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Economic application of structural health monitoring and internet of things in efficiency of building information modeling

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Abstract. One of the powerful data management tools is Building Information Modeling (BIM) which operates through obtaining, recalling, sharing, sorting and sorting data and supplying a digital environment of them. Employing SHM, a BIM in monitoring systems, would be an efficient method to address their data management problems and consequently optimize the economic aspects of buildings. The recording of SHM data is an effective way for engineers, facility managers and owners which make the BIM dynamic through the provision of updated information regarding the occurring state and health of different sections of the building. On the other hand, digital transformation is a continuous challenge in construction. In a cloud-based BIM platform, environmental and localization data are integrated which shape the Internet-of-Things (IoT) method. In order to improve work productivity, living comfort, and entertainment, the IoT has been growingly utilized in several products (such as wearables, smart homes). However, investigations confronting the integration of these two technologies (BIM and IoT) remain inadequate and solely focus upon the automatic transmission of sensor information to BIM models. Therefore, in this composition, the use of BIM based on SHM and IOT is reviewed and the economic application is considered.

Keywords: Building Information Modeling (BIM); SHM; IOT; sensor; network

1. Introduction

BIM technology is an economic application for operation and maintenance stages of the building integrated with professionals in charge of the management, administration and maintenance. In an intelligent building, the project should facilitate the maintenance operations of its constructive elements and spaces throughout the life cycle of the building. Some features of BIM technology are fundamental in intelligent buildings (Ismail *et al*. 2015, Zhao *et al*. 2019, 2020a, b). A BIM model of a building is a digital representation, with geometric 3D features associated with the other functional features of the elements, in a single model with centralized and integrated information.

The events associated with the increasing collapse of buildings have led to common concerns in recent years. Therefore, structural management, modeling and monitoring have supplied means to identify defects in the structure earlier on. The aforementioned are activities established in the broader discipline of Structural Health Monitoring (SHM), which utilize engineering and scientific and basics in order to prevent damages to property and life. Nevertheless, in regards to the development of measures to effectively surveil the structural change process, the domain of Construction Informatics (CI) pivots upon the conveyance of construction information, information processing activities and visualization, and has extended a practicable approach to address this obstacle.

CI includes technology and computer science fields, Integrated Information Systems (IISs), and system analysis engineering, and since the 1970s they have been employed for purposes of information exchange, and data acquisition and processing. The burgeoning of automatic data acquisition technologies, such as but not limited to Radio Frequency Identification (RFID) and sensor technologies, in the 2000s has enabled the institution of Construction Information Systems (CISs) and Decision Support Systems (DSSs) alongside revitalizing structural management and monitoring.

The expeditious growth and broad use of CI have improved management effectiveness and efficiency and considerably increased the industry of building monitoring.

Although a majority of CI based information systems have particularly been conceived to handle the building

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construction process, only a small number of them employ SHM methods, some of the other scholars like Ashton suggested a hopeful framework for promoting industrial economic applications and systems (IoT). Significant progress, especially in recent years, has been realized in salient IoT technologies such as but not limited to intelligent computing, sensor networks and sensor technologies. The deployment of IoT devices is facilitated by these technologies in the building environment for SHM economic applications such as Early Warning Systems (EWSs).

Different types and shapes of concrete are available such as self-consolidating, porous, high strength, lightweight and green concrete. There are two major properties defined for concrete, including fresh and hardened properties (Alabduljabbar *et al*. 2020, Alaskar *et al*. 2020a, b, c). The most primitive properties of concrete such as slump and workability are the fresh properties. However, hardened properties refer to the essential factors like shear strength, flexural strength, compressive strength and corrosion resistance (Alyousef *et al*. 2020, Cao *et al*. 2020a, b, c, d). Several methods have been considered to improve these properties including; the inclusion of fibres, surface protection and cementitious replacement powders (Shariati *et al*. 2010, 2011a-d, 2014, 2016, 2018, Hamidian *et al*. 2011, Sinaei *et al*. 2011, Mohammadhassani *et al*. 2014a, b, c, Arabnejad Khanouki *et al*. 2016, Toghroli *et al*. 2017, 2018b, 2020, Heydari and Shariati 2018, Nosrati *et al*. 2018, Ziaei-Nia *et al*. 2018, Li *et al*. 2019, Luo *et al*. 2019, Safa *et al*. 2019, Sajedi and Shariati 2019, Suhatril *et al*. 2019, Trung *et al*. 2019b, Xie *et al*. 2019, Afshar *et al*. 2020, Naghipour *et al*. 2020a, Yan *et al*. 2020a-i).

