Identification codes used in BIM and BMS

tion and Further Specification are integrated and (iii) similarly, in BIM; BP and TP are integrated. After integrated different concepts used in BMS and BIM systems, the common data is gathered from these systems. The data is gathered according to the used conventions for each of the device and other related categories.

Categorizing the information helps to simplify the complex data. This complex data is managed to distinguish between various devices and rooms at different buildings. The common data, i.e. the information used at BMS and BIM, provides a complete view of various devices used in all buildings and also contributes in grouping variety of available data, for analysis.

B. Ontology Construction

The common data is analyzed to construct concepts for Ontology Model. Based on BMS and BIM systems' data, it is decided to keep both as separate concepts. Therefore, the BMS taxonomy is further extended to 3 concepts i.e. BACnet, Object Purpose and Environmental Variables. Each of these concepts is categorized accordingly. For example, BACnet taxonomy is categorized to sub-concepts of Device, Object Instance and Object Type; similarly Environmental Variables taxonomy is categorized to Physical Quantity, Aggregation Type, Environment Specification and Further Specification. The BIM taxonomy is extended to two concepts i.e. BP taxonomy and TP taxonomy and categorized accordingly, as shown in figure 1.

The collected common data from various systems use identification codes for each device and other entities. The common data is used as instances in Ontology Model. Therefore, the concepts are populated using common data. The concepts are used to define a device, device location, device connection with systems & sub-systems, characteristics of a device and importantly the data of device purpose (i.e. Object Purpose). The required data is categorized according to characteristics and functionality of a device. Characteristic of device is the Environmental measured data (i.e Environmental Variable), a code, which consists of 5 alpha numeric digits. Functionality of device is the BACnet object (i.e. Object Purpose) that determines different aspects of data semantics, which is gathered from active devices and various operations performed on the data. The Object Purpose consists of Present Data, User Defined Data, Historical Data, Event Definition and Algorithmic Parameters. Some of the objects are used as the "*Algorithmic Parameters*" and the purpose of the Algorithmic Parameter is added to it; for example, Present Data with input value is named as "*Present Input Value*".

The challenging step is to integrate the concepts by defining relationships between them. Various identification codes are used to identify devices and other entities in BMS and BIM systems; it is complicated to link them, as they are theoretically explained. This is because that the similar devices have different identification codes. These different identification codes for similar entities are used by primary data sources to identify the devices or devices at location. Therefore to link each concept, an identifier is defined at each step, according to requirements. Hence 3 different identifiers are used as concepts. The predicates are assigned to link the identifiers with other concepts accordingly. The identifiers are also linked with each other subsequently. The identifiers are "*BIMIdentifier*", "*BACnetIdentifier*" and "*QuaID*", as shown in figure 3. These identifiers are populated according to total number of devices installed in a building, total number of active devices and total number of characteristics of devices, respectively. An Ontological restriction is used at Root Ontology, that explains a device is an active device if we are able to get data of location and device information (i.e. BIM) and device has some purpose of functionality (i.e. Object Purpose), as shown in figure 3.

The Ontology contains two loop relations at "*BACnetIdentifier*". One is used to describe internal logic of BMS objects and other is for hidden relations between BMS objects. The purpose of modeling internal logic is to relate various devices in BMS. For example, if a device is controlling air condition and using an algorithm that controls fan speed, then the relation between the BACnet devices is represented by an algorithm. According to this relation, subject is air condition and object is fan speed control. The same relation applies to the device representing set-point value (i.e. requested room temperature) and the fan speed. This relation is made after examining regulation algorithms in BMS. The hidden relations between BMS objects are not explicitly described by internal logic of BMS devices. Considering air conditioning controller from previous example, there is also a room temperature sensor, which represents a particular BMS object. The value of temperature is influenced by the fan speed and the set-point value. However, this relation was not defined in the regulation algorithm. Instead, it was checked (or understood) by physical installation of the hardware, i.e. the relation exists because the temperature sensor and the fan, which are installed in the same room.

Analyzing common data and defining concepts provides an overview of Ontology Model. Relationships between the concepts define logical association of entities in BMS and BIM. These relationships, i.e. predicates, are conceptual relationships and are used by building operators at the campus. Therefore, definition of relationship is keenly considered according to technical aspect of BMS and BIM.

