Designing a Novel Smart Home Monitoring Systems with the Integration of BIM and WSN

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DESIGNING A NOVEL SMART HOME MONITORING SYSTEM WITH THE INTEGRATION OF BIM AND WSN

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ABSTRACT

In the recent years, the Building Information Modelling (BIM) has become one of the hottest research area in computer science. It attracts many researchers from huge various research domains. Not only the researchers from computer science but also researchers from environmental health, archeology and cultural heritage started working in BIM and its integration with Wireless Sensor Networks (WSN). In this paper, we focus on the integration of BIM and WSN. We tackle one of the major challenges of this integration: how to manage sensor streams by using a digital model of the environment and how to integrate sensor data with the environmental data. Even there are few studies that manage multi sensor data streaming, these approaches are often fitted to a single application and mostly they are independent from the building model. To overcome this problem, we propose a novel real-time environmental monitoring system based on the BIM principles. In this study, we present a multi-application monitoring system architecture. As a testbed environment, the university campus is preferred and for the prototype chosen offices and classrooms are equipped with sensor devices. Real data are enriched with the simulated data to get a large database. The 3D digital model introduces the numerical model of the building and a sensor integration is achieved on the given digital model.

KEYWORDS

Pervasive environment, Building information modelling, Sensor technology, Sensor integration, Wireless sensor networks

1. INTRODUCTION

We live in an era where our lives are surrounded by highly advanced technological devices. In recent years, there has been a great trend to work on the field of Building Information Modelling (BIM) and the integration of wireless sensor networks (WSN) into digital model of a building. It is considered that to build a robust smart city, a well-connected smart building has a crucial role.

Over the last few decades, popular attention to smart building has increased. Smart building and sustainability are intertwined. Since traditional buildings are primary consumers of a significant portion of energy resources, we need smart buildings that are designed based on sustainable construction standards to consume less energy than traditional buildings and to minimize their impacts on the natural environment. Thus, smart buildings became one of the major application domains of smart environments such as smart cities. Smart building technology brings in some nice features such as security, comfort and accessibility. It can also enhance the energy consumption of the buildings.

Advanced technology based smart devices form an environment (the environment we live in) in which each device may interact with the other devices and with the human. This interaction opens a new era in the technology and a research domain so called Internet of Things (IoT). It is considered as the next wave in the era of computing [Gubbi, 2013]. A generic description commonly adopted by the researchers is that the IoT is the network of objects that surround us with the understanding that information and communication systems are invisibly embedded in the environment around us. Objects may embed various sensors, actuators, UI devices, etc. This invisible network covers smart connectivity, cloud computing, context-aware computation, etc.

We spend most of our life in the buildings and enhancing living environment through the use of smart technology has a crucial role to improve the ambience in buildings and also working environments. To reduce energy consumption, management of the building (monitoring via control based wireless sensor networks and actuators) is required [Wu, 2014], even taking into account energy consumption of the monitoring system itself [Pinarer, 2017].

BIM has become a powerful technology based on an object-oriented approach, which fulfills all the functions of traditional 3D CAD/CAM techniques. With BIM technology, a virtual building model is built numerically, which can be very useful for planning, design, pre-build and post-build processes [Azhar, 2012]. The BIM is generally visible in 3D, but it also includes data that can be used by other analysis applications, such as energy consumption simulation, cost estimation, natural lighting, etc. Figure 1 from a market report presents the possible market usage of BIM.