Experimental data can be employed for data prediction instead of time-consuming tests (Mutlib *et al*. 2016a, b, 2018). In recent years, various techniques have been used for this purpose, such as artificial neural networks. Extreme learning machine, neural network, genetic programming and other functional networks are applied to predict and validate the experimental data. Moreover, finite element method is one of the reliable ways, which is utilized by researchers for response prediction (Arabnejad Khanouki *et al*. 2011, Daie *et al*. 2011, Sinaei *et al*. 2012, Mohammadhassani *et al*. 2013, 2014b, 2015, Toghroli *et al*. 2014, 2016, 2018a, Toghroli 2015, Mansouri *et al*. 2016, 2019, Safa *et al*. 2016, 2020, Sadeghipour Chahnasir *et al*. 2018, Sari *et al*. 2018, Sedghi *et al*. 2018, Katebi *et al*. 2019, Shariati *et al*. 2019b-g, 2020a-i, Trung *et al*. 2019a, Xu *et al*. 2019, Armaghani *et al*. 2020, Qi 2020).

Dynamic response of structures has been investigated by several studies. Besides, full-cyclic, half cyclic, reversed cyclic, and shack table experiments have been used for structural behaviour assessments (Arabnejad Khanouki *et al*. 2010, Jalali *et al*. 2012, Shariati *et al*. 2012c, d, 2013, 2017, 2018, 2019a, 2020a, i, Khorami *et al*. 2017a, b, Zandi *et al*. 2018, Milovancevic *et al*. 2019).

Various kinds of formed steel have been used in construction economic applications such as cold and hot-formed types. Cold-formed steel sections are considered for storage economic applications and industrial purposes. In this regard, steel racking and upright-beam systems are utilized in recent studies, and their effectiveness has been proved (Shah *et al*. 2015, 2016a, b, c, Chen *et al*. 2019, Naghipour *et al*. 2020b).

Shear connectors are one of the principal parts of the composite systems, which can enhance the shear strength and load transmitting potential of the composite structures. The performance of connectors could be affected by elevated temperatures. Therefore, various papers have studied the effect of high temperatures on strength loss of connectors (Shariati *et al*. 2011c, 2012a-e, 2015, 2020c, Shariati 2013, 2014, Khorramian *et al*. 2015, 2017, Shahabi *et al*. 2016a, b, Tahmasbi *et al*. 2016, Hosseinpour *et al*. 2018, Ismail *et al*. 2018, Nasrollahi *et al*. 2018, Paknahad *et al*. 2018, Wei *et al*. 2018, Davoodnabi *et al*. 2019, Razavian *et al*. 2020).

IoT-based economic applications possess the ability to not only advance the entirety of the structural monitoring process, management and modeling but also to support the implementation of sustainable decision making and early warning.

Hence, in this paper, a recapitulation of Building Information Modeling centered upon SHM and IOT is provided.

2. Related works

Napolitano *et al*. (2018) evaluated visualization methods in this area, identified existing defects, and developed a novel method for the obtaining and visualization of SHM data and metadata in 3D. They also indicated a technique and digital workflow to integrate the SHM data, meta data, and sensor networks into a virtual reality environment through incorporating informational modeling and spherical imaging. Kang *et al*. (2018) discovered a neoteric monitoring framework based on IoT and BIM Technology. In the recommended structure, BIM has been employed to keep the three-dimension data of the building, whereas influx DB, a time-series database, has been provided for purposes pertaining to the monitoring of data storage. Subsequently, cost-effective and reliable communication was provided by a monitoring server based on protocol of ‘Message queuing telemetry transport’. Evaluating the advanced system and corresponding IoT sensors indicated that incorporation BIM and IoT technology supplies a holistic outlook of buildings status and enhances information usage.

Baracho *et al*. (2018) studied the implementation of technologies in the field of Architecture, Engineering and Construction (AEC), in light of the following purposes: Identification of the contemporary status of literature on the materials regarding building automation, advances and concepts of smart building, information retrieval and modeling IoT in buildings in the information science context, intelligent Building and Information Modeling (BIM); and also they suggested the employment of IoT in a research laboratory of UFMG.

Chang *et al*. (2018) represented a method to provide and visualize sensor data in BIM with numerous views to support complicated decisions mandating interdisciplinary information.

