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Using Big data Analytics for BIM enabled Facilities Management

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Abstract

Ensuring safety in facilities has always been a critical job for facility managers. Deployment of data acquisition systems can help to redure hazards such as fire, water flooding and burglaries. Building Information Modeling (BIM) is an emerging software technology that is revolutionizing the architectural, engineering and construction (AEC) industry and presents extensive solutions for facility management. In an attempt to monitor and manage buildings data, this work reports upon a system architecture that utilizes BIM and wireless sensor technology to produce a proactive safety and emergency management system. However, integrating BIM data with data readings coming from sensors motes will challenge the traditional approaches to data management and huge sensor data will contribute to the emerging paradigm of big data. In order to process this big data and extract relevant information out of it, a prototype system has been designed that collects real-time sensor data remotely from wireless sensors placed in a building. The results of processing BIM and sensor data in a big data architecture have demonstrated that proposed system can store information in support of safety and property management in a cloud-based environment and can effectively provide data reports to facility managers with the most accurate information needed to make decisions and ultimately attempts to reduce property hazards during the facility management phase of a building lifecycle.

Keywords
Building Information Modeling, Big data analytics, Facility Management, Sensors

1. Introduction

Facilities management is concerned with the management of the working environment together with the delivery of support services to that environment (Wetzel and Thabed, 2015). Through this process a large volume of relatively low value transactions takes place. Improving the delivery of facilities monitoring and management services through the use of Information and Communication technologies (ICT) has been a recurrent topic over many years (Tomašević *et al*., 2015). More recently, attention is concentrated on BIM enabled mechanisms that can make use of existing building information with real time sensory data to reduce hazards in buildings (Li *et al*., 2015).

The major hazard is facing buildings is the fire (Groner, 2016). Local authority fire and rescue services attended around 154,700 fires in England during 2014-15, out of these, approximately 28,200 were building fires that caused thousands of deaths, serious injuries and millions in property loss (Department of Communities and Local Government UK, 2015). The next most major threats to buildings are vandalism and burglary. Vandalism is the maliciously marking upon and damaging of property which can results in a great loss if the vandals cause serious problems such as fire (Lincoln, 1990). In addition, vandalized property can cost huge amount of money to the property owners for the restoration of buildings to selling condition. Burglaries and thefts also impose large costs to building occupants and during past three years in U.S. it has been observed that around 90 percent of burglary in buildings usually involves plumbing or copper electrical materials. The threat of significant damage to vacant property during winter is very real and can cost thousands of dollar to repair as well as potentially delaying new occupants from moving in. Adverse weather conditions makes susceptible to water pipes breakage in facilities due to freezing then temperature rises and water may flow for days and remain undetected because water flow alarms are either disconnected or out of service. In addition, rain water entering in the facilities can also extensively damage the structure and its contents. In order to proactively monitor a building for safety hazards, collection and integration of information from various systems in a buildings is required that will challenge the traditional approaches to data management and huge data will contribute to the emerging paradigm of big data.

The objectives of this paper are: (1) to understand Big data technology framework that is Hadoop for this paper, (2) to review current research on integrated solutions based on Building Information Modeling (BIM) and wireless sensor technology; (3) to integrate BIM and sensor data with Hadoop architecture for processing and visualizations; and (4) to validate the feasibility of the proposed solution through an initial prototype system. The proposed integration of BIM with data acquisition sensor technology using Hadoop will not only contributes to reduce the building hazards but will also help facility managers to understand the acquired data in a more better and detail manner for decision making.