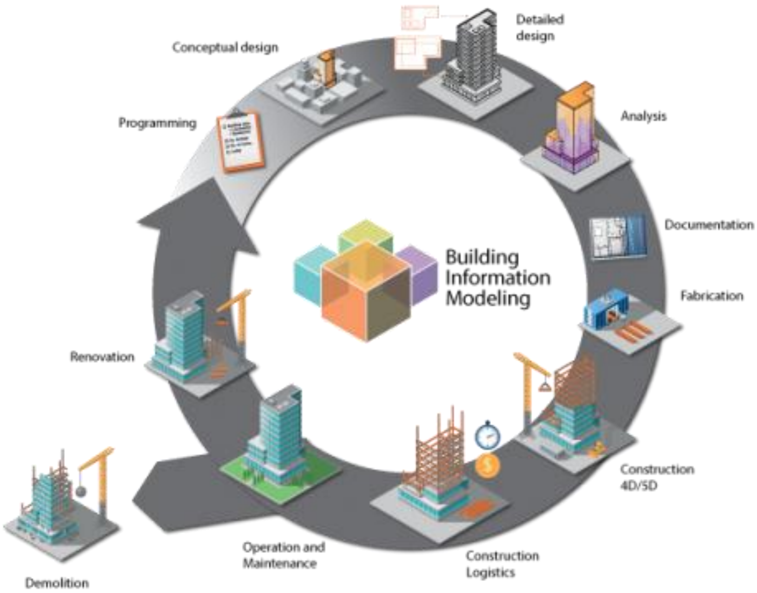

Figure 1. Product scope of BIM and Market Opportunities (Global Building Information Modeling (BIM) Market Report)

BIM is an emerging trend in the Architecture, Engineering and Construction (AEC) sector, which can be used to improve building life cycle performance and productivity throughout the design process, construction, operation and maintenance. BIM is an innovative methodology that can be used to improve the performance and productivity of an asset owner's construction, operation and maintenance processes. BIM provides a multi-collaborative platform for sharing semantic and geometric information within the project management team throughout the asset lifecycle. It allows us a standardized means of sharing and exchanging information about building data. It provides a virtual model of a building with all minor details prior to its physical construction. There are several definitions of BIM. The National Institute of Building Sciences of the United States (NIBS) defines BIM as "a digital representation of the physical and functional characteristics of an installation. [Eastman, 2011] defines BIM as a modeling technology and a set of associated processes for generating, communicating, and analyzing building models. [Isikdag, 2015] defines BIM as the digital representation of a building containing semantic information about building elements. BIM also defines an information management process based on the collaborative use of semantically rich 3D digital building models at all stages of the project and building lifecycle. A BIM is defined by its object model schema. IFC - Industry Foundation Classes is currently the most widely used BIM standard. According to [Azhar, 2012], BIM is one of the emerging developments in the architectural, engineering and construction industries.

In this study, we construct a 3D model of a building (a building of our university as a prototype) and deploy the wireless sensor devices in the offices and classrooms to acquire temperature, humidity, emission of CO_2, occupancy and luminosity data. A database system is constructed in order to register all stream sensor data into database. This database is served to other applications that require sensor data. We consider that every sensor device individually is a service provider (from the user point of view) serves physical measure (such as temperature, humidity etc.) All the deployed sensor devices are virtualized in the 3D model that called BIM. Via BIM, we can manage the locations of each sensor device. Afterwards, we developed a user interface to manage the BIM and the sensor environment. By using this interface, based on the user preferences on building-floor-room and available services in that room, a subscription to that sensor devices are made and sensor data stream is launched.

The remainder of this paper is organized as follows: related works are given in Section 2. Section 3 presents the architecture of the proposed real-time smart home monitoring system. Finally, we conclude in Section 4.

2. RELATED WORK

The literature review shows that there is a big trend on working on the integration of BIM and WSN and the existing works in this area are divided in three main sub researches: using BIM during the construction phase of a building, using BIM for the management of the smart home system and using BIM in cultural heritage.

2.1 Benefits of BIM in early stages of construction

With the recent improvements in architecture, softwares and platforms specialized in architecture are now capable of integrating other systems such as sensor networks. This gives a huge opportunity to users to manage the area even during the construction phase of the building. In such systems, the researchers benefit the sensor technology to monitor the construction environment where the field is occupied by the workers. Such systems are called environmental health where the sensor data is used to get information about the environment such as temperature, humidity etc. Although many appropriate data acquisition technologies are available and used in other sectors, applications in the construction sector are not very common [Vaha, 2013].