Wang *et al*. (2017) introduced a new IIS based on IoT, that has been developed to enhance the efficiency of the complicated tasks in economic applications CI and emphasized the significance of a systematic method toward combined information systems for efficient collection of information and monitoring of structural health. (Del Grosso *et al*. 2017) investigated the integration of 6D digital models with SHM databases, decision support systems for operation and maintenance, and condition assessment algorithms.

The use of BIM pertaining to the management of monitoring system data, especially in SHM systems, was studied by Valinejadshoubi *et al*. (2019). Through employing Revit architecture and Revit structure to model a four-story office building in order to demonstrate the viability of visualizing and creating the data regarding the sensors installed within the structure with the aim of monitoring the structural health. Additionally, the BIM model is rendered dynamic through the linking of relevant external resources associated with the sensors such that the information pertaining the sensors is up to date and that the sensor data is capable of being managed in real time. This research establishes the premise for supplementary economic application of utilizing BIM in SHM purposes (Valinjadshoubi *et al.* 2016).

Theiler *et al*. (2017) in their paper enables monitoring-related information to be described using BIM.

3. BIM

The conceptualization of BIM has been in existence ever since the 1970s whereby the term, BIM, made its initial appearance in research written by Van Nederveen and Tolman (1992).

Spanning the past decades, BIM has matured into a key technological input within the industries of construction and building for analysis and design of civil infrastructure (Eastman *et al*. 2011, Smarsly and Tauscher 2016). The objective of BIM is to provide an integrated digital methodology that supports planning, maintenance and operation of structures throughout their whole lifecycle.

According to the National BIM standards committee (NIBS 2008), BIM's gross scope is vast and is capable of being elucidated within the relations of three categorizations: (1) BIM as "a collaborative process" that encompasses automated process capabilities, business drivers, and open information standards use to information fidelity and sustainability; (2) BIM as "a facility lifecycle management tool" of notably acknowledged procedures, information exchanges, and workflows, and (3) BIM as "a product" of digital representation of functional and physical characteristics of a facility (Bai 2013).

Traditional building designs were primarily dependent upon two-dimensional drawings (elevations, plans, sections, etc.). BIM expands this surpassing 3D, ameliorating the three primary spatial dimensions (width, height and depth - X, Y and Z) with time and cost as the fourth and fifth dimension respectively. Accordingly, BIM encompasses more than geometry and includes geographic information, light analysis, quantities and properties of building components, and spatial relationships (Bai 2013).

During the design phase, 3D digital models are constructed through automatically integrating the individual disciplines of engineering involved (co-design phase). However, they are also capable of being constructed by drawing from pre-existing design documents originating from the traditional design processes.

Three dimensional digital models institute the foundation for subsequent expansions and are capable of being manufactured at disparate development levels (LOD) depending on the considered design phase (detailed, preliminary). Through the addition of relevant objects, time, and data concerning the construction phase (4D Models), it is rendered possible to perform the construction planning process and with the addition of cost data (5D Models), construction costs and cash-flow analyses are able to be carried out (Del Grosso *et al*. 2017).

Contemporarily, BIM procedures, for buildings, have been reasonably well founded up to the 5th dimension, however, a range of hurdles persist regarding broadening these stratagems to the facility management stage and the infrastructure field (Del Grosso *et al*. 2017, Tian *et al*. 2019a, b, c, d, e, f).

Typically, there are hundreds to thousands of documents for each project and human interpretations are required to tie them together. Effective coordination betwixt communication of the design to the field and the design disciplines has proven to be a persistent obstacle. BIM has significantly altered the way the building information is managed by the construction industry. BIM involves digital modeling software to further effective management and designing of a project (Valinjadshoubi *et al*. 2016). It provides powerful novel values to the construction firms while reducing the hurdles betwixt disciplines by sharing and encouraging knowledge throughout the project life-cycle. BIM improves constructability, shortens the completion time of the building project. In a BIM project, multiple documents are not used like the traditional ways (Australian Construction Industry 2014). Instead, it is constructed digitally as a database in BIM software. Rather than being subjected to examine at different drawings, schedules and specifications regarding information of a particular element, an intelligent object in the BIM model has all the information built into it (Fulford and Standing 2014, Valinjadshoubi *et al*. 2016, Akhoundan *et al*. 2018, Tian *et al*. 2020a, b, c).

4. BIM maturity levels

BIM Alliance Sweden is a non-profit organization first created by merging of three unions, named the former organization Open BIM, building SMART Sweden and Facility management information, in order to develop common strategies processes, methods and tools for BIM-implementation, management and development. Since the initiative started over 170 companies have joined this alliance (Nguyen 2016).