2. Big Data technology framework – Hadoop

Big data is not a single technology, technique or initiative; rather it is a trend across many areas of technology (Ghazi *et al*., 2015). It refers to those initiatives and technologies that involve data that is too diverse and fast-changing. Data that is continuously being generated from machines, sensors from Internet of Things, mobile devices, network data traffic, and application logs leads to the generation of the big data (Valsamis *et al*., 2016). To analyse and correlate the data sets of this exponentially growing data, the operational facts of data like volume, velocity, variety, variability and complexity need to considered. Various dimensions as well as data streams are mined to handle and store this voluminous amount of loosely structured or unstructured data. Big Data also refers to collection of large data sets whose size is beyond ability of traditional data processing applications and other relational database management tools to process, manage and capture the whole data within the desired span of time (Garg *et al*., 2016).

Hadoop (Highly Archived Distributed Object Oriented Programming) is a Java framework technology created by Goug Cutting and Mike Cafarella in 2005 overcomes all traditional limitations of storage and computation of huge volume of data (Vijayakumar *et al*., 2015). It is very cheap, simple and easy to use. As it allows working on multiple cluster nodes simultaneously so it offers linear scalability thus reducing scalability related issues (Vijayakumar *et al.*, 2015). It helps to store, access and gain large resources from big data in a distributed fashion at high degree of fault tolerance and high scalability. It handles large number of data from different systems like images, videos, audios, files, sensor data, and much more that can be in a structure, unstructured or semi-structured format (Garg *et al*., 2016). All these information can be stored in a Hadoop cluster without any schema representation. There are many components involved in Hadoop like Avro, Chukwa, Flume, HBase, Hive, Lucene, Oozie, Pig, Sqoop and Zookeeper. In this paper, Hive is used to develop a prototype system.

3. Research Methodedology

To have broad understanding of BIM based integrated solutions for facility management, a historical perspective is taken in this paper. The initiatives from various researchers are discussed and how they differ each other are listed in Table 1. A literature review highlights some significant attempts of integrating BIM with different sensing technologies. With regard to integrated applications, the 2009`s saw attempt to gather requirements for integrating BIM and sensor technologies to create sensor based aware environments in order to automate facility operations. Integrated applications for introducing the concept of energy efficiency in buildings began appearing after 2012 as shown in Table 1. The developed management systems based on BIM and sensor technologies in last few years mainly involved energy monitoring, management and safety risk analysis of buildings using acquired building performance data. Furthermore, the emergence of the “BIM based real time energy monitoring concept” directly promoted the development of the smart buildings. However, there is very limited literature available that offer Bigdata solution in BIM and sensor based environment (Chen *et al*., 2016). After this detailed review, a system architecture for a facility monitoring and management is developed by keeping the idea to fulfil the need of Bigdata that is followed by an initial prototype development as a proof of concept (see Figure 1).

Table 1: ***Qualitative Analysis of BIM and Sensor Technology Applications for Facility Management***

Case	Introduction to a cloud-based tool for viewing, storing, and analyzing massive Building Information Models online.	Integration of (BIM) into a geographic information system (GIS)-based facilities management (FM) system.	Fire control management system using BIM environment.	BIM based facility management and building operations.	Post Occupancy Evaluation (POE) in residential buildings using BIM and sensors.
Reference	(Chen *et al*., 2016)	(Kang and Hong, 2015)	(Shiau and Chang, 2012)	(Cahill *et al*., 2012)	(Guinard *et al*., 2009)
Location	Building – Indoor	Building – Indoor	Building– Indoor	Building – Indoor	Building – Indoor and Outdoor
Purpose	To develop a BIM data center that can handles the big data of massive BIMs using multiple servers in a distributed manner and can be accessed by multiple users to concurrently submit and view BIMs online in 3D.	To propose and develop a prototype system to implement a mapping method from BIM including FM data to GIS.	Automated the control of the facilities in the buildings to provide a convenient and safe living environment.	Maintaining the synchronization of BIM with the latest building performance data.	Monitoring devices located in within the building for identifying energy consumption (gas and electricity) and thermal performance of the building fabric.
Findings	Presented a cloud-based system framework based on Bigtable and MapReduce as the data storage and processing paradigms for providing a web-based service for viewing, storing, and analyzing massive building information models (BIMs).	BIM/GIS-based information Extract, Transform, and Load (BG-ETL) architecture has been implemented that separates geometrical information from that relates to the relevant properties.	Authenticity of fire alarms has been determined using video display to prevent disturbances and panics brought by false alarms.	1-Implementations of BIM Server and Information Technology for Optimized Building Operation (ITOBO) data management systems is examined. 2-Identification of relevant Industry Foundation Class (IFC) objects to support a static data value from a sensor data source.	1-Implemented a new vision to conduct post occupancy evaluation in residential dwellings. 2-Established the core understanding of the relationship between the fabric and the building use by the integration of BIM with sensors.
Key technologies	Apache Hadoop	Geographic Information system	Fire sensors, Video cameras	Temperature and CO_2 sensors	Temperature, humidity and energy