[Riaz, 2014] offers a solution based on WSN and BIM for environmental monitoring in confined spaces. The authors propose a prototype titled Cosmos to monitor the physical condition and safety of operators. The presented system includes a notification mechanism to alert building supervisors and the responsible to take the necessary action if needed/in case of emergency.

[Kiani, 2014] introduces a prototype system for visualization of sensor data. It is used for the real-time environmental monitoring, visualization and reporting of the construction. The study uses the standard BIM software and modifies it to view and manage sensor data in real time in its native environment.

[Lee, 2012] highlights a major problem for tower crane operators. They often operate a tower crane with blind spots. To solve this problem, video camera systems and collision avoidance systems are often deployed. However, current video camera systems do not provide accurate distance and do not include the vicinity of the crane. A collision detection system provides location information only as digital data. The authors present a tower crane navigation system providing three-dimensional information about the building and its surroundings, as well as the position of the lifted object in real time, using various sensors and a BIM. The proposed system indicates the location of an object raised in the context of a built building and its surroundings, in the manner of an automobile navigation system, indicating the location of an automobile in the context of roads and of historic buildings.

2.2 Benefits of BIM in smart building management

Besides the construction phase, BIM mainly is used in smart home monitoring and management systems. The studies in this part focus on managing sensor data flows and the integration of BIM and the actuators in the environment.

[Liu, 2009] introduces that a digital model of a building provides a useful information about the spatial context information. The authors tackle the lack of integration of sensor information and BIM. Authors declare that all information about the environment can be achieved via analyzing sensor data and integration sensor metadata to building model.

[Park, 2016] offers a tracking system. The study proposes an integrated approach that merges information from Bluetooth beacons and motion sensors, extracts map knowledge information from a BIM, and integrates aggregated sensor data with map knowledge to estimate position of a target. The tracking system consists of three main components (BLE - Bluetooth Low Energy - sensors, motion sensors and BIM). BLE sensors were used to estimate real-time position information, motion sensors were used to obtain relative motion information, and a BIM was used as a geometric constraint. The BIM used in this study can detect and correct false movements, such as moving through a wall, and viewing the BIM on a mobile device. Building geometry and object information are extracted into an XML-readable file and imported into the system. This information serves as a geometric constraint. Relevant BIM data is converted to a format compatible with a mobile device and used for real-time visualization of the model.

[Hu, 2014] focuses on the advanced lighting system. Since improper sensor placement can compromise system performance, inconvenience occupants and reduce savings, the placement and orientation of occupancy sensors and photoelectric sensors are essential in these systems. Thus, the authors present a method for automating the deployment of the detection device. Since the BIM contains a detailed geometry of building elements, the proposed system can accept sensor parameters and user constraints for sensor placement. With all entries, code compliance and performance requirements are verified. The proposed approach is an optimization in which if the solutions are found to be non-compliant, the process goes backwards to evaluate alternative solutions.

[Kim, 2012] offers an energy management system called EnerISS (System for planning and integrated urban management of energy). The platform middleware retrieves geospatial data from a GIS database and data from each sensor installed on the city and provides the browser-based client with the appropriate hosted information to display the location-specific geolocation characteristics. respective energy. The study introduces a new urban data structure model for monitoring and visualizing aggregated and real-time reports of various energy uses.

2.3 Benefits of BIM for cultural heritage

In the area of architectural risk management, many cultural heritage organizations have conducted research on methods and tools for assisting conservation planning and management decisions. Risk management can be defined as the process of identifying, assessing and analyzing potential damage or establishing a strategy to reduce damage to cultural heritage. However, the risk management of architectural heritage is more complicated due to the combination of structural instability and component degradation. Thus, new methods and tools are needed to assess, analyze and implement a damage reduction strategy for architectural heritage risk management.

[Lee, 2019] proposes a new form of metadata and a framework for Risk management using historical building information modeling (HBIM) data in a virtual environment for architectural heritage risk management is suggested. To this end, it is important to share enriched data between those who monitor and diagnose inheritance and those who recognize the context of the information.

