LIVE BIM FOR CAPTURING DYNAMISM OF PHYSICAL SPACES, OCCUPANTS AND ASSETS THROUGH LINKED DATA

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ABSTRACT

Efforts are being made by researchers and practitioners to realize the true definition of BIM (Building Information Model/Modelling). With an emphasis on the information (than the geometry representation), spatial relations and contextual information derived from BIM can aid users to better understand spaces and assets in the building. Data-infused BIM (aka live BIM) tries to capture the dynamism of the building (related to occupants, environment, physical systems, etc.) and use it for better decision making during the operation phase. This requires heterogeneous data coming from different sources to provide the live status of building systems and occupants. This paper investigates the system requirements for asset management of HVAC (Heating, ventilation, and air conditioning) systems in buildings using live BIM and linked data through the semantic web.

INTRODUCTION

The operation phase of an asset is the longest period of a building's project lifespan. There are three types of assets: property assets, fixed assets and movable assets (Service Works Global n.d.); Fixed assets are important for organizations and especially assets such as HVAC (Heating, ventilation, and air conditioning) are big contributors to building expenses in operational phase(such as maintenance and energy). Standards are widely used to achieve the intended outcome through effective management of assets. For example, ISO5500 standard was the first, and one of the most widely used international standards designed for asset management through Asset Information Modeling (AIM). Some of the other widely used standards are Total asset management (TAM), Life Cycle Asset Management (LCAM) and Enterprise Asset Management (EAM) [5]. BIM and linked data (structured data which is interlinked with other data) could act as enablers of asset management in the building. For this purpose, BIM must be enriched with operation information along with retaining a connection to other information sources through linked data. This can lead to broader adoption of AIM and creating an ecosystem of shared information that asset managers can use for decision making.

In this paper, we intend to develop a set of requirements that can aid in realizing live BIM, which aids facility managers, asset managers and specially BIM managers in real-time for decision making during the operation phase. To achieve this goal, a clear set of data requirement needs to be identified for the system. The PAS 1192-3 specification is similar but does not look at the real-time asset management system. The proposed set of requirements attempts to enable provision for real-time status of occupants and assets within physical spaces and allow further use of information for tasks such as data analysis, diagnostics and autonomous control. This live BIM, linked data-enabled system will create a data-infused BIM by allowing information to be captured and reported back to BIM. The use case selected in this study is the management of HVAC systems and sub-system assets in a building during the operation phase. Presently the information in BIM does not reflect the current status and hence is not being utilized for asset management; This paper investigates the asset information required as its objective in order to have a live BIM representing the current status of the building, assets and occupants that can be further be used for different organizational requirements. The scope of this investigation is set for asset management of the HVAC system for BIM managers but can be modified to be used for other use cases.

BACKGROUND

While BIM has been extensively adopted during the design and construction stages, its penetration to the operation phase has been much more limited as shown in Figure 1. Live BIM intends to upgrade the BIM to a living digital twin of the building that consists of building information in the entire lifespan of the building. In order to create live BIM, sensory data (i.e., measured data, collected by sensors) or real-time repositories (i.e., BAS system) can be used to represent the current 'state' of the facility. The information is usually stored in BIM-specific data standard formats. The most famous one is IFC (Industry Foundation Classes) and COBie, which is the IFC MVD (Model View Definition) used for operation and maintenance information of buildings.

The concept of 'linked data' is closely tied to 'semantic web,' i.e., the web of data, as well as technologies such as RDF (Resource Description Framework), OWL (Web Ontology Language), SPARQL (Simple Protocol and RFD Query Language) which are the semantic web enablers. Linked data defines the relationships among data that are readable and accessible by semantic web tools. These interrelated datasets on the web are known as linked data ("Data - W3C" n.d.). Achieving linked data has three requirements: (1) URIs (Uniform Resource Identifiers), (2) RDF (triples linking one object to another) and (3) HTTP (Hypertext Transfer Protocol). This combination enables each entity to be uniquely identified by a URI and be related using RDF triples associations that ultimately bring the data model together uniformly so that they can be accessed by HTTP protocol that enables access to the desired entity.

The applications that can utilize linked data can follow the RDF links by accessing them through their unique identifiers. Accessing the entity description in return can potentially allow the discovery of additional linked data sources. The server hosting such data responds to requests through RDF schema or OWL definitions (Liu and Özsu 2018). In the literature, linked data is used for energy intelligence use cases where the linked data cloud forms a rich knowledge base and semantics about the building, building-related performance indicators, and other contextual data (Curry et al. 2013).