other than BIM	(GIS)	consumption sensors

4. Prototype System Design and Implementation

After an extensive literature review and semi-structured interviews with industry experts, a prototype system was designed with four basic elements which were: (1) BIM software; (2) Sensing motes; (3) Big data technology platform and (4) Data visualization software.

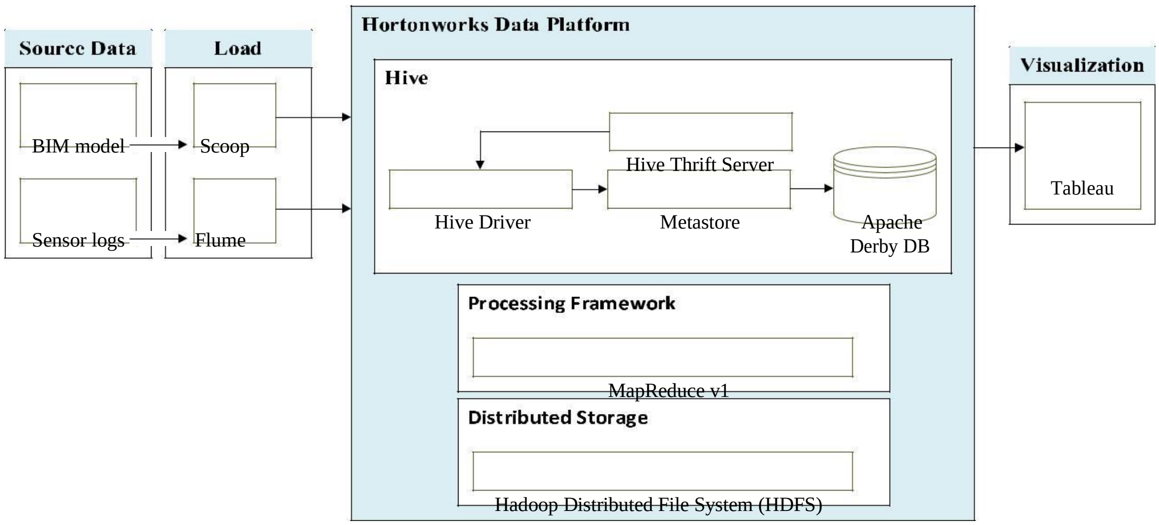

Figure 1: Hive Architecture for Data Integration and Visualization

The choice of development environment included: Autodesk Revit Architecture 2013; Crossbow`s TelosB motes for WSN, Hortonworks data platform (Sandbox) for Hadoop implementation and Tableau for data visualization (see Figure 1). Based on these essential elements, a prototype system was developed to achieve the goal of visualizing real-time sensor data of a building. The prototype system focuses on the following:

- Monitoring the temperature, activity and water sensor values using wireless sensing motes placed in different locations in a building.
- Aggregating the sensing motes values to a centralized WSN gateway mote.
- Saving the aggregated sensor values with their corresponding location identification (ID) with timestamps to system database.
- Importing as well as integrating sensor and BIM data files in Hadoop.
- Visualizing the sensor data reports in Tableau software with respect to a BIM model.