The existing studies in the literature propose a local solution for environmental health and monitoring. However most of the proposed approaches are not at level of being prototype and are not suitable for every environment.

Besides, multi sensor data management are not handled in these studies and they are bounded by predefined building applications. Even there are few studies that manage multi sensor data streaming, these approaches are often fitted to a single monitoring application. In this study, we present a **multi-application monitoring system architecture** where multiple users are allowed to get served by multiple services.

3. ARCHITECTURE

3.1 Architecture

BIM is currently widely used in the design and engineering phases, but very little effort has been expended to consider the combination of sensor technology and BIM. A full integration of BIM and WSN is extremely required to real time smart home monitoring systems and to stay connected to the environment/ stay connected to other systems.

In this study, we construct a 3D model of a building (a building of our university as a prototype) and deploy the wireless sensor devices in the chosen offices and classrooms to acquire temperature, humidity, emission of CO_2, occupancy and luminosity data. Due to having limited electronic components, we enrich the real data with the simulated data. Thus, in database, a huge number of sampled data are obtained. A database system (using Open Source MySQL platform) is constructed in order to register all stream sensor data into database. It is a continuous sensor data streaming that each sensor device measures the physical measure periodically and sends to the sink (base station). This database is served to every application that requires sensor data. Once a database structure is well constructed, every sensor device individually becomes a service provider (from the user point of view) that serves physical measure. The architecture of our proposed system is illustrated in Figure 2.

We used Autodesk Revit software architecture platform to model the building and its environment. Since model of building gives a very detailed information about the environment, the descriptions of the deployed sensor devices and the locations are covered by the digital model as well. Thus, the XML file (export the model as a XML file) gives all the relevant information about the sensors. A XML parser is developed in Python 3 to read that file and understand the information about the sensor devices such as which sensor devices are located in which room, which services are available from each sensor etc.

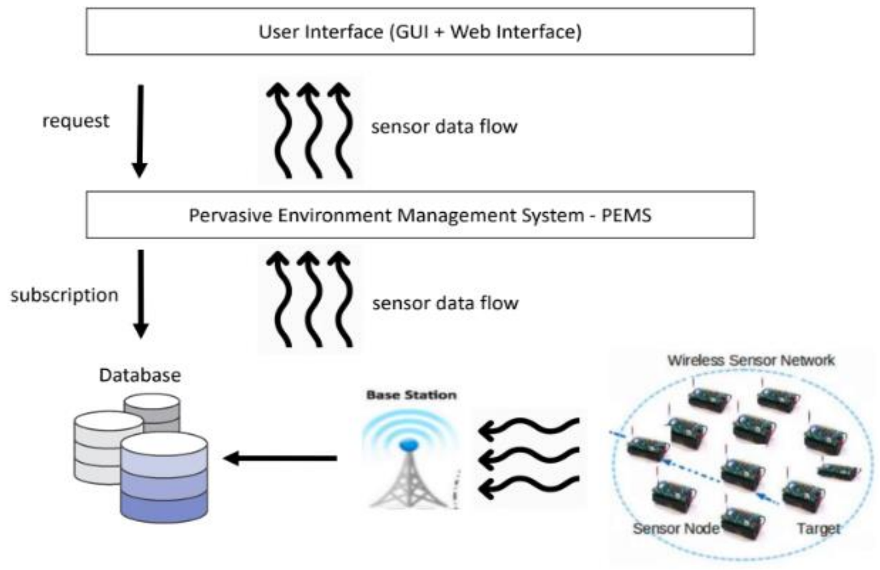

Figure 2. Architecture of The Proposed System

3.2 Hardware Setup and Implementation

For a prototype, chosen offices and classrooms are equipped with ESP8266 and relevant sensor devices. As sensor devices, temperature, humidity, emission of CO2, presence and luminosity sensors are used. The acquired data is sent to the base station via ESP8266 wifi module (by using MQTT). Another ESP8266 stands for a base station and gather all acquired data from all the sensor devices. Through a serial port, sampled and sent data are inserted to the database. Instead of using commercial sensor devices, we prefer to build our own electronic circuits to avoid having hardware constraints.