Asset management and facility management are often used interchangeably and have their standards. In this study, based on ISO 5500, we consider facility management as a sub-part of asset management.

Moreover, we use the ISO 5500 standard definition, which states that asset management involves the balancing of costs, opportunities and risks against the desired performance of assets to achieve the organizational objectives. Asset management does not focus on the physical assets alone; but the value that they can provide to an organization. In this study, we look at the physical assets, occupants, and the spaces they occupy.

The asset management system is created to support the following features (asset performance guidelines – practice notes" n.d.):

Inventory and condition ratings/performance measurement. Deterioration prediction features: and how and when to spend money to maintain/preserve the condition.

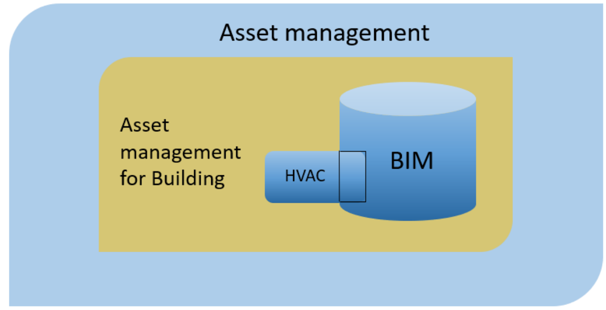

Figure 1 BIM based asset management of HVAC

REQUIREMENTS OF LIVE BIM TO SUPPORT BUILDING ASSETS (CASE OF HVAC)

Buildings have several components that need regular inspection and evaluation; this makes the building a very challenging asset to manage (Hegazy et al. 2012). HVAC is one of the primary building systems and accounts for 40% of the energy consumption in commercial buildings ("Annual Energy Outlook 2017" 2016).

The use of BIM for asset management has recently been explored by researchers (Heaton 2019a; b; Kivits and Furneaux 2013; Pärn and Edwards 2017, among others). It is found that BIM can support the stakeholders, including the facility managers and operation crew, as it holds the information across all stages and hence can be utilized for better decision making.

The ability of BIM to track changes in building such as state of HVAC components can be used for maintenance and upkeep of the facility. For this purpose, the frequency of tracking should be limited to avoid overwhelming the BIM with non-value-adding data.

The performance of assets can be influenced by several external factors such as weather conditions, location of the building, type of energy supply, etc. BIM managers can look at the historical performance of assets and adopt different methods of monitoring and prepare different intervention strategies (Service Works Global n.d.).

Creating the proposed live BIM that can support the physical spaces, occupants and environments, could be looked at two levels to support the information systems. At the first level, the information that is determined by the organization which requires unification, and the second level, the linked data that can be brought in for specific use cases without overwhelming the BIM. This means, for example, when asset management makes changes to organizational objectives, the required knowledge can be brought into BIM by being connected to required information that can support the use cases.

ASSET INFORMATION REQUIREMENTS FOR BIM TO SUPPORT LIVE STATUS OF HVAC

A set of requirements is proposed by reviewing the literature so that BIM can support HVAC system status for asset management and further being extensible by utilizing linked data.

Organizational Objective Identification:
Objectives for asset management should be set and the departments taking part should be identified. The objectives are desired to be set during the design and construction stages, as implementing the objective at later stages normally makes the implementation more difficult (Heaton 2019a).

Static Data:
The BIM should include the information from various disciplines, including architectural, structural, MEP (Mechanical/ Electrical/ Plumbing), site layout, and the main utility lines to the buildings. The corresponding data should contain accurate as built, as well as the complete static lifecycle information of the building.

Static data can include geometric, non-geometric and document information such as manufacturer data for building components (Becerik-Gerber et al. 2012) and also;

Dynamic Data:
The lifespan dynamic data can represent the current state of building components, spaces and occupants. This data is usually sourced automatically from sensors and cameras. In the case of asset management for HVAC systems, the data that resides in BAS (Building Automation Systems) is a trove of useful information about the building that can be leveraged to gain information (Gao and Tang 2018) about the current status of the facility which can lead to better decision making, resource management. Currently, the BIM and BAS data reside separately.