Data Acquisition and Loading

The data sensing layer consists of a network of wireless sensors that measure the environmental attributes of a physical building. Prototype system implementation consists of commercially available, open source and IEEE 802.15.4 compliant TelosB wireless sensors (motes) for real-time data acquisition. These motes need to be programmed before their deployment using a specialized programming language NesC on a TinyOS platform (operating system for TelosB motes).

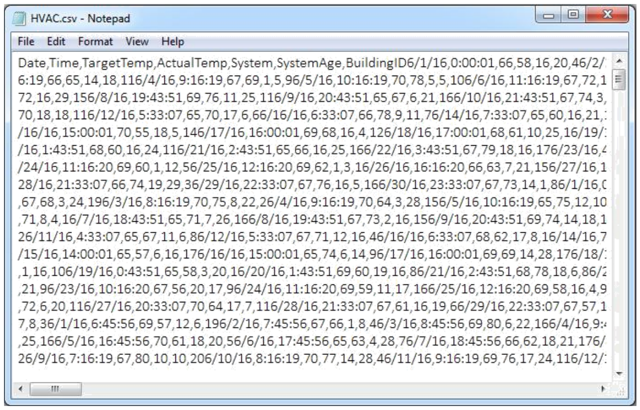

Figure 2: Sensor data CSV file

Once deployed in a facility, motes will initialize and implement operations such as neighbor discovery, data sensing, sensor data processing and sensor data transmissions. Motes are programmed to aggregate the sensor values coming from other sensing motes and forward them along with its own data to sensing gateway mote. A gateway mote is connected to a server using a standard Universal Serial Bus (USB) interface. The back-end sensor application is written in Microsoft Visual Studio 2012 (Software Development Environment) running on a server (Revit Server) to read sensing gateway mote. Sensor application is programmed to: read TelosB gateway mote; convert acquired raw sensor values in a human understandable format; and push the data to data storage layer. Figure 2 shows the sensor data file in a Comma Separated Values (CSV) format acquired from wireless sensors. Apache Flume within a Hortonworks Sandbox that is a personal, portable Apache Hadoop environment, is used to import sensor data files into Hadoop. Flume is a reliable and available service for efficiently collecting, aggregating, and moving large amounts of streaming sensor data into the Hadoop storage.

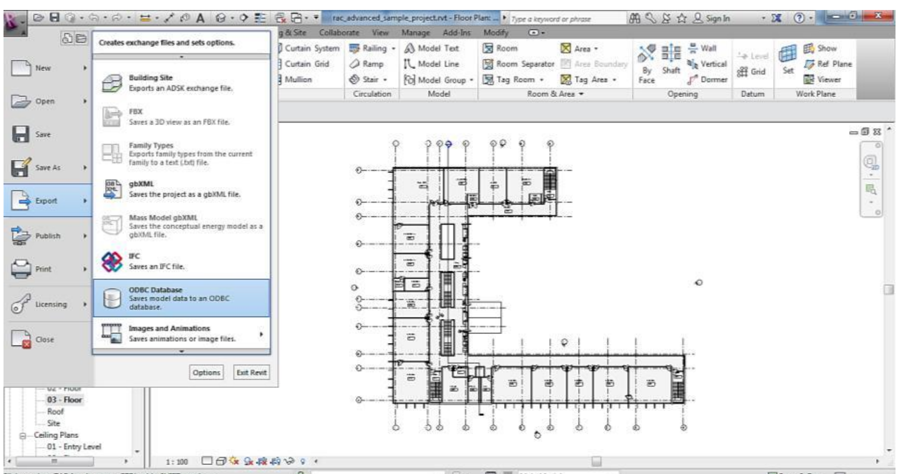

Figure 3: BIM file export from Revit using ODBC

Whereas, Apache Scoop is used to move BIM data files exported from Revit Architecture software using ODBC export feature into the Hadoop storage (see Figure 3). It is a connectivity tool for moving data from non-Hadoop data stores such as relational databases and data warehouses into Hadoop. It allows to specify the target location inside of Hadoop and instruct Sqoop to move data.