All the deployed sensor devices are virtualized in the 3D model that called the BIM. Via the BIM, the users are not obliged to have knowledge about the sensors or their locations. A user simply chooses the building-floor and the room form where he wants to get information (physical condition). Once the user submits his preferences, system based on the BIM and the sensor data stored in the model, proposes the available services from that room. Finally, the user chooses the available services from the list and the system makes the subscription to the chosen services. Here, the subscription stands for the retrieving the sensor stream data that goes to database in actual condition. The samples from the developed user interface (in Python 3) are represented in Figure 3.

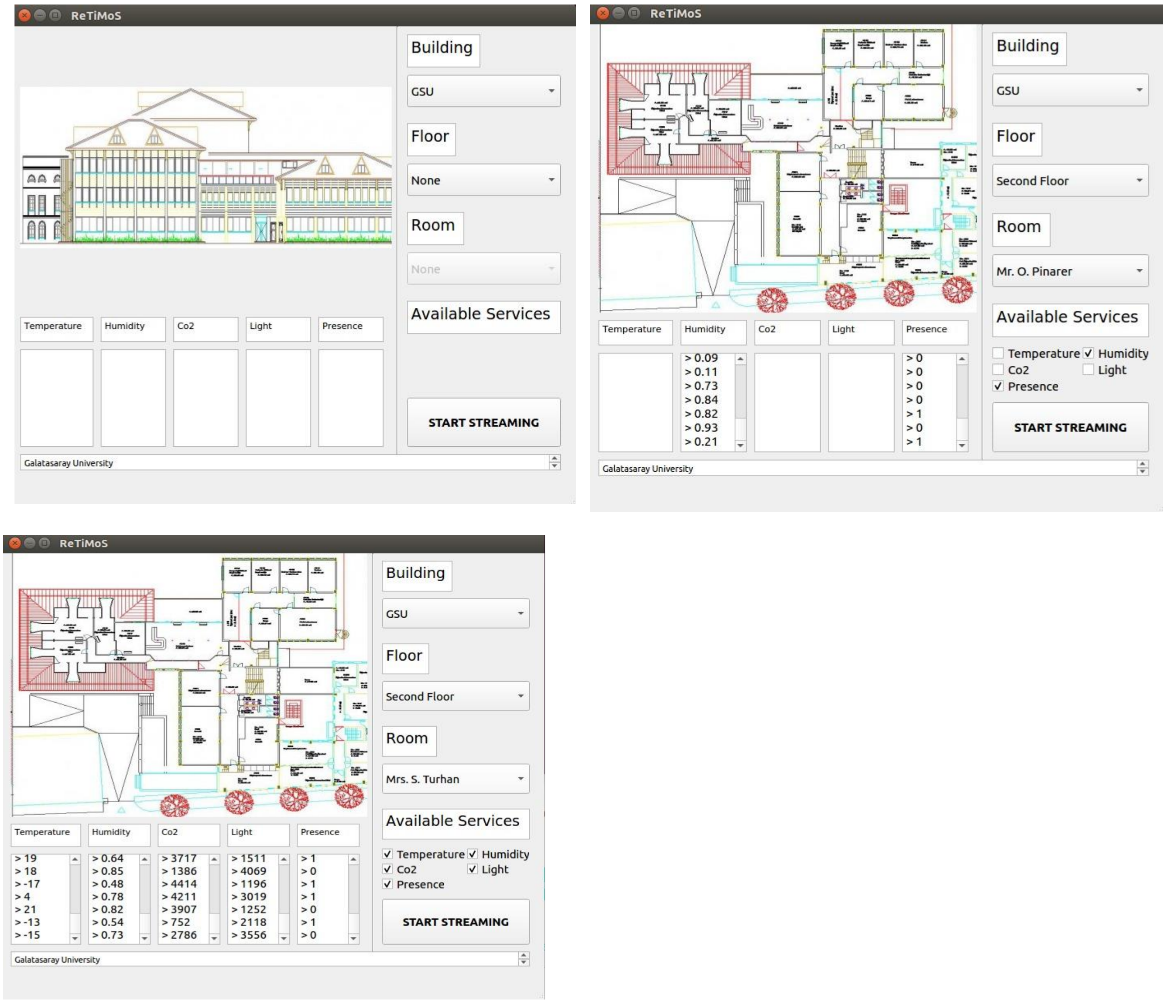

Figure 3. a. Choosing a building from the list. b. After choosing the building and a floor, a reliable plan of the floor is fetched to present the rooms on that floor. In the chosen room, presence and humidity services are available. c. Streaming data from the chosen services

4. CONCLUSION AND DISCUSSION

In this paper, we point at a major challenge of smart building monitoring systems: using the 3D model of the building to manage sensor network for real time monitoring systems. Here, we focus on the integration of BIM and WSN in smart home environments and connected systems. By relying on declarative PEMS principles, we present a sustainable declarative monitoring architecture to process massive raw data from sensors assisted by digital model of the building. In the further phases of this study, we are planning to integrate a continuous query structure to retrieve sensor stream data to fulfill user requirements successfully. Besides, the researchers in this domain have difficulties to find a working physical testbeds to run and test their approaches, algorithms. We are working on converting our system in a public testbed where users can connect remotely and deploy their novel approaches.

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REFERENCES

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modelling (BIM): now and beyond. Construction Economics and Building, 12(4), 15-28.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future generation computer systems, 29(7), 1645-1660.