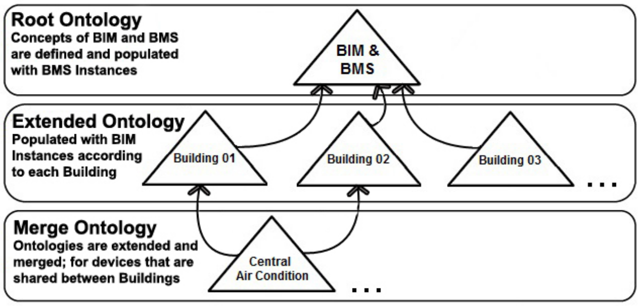

Fig. 2: Overview: Levels of Ontologies

C. Extending Ontology Model

Defining concepts and relationships in Ontology Model, facilitates in improving final results according to requirements. Major issues related to repetitive results are solved using identifiers, but after populating the Ontology for a second building in same site at Root level of Ontology, again generates repetitive results, this is because of similar alpha-numeric numbers assigned to floors and rooms in different buildings.

To avoid recursive results, due to similar floor and room numbers in different buildings, the Ontology Model is extended to Extended level Ontology, as shown in figure 2. The common data of BMS is populated at Root level Ontology, but the relations between instances of BIM with BMS are specified at Extended Ontology. Therefore, for each building at the campus, an Extended Ontology is used, to keep the uniqueness of location and device information. In some buildings a device is shared, such as Central Air Condition, therefore merge technique is used to relate the device with locations, where the device is actively functioning, as shown in figure 2. Hierarchy is used for Ontology Model, which depends on analysis of relevant concepts in terms of entities and integrated data of BMS and BIM [16]. In taxonomic relations, links are established on canonical structure of concepts and lexico-syntactic patterns [17] are used to construct unique Ids for meaningful Ontology according to BMS and BIM.

IV. Scenario

In this section, use cases explains requirements of facility managers. Facility managers perform analysis, based on readings generated by active devices. Building operators compiles a list of active devices and forward it to facility managers. The search is carried out with the help of Ontology Model, to compile the list. Therefore, complete information of a room (i.e BBA01N01001a, as shown in figure 1), is provided in query to search active devices. Similarly, it is also required to get information about a list of rooms in a building, by providing complete information of a device (i.e. CBBE001). Therefore, the Ontology Model is able to compile a list of rooms and sent to building operators, where that specific device is operational.

The most interesting part of the work is to find all those active BMS Objects that have the Object Purpose "*Present Input Value*", Object Quantity "*TKA14*" (i.e. air temperature) and installed in a room "*BBA01N01001a*". Here, the BIM and BMS information is used to find the BACnet address that specifies all parameters. It is further explained in section V.

Facility managers also require to find out all BIM devices or BACnet addresses, which are installed in a room. The inverse of this use case is also useful, for example to search a room where specified devices are installed. Such queries facilitate facility managers to perform analysis for future decision making and planning.

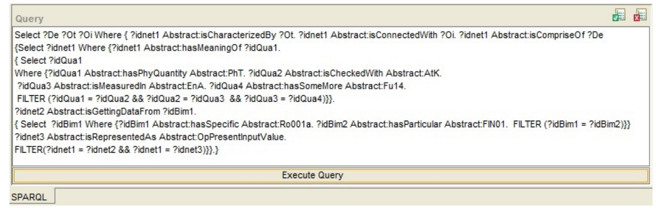

Fig. 4: SPARQL Query

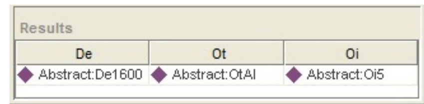

Fig. 5: Result of SPARQL Query

V. Information filtering

Capability of the model is to filter relevant requirements to facilitate user according to her queries. The Ontology Model provides available information of connected devices, its Systems & Sub-Systems, characteristics, functionality and also location information where devices are installed. A pictorial illustration of developed Ontology is represented in figure 3.