Data Frequency:
To have a live BIM without overwhelming the model itself, it is necessary to define the frequency of updating the required data that can support each function. Depending on the use case, it can span from less than a second to more than months. To support HVAC maintenance, ANSI/ASHRAE/ACCA Standard 180-2018 can be used for inspection and maintenance of the frequency of HVAC components and systems. Table 1 is an excerpt from the twenty-five equipment/systems listed in this standard, for which the intended inspection /maintenance frequencies are listed. The inspection and maintenance task can vary, and some common examples are provided in the table. The frequency can also vary from weekly to annually and similarly corresponding corrective action is mentioned.

Table 1: Excerpt from Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems from ANSI/ASHRAE/ACCA Standard 180-2018

System	Inspection	Maintenance	Frequency	Corrective action
Air handlers	Check/ Inspect /Asses	Clean/verify/correct/record/adjust/ lubricate	Quarter to annual	Repair/ replace
Boilers	Inspect /check/ observe	Clean/adjust/record	Month to annual	Repair/ replace
Pumps	Check/ Inspect	Clean/adjust/lubricate	Semiannual to annual	Repair/ replace

Data Unification and Retaining Link to Supporting Data:
The data that is frequently used to provide the current status of building components are desired to reside in BIM (using appropriate data schema) and are part of the organizational environment. On the other hand, the information that is not set as department objectives, but is deemed relevant can benefit from linked data by retaining connections to relevant data. This will allow access to related information such as energy usage, occupancy patterns if additional requirements are identified (Curry et al. 2013) this relevant data are part of the ecosystem and could be used for the organization environment. For example, data is usually messy and disconnected. JSON-LD organizes and connects it, creating a better web, connecting BIM to the online libraries of building component families (a digital supply chain) can support simulation of solution alternatives within the facility (in the case of replacement, renovation, or rehabilitation of building systems). This can help asset managers in decision making based on efficiency, sustainability or other set criteria.

PROPOSED LIVE BIM–LINKED DATA ENABLED MODEL

Figure 2 depicts the proposed ecosystem that can support the live BIM, capable of capturing the dynamics of assets, spaces and occupants, and representing the 'as-is' condition of the facility. Such a model can evolve based on future organizational requirements and needs.

In the case of the HVAC asset management, the HVAC system can be considered at three levels, namely: building level, system-level, and equipment level. (Lecamwasam et al. 2012). The proposed ecosystem enriches the information from BIM, with sensory data that can realize requirements of the live BIM and is further enriched by being connected to AIM and other data, using linked data concepts. Live BIM holds the

HVAC systems geometric information and as well as the knowledge derived from the asset information in the form of an RDF repository that can be accessed by the BIM manager. The figure shows a standard model for data interchange on the web. RDF has features that facilitate data merging even if the underlying schemas differ, and it specifically supports the evolution of schemas over time without requiring all the data consumers to be changed. ("RDF - Semantic Web Standards" n.d.); this allows different ontologies to co-exist and the use of linked data will further allow the realization of different use cases that can be determined by the organizations.

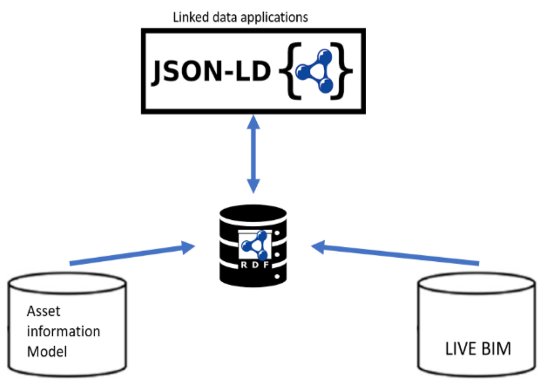

Figure 2 Live BIM-Linked data ecosystem

CASE INVESTIGATION

To develop the asset information requirements in BIM, this study attempts to investigate the minimum information required for FDD (fault detection and diagnostic) of air handling unit (AHU) and variable air volume (VAV) in an HVAC system.

AHU is the main component that is responsible for maintaining indoor air quality (IAQ) through heating and cooling (Li et al. 2019); also air handling unit's energy consumption is around 40% of total energy consumption (Dey and Dong 2016).

The experimental datasets generated by Lawrence Berkeley National Laboratory (LBNL) in LBNL's FLEXLAB test facility are intended for the evaluation of FDD technologies. ("OpenEI" 2019).

The major components of the HVAC system considered in this study are supply air fan with a variable frequency drive (VFD), cooling and heating coils, cooling and heating control valves, outdoor air (OA), return air (RA), and exhaust air (EA) dampers.

Organizational objective identification: In this case, the hypothesis is that the organization has decided to implement FDD (fault detection and diagnostic) in their building for maintenance purposes.

