Smart Building: Semantic Web Technology Services for BIM (Location and Device Information)

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Abstract. Smart Building aims to autonomously control devices and systems in given environment. These application systems are nevertheless supervised by facility management. The facility management normally is aided by heterogeneous application systems. 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 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.

1 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

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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).

Currently the integration of BMS data with CAFM and BIM is simplified to a simple structure that cannot be effectively queried because the integration part is completely missing. The integration is impossible because BMS data structure is determined by the network topology, not by the semantic structure. The semantic structure is required because the advanced analytical features of CAFM software are currently not integrated with for BMS data. This does not affect the small installations, where data retrieval and analysis can be easily performed manually. However, for large sites (hundreds of devices, thousands of sensors), the amount of data prevents effective gathering of required information. Despite of this, BMS contains large amount of accurate, up-to-date and detailed data which are 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 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 BIM data, which allows meaningful and efficient querying mechanism. This paper aims to present Ontology repository implemented for Semantic Model of BIM 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.

2 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 diagnosis 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 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 in 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 and Technology database are already in use for manual analysis and future decision making.

3 Semantic Web Technology & Smart Building

Several concepts are gathered from different systems in analyzing building operation, these systems are BIM, BMS and CAFM. Table. 1 provides overview of concepts used in the systems. For example, temperature in a particular room is a Environmental Variable, and is explained as;

- Meaning (physical quantity, ... $\rightarrow$ room temperature)

Table 1. Elements of Building Operation Semantics.

Environment Var.	**BMS**	**BIM**
Physical Quantity	Device	Location Information
Aggregation Type	Object (Data Point)	Device Information
Environmental Spec.	Object Purpose List	
Further Specification		

– Source (Location Information & Device Information → data from BIM database)
– Available data (device, ... → BMS network addresses for real-time data, historic data and event triggers)
– Relations (which variable is influenced by & what is influenced by a variable)

Detailed description of BIM is explained below. The Ontology Model is based on practical experience and requirements required for the campus's BIM systems. The BIM at campus integrates 200 buildings 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].

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.

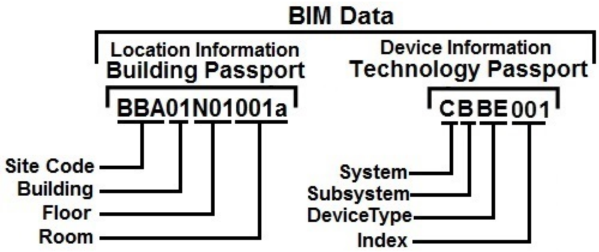


Fig. 1. Identification codes used in BIM and BMS.

3.1 Semantic Web and Complex Data

The complex data used in BIM systems, is analyzed to construct Ontology Model. The Ontology Model is constructed in Protege 4.3 tool. BIM system is using different conventions for a single device installed in a room. Therefore, each of the related information, used in BIM, is integrated with each other. The information used for integration is the Location Information and Device Information. After integrated different concepts used in BIM system, the common data is gathered from the system. 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 BIM, provides a complete view of various devices used in all buildings and also contributes in grouping variety of available data, for analysis.

3.2 Ontology Construction

The common data is analyzed to construct concepts for Ontology Model. Based on BIM systems' data, it is decided to keep it as a one concept. Therefore, the BIM taxonomy is extended to two concepts i.e. BP taxonomy and TP taxonomy and categorized according to Room, Floor, Building and Sitecode for BP and System, Sub-system, Device Type and Index No. for TP, 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.

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 BIM system; 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 an identifier is used as concept. The predicates are assigned to link the identifier with other concepts accordingly. The single identifierused for BIM system is "*BIMIdentifier*", as shown in figure 3. This identifier is populated according to total number of Location Information in buildings and total number of active 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), as shown in figure 3.

Analyzing common data and defining concepts provides an overview of Ontology Model. Relationships between the concepts define logical association of entities in 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 BIM.

3.3 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 BIM is populated at Root level Ontology, but the relations between instances of BIM 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. Hierarchy is used for Ontology Model, which depends on analysis of relevant concepts in terms of entities and integrated data of 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.

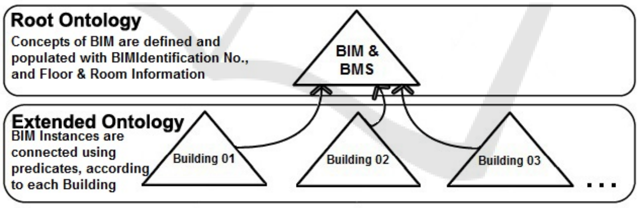


Fig. 2. Overview: Levels of Ontologies.