Getting BACnet address; The BMS Object is searched using Ontology Model, by providing room information, using BIM database, Environmental Variable (i.e. Object Quality) and Object Purpose. This helps to find out BACnet address of BMS, which is further filter to find the BMS Object. Following logic is used to search for BACnet address.

Identifier (?BMS-ID) $\wedge$ *isGettingDataFrom (?BMS-ID, ?BIM-ID)* $\wedge$ *hasInformationOf (?BIM-ID, ?RoomLocation)* $\wedge$ *hasInstalled (?BIM-ID, ?DeviceType)* $\wedge$ *hasEnvironmentalSpec (?BIM-ID, ?ObjectQuality)* $\wedge$ *isRepresentedAs (?BIM-ID, ?ObjectPurpose)* $\rightarrow$ *isConnectedWith (?BMS-ID, ?BACnetAddress)*

Figure 5 describes results of query, the query is pictorial explained in figure 4. The figure 4 is following the logic which is used for getting BACnet address. The result of query explains that the quired BMS Object has Environmental Variable i.e Air Temperature sensor (i.e. code is "*TKA14*"), Purpose of Object is to get "*PresentInputValue*" and is installed in "*BBA01N01001a*" room. In this query initially the room and then the active Air Temperature sensors in whole building are filtered. After filtering required room and the sensor, the ID of BMS Object is searched according to Object Purpose. Finally, the required active BMS Object is selected according to defined parameters.

The Ontology Model personalizes the information related to BIM and BMS to reduce information load by filtering irrelevant data according to requirements. Thus the Ontology Model is developed according to explained structure of BMS and BIM. SPARQL queries are applied, subsequently to requirements of building operators and facility managers. The Ontology Model is personalizing and harmonizing the information of BMS and BIM. This saves time by filtering irrelevant data, according to user's requirements.

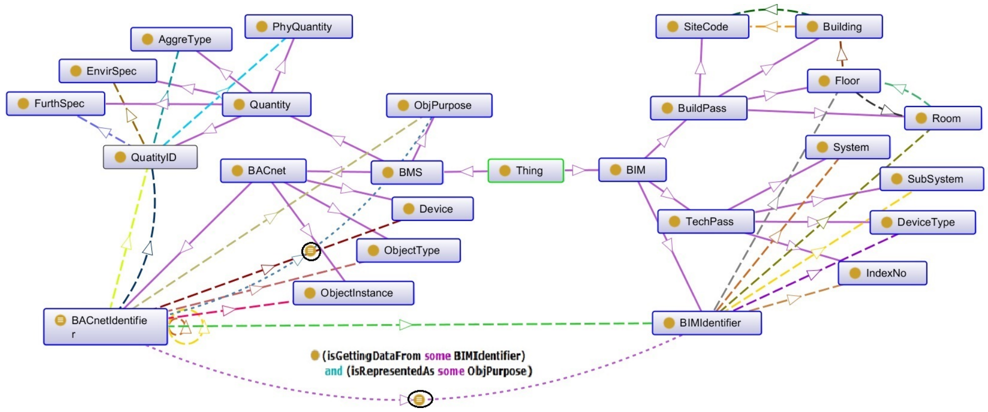

Fig. 3: Root Ontology Model

VI. Conclusion

This article focuses on FM and explains the integration of BIM and BMS systems. The proposed approach addresses the Semantic Technology used for BMS and BIM. Therefore, facility managers are able to perform operation analysis in large-scale environments. The designed ontology covers the concepts of BMS and BIM, used for Location Information, Device Information, BACnet Address, Object Purpose and Environmental Variables. The Ontology Model enables reasoning the BMS and BIM information based on defined hierarchical structure. Ontology Model helps the developers to focus on user interface and analytical methods rather than on collecting integrated data provided at various systems. Therefore, facility managers are able to perform analysis and decision making for future planning. This is the significant improvement in current analysis work flow.

The research is expendable in several areas of large-scale BMS data analysis by introducing "Semantic Smart Building Ontology". Initially, advanced analytical tools should be developed, based on the historical data gathered in BMS. Additional research is required in the field of user interfaces, both for the query definition and results presentation. Next step of the project is to integrate the Semantic Ontology Model with Indoor Navigation system. This will extend the horizons to use Smart Devices for Facility Management.

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