Hu, J., & Patel, M. (2014). Optimized Selection and Placement of Sensors using Building Information Models (BIM). In IES Annual Conference.

Isikdag, U. (2015). Building Information Models: An Introduction. In Enhanced Building Information Models (pp. 1-12). Springer, Cham.

Kiani, A., Salman, A., & Riaz, Z. (2014). Real-time environmental monitoring, visualization, and notification system for construction H&S management. Journal of Information Technology in Construction, 19, 72-91.

Kim, S. A., Shin, D., Choe, Y., Seibert, T., & Walz, S. P. (2012). Integrated energy monitoring and visualization system for Smart Green City development: Designing a spatial information integrated energy monitoring model in the context of massive data management on a web based platform. Automation in Construction, 22, 51-59.

Lee, G., Cho, J., Ham, S., Lee, T., Lee, G., Yun, S. H., & Yang, H. J. (2012). A BIM-and sensor-based tower crane navigation system for blind lifts. Automation in construction, 26, 1-10.

Lee, J., Kim, J., Ahn, J., & Woo, W. (2019). Context-aware risk management for architectural heritage using historic building information modeling and virtual reality. Journal of Cultural Heritage.

Liu, X. & Akinci, B. (2009). Requirements and evaluation of standards for integration of sensor data with building information models. In Computing in Civil Engineering (2009) (pp. 95–104).

Park, J., Cho, Y. K., & Ahn, C. R. (2016). A wireless tracking system integrated with bim for indoor construction applications. In Construction Research Congress 2016 (pp. 2660–2668).

Pinarer O., Gripay Y., Servigne S., Ozgovde A.& Baskurt A. (2017). Dynamic energy-aware sensor configuration in multi-application monitoring systems. Pervasive and Mobile Computing, vol. 41, pp. 192-204.

Riaz, Z., Arslan, M., Kiani, A. K., & Azhar, S. (2014). Cosmos: A bim and wireless sensor based integrated solution for worker safety in confined spaces. Automation in construction, 45, 96–106.

Vähä, P., Heikkilä, T., Kilpeläinen, P., Järviluoma, M., & Gambao, E. (2013). Extending automation of building construction—survey on potential sensor technologies and robotic applications. Automation in Construction, 36, 168–178.

Wu, W., Yang, X., & Fan, Q. (2014). Gis-bim based virtual facility energy assessment(vfea)—framework development and use case of california state university, fresno. In Computing in Civil and Building Engineering (2014)(pp. 339–346).