Data unification and retaining link to supporting data: To set up a BIM-linked data ecosystem system, initially the frequently used data (in this case, HVAC system data for the AHU and VAV and building data belonging to a test facility named FLEXLAB) are required to be unified into BIM which will be the considered as the organizational environment. This data can come from the existing building model, facility management and building automation sources. Access to related data that may be required (in this case, e.g., occupant data) will create the ecosystem intended. As implemented in the literature (Delgoshaei et al. 2017), ontologies such as FDD ontology, spatial ontology, HVAC ontology, building ontology and sensor ontology can form the semantic information model.

Dynamic data: The dynamic data in this experimental study are sourced from a data acquisition system (DAS). The data are collected for two seasons, namely winter and summer of the year 2017, which can be used further by adopting a data-driven methodology for the purpose of FDD. The knowledge derived from the analysis is sent back to BIM. The system faults investigated in the system are for either leakage or stuck position.

The type of fault that are considered in this study are as below.

Table 2: Excerpt from Experimental input scenarios included in the dataset for the AHU sub-system.

Fault No.	Fault type
F0	Un-faulted
F1	OA damper
F2	Valve of Heating Coil
F3	Valve of Cooling Coil

Static data: The BIM data are static in nature, but the intended live BIM is enriched with knowledge derived from real-time data, which represents the current and the stateful status of the building and its assets. The table below indicates the suggested static data required, which can differ depending on the building and organization requirements. There are studies that have investigated the identification and representation of facility information for FM and asset management (Yang and Ergan 2017) such information requirements can be used in addition to organization identified information.

Table 3: Data identified to satisfy organizational requirements for the AHU use case. Adapted from (Yang and Ergan 2017)

Number	Information requirements
1	Geometry
2	Spatial
3	AHU and VAV
4	Faults in AHU and VAC

5	Knowledge extracted from the data acquisition system
6	Events data (Door and window state)
7	Occupancy data
8	Maintenance
9	Reported problems
10	Operation schedule of equipment
11	Setpoints and ranges for HVAC equipment
12	Maintenance history
13	Complaints log

Data Frequency: The time step desired for the purpose of data analytics of the AHU system is usually about every minute based on literature (Li et al. 2019; Yan et al. 2020) and the experimental data were as well recorded at the one-minute interval.

Creating a live BIM and capturing the dynamism can overwhelm the BIM model where (.ifc) is the most widely adopted format for IFC in practice, and further (ifcOWL) which is a Web Ontology Language (OWL) representation of the Industry Foundation Classes (IFC) schema can increase the file size from 100% to a maximum of 1372% which translates to large file size. Even using the proposed JSON (JavaScript Object Notation) increases the file to 148% of the original (.ifc) file ("IFC Formats - buildingSMART Technical" n.d.). Hence, in order to realize live BIM without overwhelming the BIM (i.e., The IFC file), one must set the frequency of knowledge acquisition to have a live BIM representative of the current status of asset and building; we suggest the use of the ASHRAE Standard 180-2018 to set the frequency of the update, In this case, the frequency can be set in between quarterly and yearly depending on the components being looked at.

The proposed approach is a first step in the development of a live BIM-based linked data ecosystem for identifying the system requirements for capturing the dynamics of spaces, occupants and assets.

CONCLUSION

The current approaches for developing asset information requirements involve identification of requirements during the pre-planning stage and hence, these requirements can lead to unforeseen needs by BIM managers. Also, these systems are often created for specific needs and hence cannot be easily implemented for other use cases. By adopting live BIM and linked data, we can support the HVAC use case by including maintenance and upkeep information of the facility in BIM and allowing further extensibility by retaining links to other needed information to support other HVAC related objectives set by asset management or other use cases. To implement the ecosystem, it will be required to accommodate dynamic data and also a linked data environment needs to be created, which will further require interchange formats such as JSON for the creation of a linked data ecosystem. The linked data and live BIM approach can facilitate having a stateful BIM, where the dynamics of physical spaces, occupants and assets can be captured dynamically and intends to allow future modifications to the needs of organizations for use cases such as asset management of HVAC system. This study identifies the minimum requirements for the creation of the proposed ecosystem and proposes the adaptation of JSON linked data for the proposed ecosystem. The current limitation of this investigation is that in order to validate the AIM it needs to be applied in an organization with actual requirements and goals and hence the future direction of this study is implementing the requirements identified in this work to an organization with asset management requirements for the HVAC system and creating the ecosystem proposed.

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