4.2 Data Processing and Analysis

Sensor and BIM data files are now loaded into Hadoop storage that is also known as HDFS. Hadoop Distributed File System (HDFS) is a base layer of Hadoop that is self-healing, fault tolerant and provides scalable, reliable and fault tolerant data storage on commodity hardware. It works closely with MapReduce by distributing storage and computation across large clusters by combining storage resources that can scale depending upon requests and queries while remaining in budget. HDFS accepts data in any format like text, images, videos, etc. regardless of architecture and automatically optimizes for high bandwidth streaming (Patnaik *et al*., 2015).Whereas, MapReduce is a software framework used in Hadoop to write applications which process and analyze large data sets such as sensor data streams in parallel on large multi node clusters of commodity hardware in a reliable manner (Patnaik *et al*., 2015).

Once loaded data files are processed in Hadoop, it has to be analyzed so that meaningful information can be extracted out of it for facility managers which can serve as decision support system. Hive is used to link sensor data streams with BIM data using unique room and building identification (IDs) (see Figure 4). Hive, an open-source solution built on top of Hadoop that supports queries expressed in a SQL-like declarative language - HiveQL, which are compiled into map-reduce jobs executed on Hadoop (Thusoo *et al*., 2009). It also includes a system catalog, Hive-Metastore, containing schemas and statistics, which is useful in data exploration and query optimization. In order to monitor data that has been processed using HiveQL scripting, a Tableau software is used to have sensor data visualizations. Tableau offers data connectivity feature with Hortonwork Sandbox using live data connection with Hadoop storage that is not feasible with conventional spreadsheets (see Figures 5 and 6).

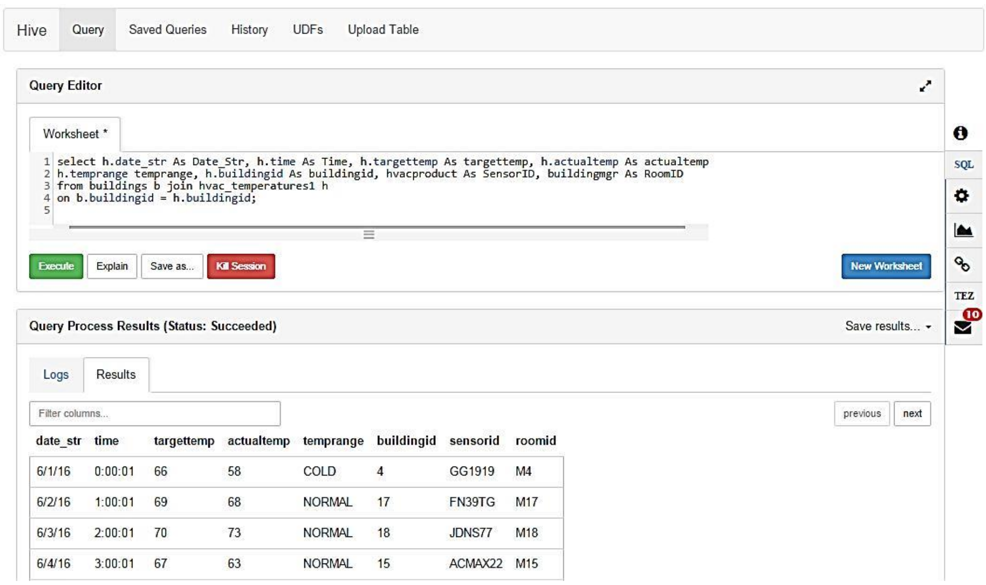

Figure 4: Sensor data loading in Hortonworks platform (Hadoop)