4 Scenarios

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.

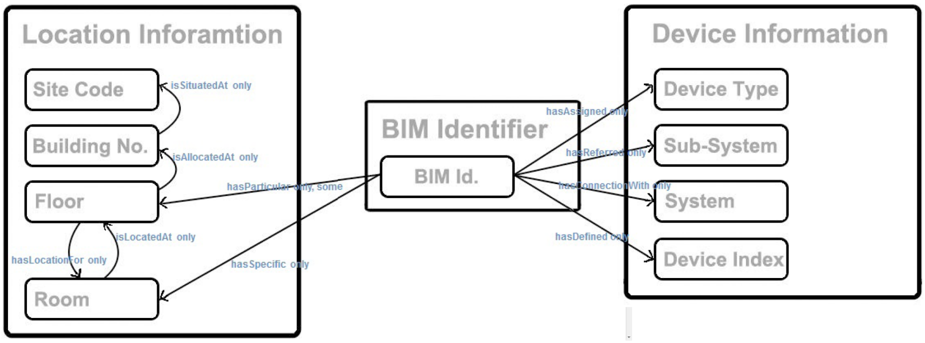


Fig. 3. Root Ontology Model.

Facility managers also requires 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.

5 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.

Selecting List of Devices. Using following logic; list of devices is selected, through SPARQL query, which is installed in a room. In figure 4, complete information of room, i.e. BBA01N01001a, is provided at extended level of ontology, to search for deivices that are installed in that perticular room. The figure 4 shows that only room and floor information is provided in the query, this is because, as shown in figure 2, query is applied at the specific Sitecode and Building. Therefore, the query is applied at extended level. The results of the query are shown in figure 5. If it is required to search the Sitecode and Building then the Onology is selected through application and the smilar SPARQL query is applied to other Buildings and Sitecode.

Identifier (?ID) $\wedge$ *hasSpecific (?ID, ?Room)* $\wedge$ *isEquipedWith(?Room, ?DeviceType)* $\wedge$ *hasPerticular (?ID, ? Floor)* $\wedge$ *isAllocatedAt (?Floor, ?Building)* $\wedge$ *isSitutatedAt (?Building, ?SiteCode)* $\rightarrow$ *hasAssigned(?ID, ?DeviceType)*

Selecting List of Rooms. Described use cases facilitate facility manager's requirements. The Ontology Model filters all rooms, which are queried according to device

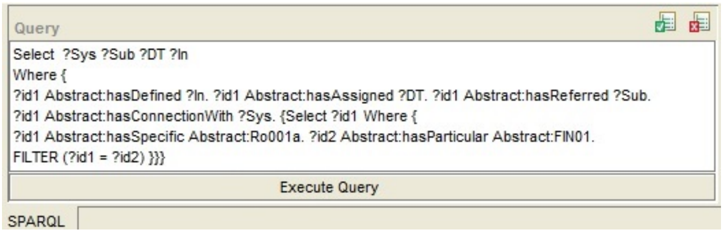
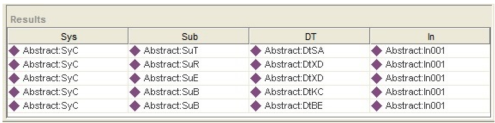


Fig. 4. SPARQL query for Selecting List of Devices.



Results

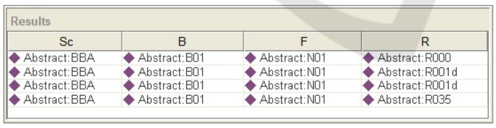
Sys	Sub	DT	In
Abstract:SyC	Abstract:SuT	Abstract:DtSA	Abstract:In001
Abstract:SyC	Abstract:SuR	Abstract:DtXD	Abstract:In001
Abstract:SyC	Abstract:SuE	Abstract:DtXD	Abstract:In001
Abstract:SyC	Abstract:SuB	Abstract:DtKC	Abstract:In001
Abstract:SyC	Abstract:SuB	Abstract:DtBE	Abstract:In001

Fig. 5. Results of SPARQL - List of Devices.

information. A list of rooms is selected and sent to facility manager, according to complete room information. For filtering required information, following logic is used to create the query, as shown in figure 6.

Identifier (?ID) ∧ hasAssigned (?ID, ?DeviceType) ∧ hasConnectionWith (?ID, ?System) ∧ hasReferred (?ID, ?SubSystem) ∧ isEquipedWith (?Room, ? DeviceType) → hasSpecific (?ID, ?Room)

Fig. 6. SPARQL query for Selecting List of Rooms.



Results

Sc	B	F	R
Abstract:BBA	Abstract:B01	Abstract:N01	Abstract:R000
Abstract:BBA	Abstract:B01	Abstract:N01	Abstract:R001d
Abstract:BBA	Abstract:B01	Abstract:N01	Abstract:R001d
Abstract:BBA	Abstract:B01	Abstract:N01	Abstract:R035

Fig. 7. Results of SPARQL - List of Rooms.

According to the scenario; for example, a building operator search for a list of room that has Device Type SK connected with System C and Sub-System F. Therefore, she has to provide the device information in SPARQL query, as shown in figure 5. Initially the query selects all those identifiers who has Device Type SK, System C and Sub-System F, therefore a long list of identifiers is selected. In second step, pattern matching process is performed. Therefore initially, the identifiers of Device Type SK having Sub-System F are filtered. Then the resultant identifiers from Device Type SK and Sub-System F are filtered according to System C. The identifiers other than System C are removed from filtered list. At this point, all those identifiers are listed, whose System is C, Sub-System is F and Device Type is SK. Finally, according to the filtered list of identifiers, complete information of Room is selected according to Site Code, Building Number, Floor and Room information.

Figure 7, describes results of above defined query. The query is applied on Semantic Model of one building i.e. BBA at Extended Level of Ontology. The results explains that the queried device, which is connected to System C and Sub-System F, and is actively functioning at three rooms of the building. The results also describes that two of the devices are installed in one room, i.e. the room R001d, shown in figure 1, is at Floor N01, Building 01 and Site Code BBA. The complete location address of the room is BBA01N01001d, this address is understandable by end-users at campus.

Selecting List of Rooms using Device Index. Using the Device Index in SPARQL, as shown in figure 8, it is quit clear from the results of the SPARQL query, as shown in figure 9, that room information is displayed once where the device is installed. In section "Selecting List of Rooms" the room "BBA01N01001d" is displayed twice in the SPARQL query result, in figure 7. This difference explains that when Facility Managers need to know that a specific device, according to device index, is installed in how many rooms then the SPARQL query shown in figure 8 is used, otherwise to know how many rooms have the devices (i.e. CFSK) are activly working then SPARQL query shown in figure 6 is used.

Identifier (?ID) ∧ hasDefined (?ID, ?DeviceIndex) ∧ hasAssigned (?ID, ?DeviceType) ∧ hasConnectionWith (?ID, ?System) ∧ hasReferred (?ID, ?SubSystem) ∧ isEquipedWith (?Room, ? DeviceType) → hasSpecific (?ID, ?Room)

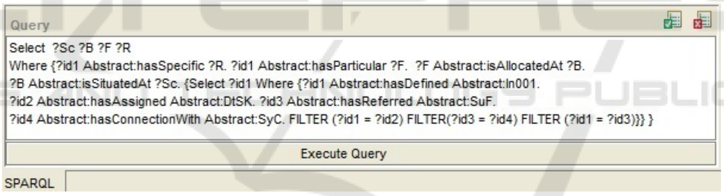
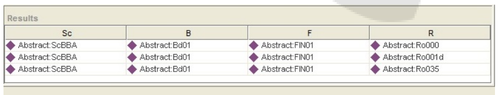


Fig. 8. SPARQL query for Selecting List of Devices.



Results

Sc	B	F	R
Abstract:ScBBA	Abstract:Bd01	Abstract:FIN01	Abstract:Ro000
Abstract:ScBBA	Abstract:Bd01	Abstract:FIN01	Abstract:Ro001d
Abstract:ScBBA	Abstract:Bd01	Abstract:FIN01	Abstract:Ro035

Fig. 9. Results of SPARQL - List of Devices.

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.

6 Conclusion

This article focuses on FM and explains the integration of BIM system. The proposed approach addresses the Semantic Technology used for BIM. Therefore, facility managers are able to perform operation analysis in large-scale environments. The designed ontology covers the concepts of BIM, used for Location Information and Device Information. 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 BIM and 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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