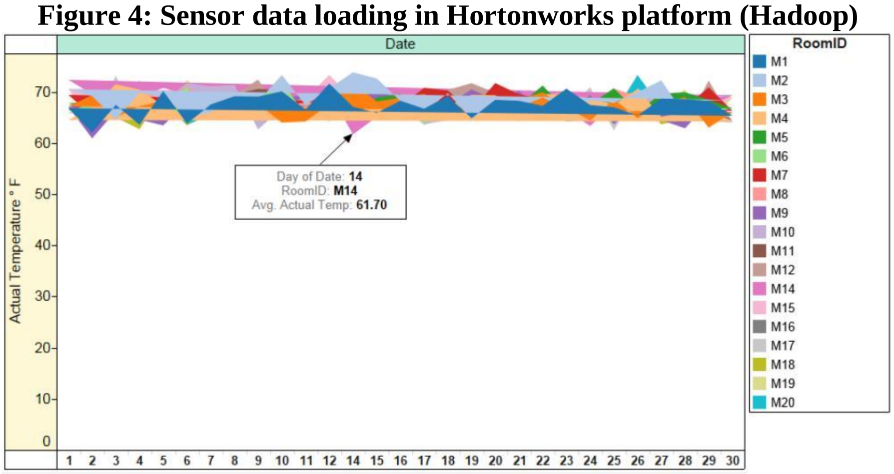

Figure 5: Sensor data visualization with respect to Room Ids.

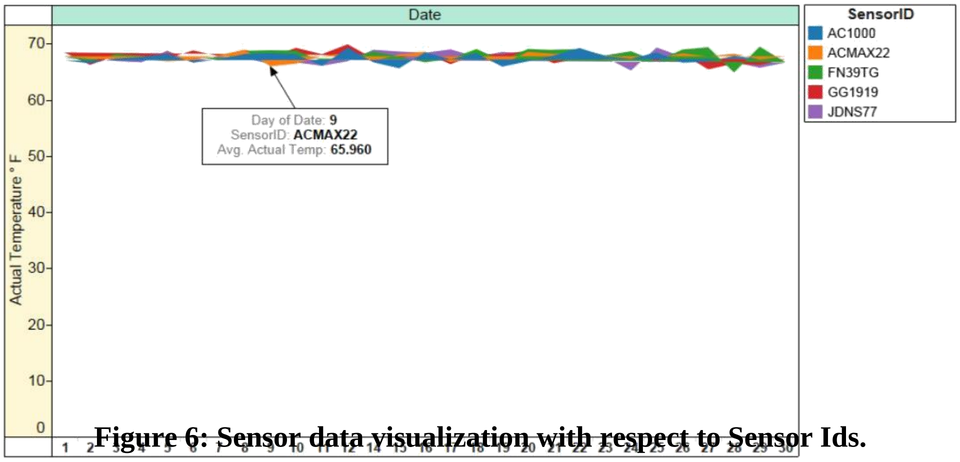

Figure 6: Sensor data visualization with respect to Sensor Ids.

Future works and Conclusion

The developed prototype application explores the integration of BIM and sensors with Hadoop architecture to gather real-time sensor data, notifies facility managers about sensor data to make decisions; and ultimately attempts to analyse sensor data using Hadoop platform to reduce building hazards during the facility management. The research has highlighted the importance of monitoring vacant buildings since vacant buildings are prone to theft and abuse more frequently. In order to address the building hazards associated, developed prototype system promotes a proactive safety management system where the information requirements of safety management of facilities can be addressed. The designed application is at initial stage of development and incorporation of other environmental and activity monitoring sensors will add more value to a designed system to reduce vacant building hazards. The next step for this research is the prototype evaluation by industry experts to find the possible barriers and utilities of developed application from construction industry perspective. This understanding will lead to drawing up user needs, gathering system requirements and eventually full system design and its evaluation.

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