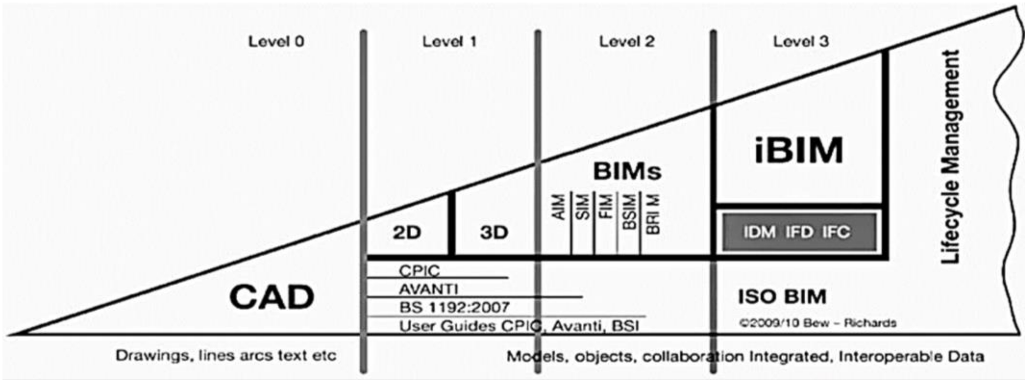

Fig. 1 BIM maturity levels (Bew and Richards 2008)

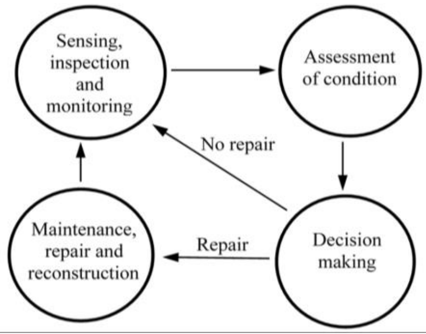

Fig. 2 Circular flow of structural health monitoring and maintenance activities

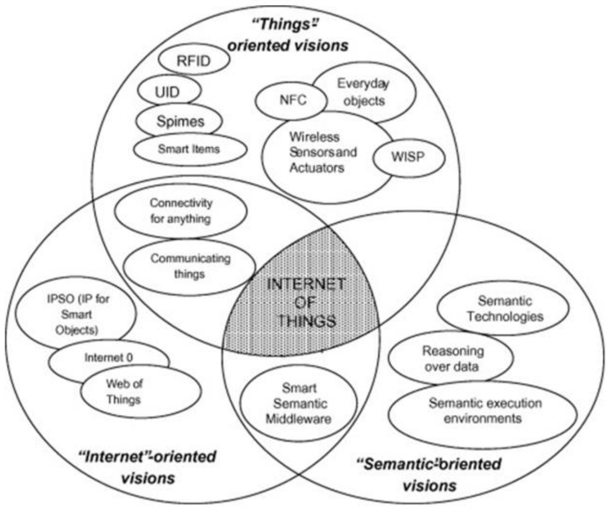

Fig. 3 Internet of things (Atzori *et al*. 2010)

One of the developments that has grown out of the alliance is the appropriation of Bew and Richards, four levels of BIM-maturation (Fig. 4) to Swedish conditions. (Bew and Richards 2008). According to the BIM-alliance level 0 is when CAD drawings are printed to be used as a main analog document of buildings. 95% of users' drawings are not coordinated, and approximately 25% have to be reworked (Nguyen 2016).

The level 1 is when computer files are mainly used, either as 2D or 3D models, however, at level 1 these models cannot handle object information and cannot operate with other systems. Management of files is isolated and not integrated into a facility management system.

At level 2 the system uses information in object-based models, and it has some interoperability. Building related information and attributes can be used by the facility companies.

Level 3 covers a future scenario where standardized information models are used throughout the building's life-cycle, and support systems in the organization's practices. Information is supplied in open databases and is connected through web-economic applications.

Bew and Richards estimate a possible 2% increase in profit through less risk and improved collaborative processes (Bew and Richards 2008, Nguyen 2016).

5. The role of SHM

SHM is a process providing real time and accurate data regarding the performance and condition of a particular structure (Glisic *et al*. 2010, Napolitano *et al*. 2018). It can be explicated by breaking the process down to five core monitoring activities, namely: (1) definition of the SHM strategy; (2) installing of the SHM system; (3) maintaining of the SHM system; (4) management of data and metadata; (5) closing activities (if any) (Glisic *et al*. 2010, Napolitano *et al*. 2018).

Structural health monitoring and maintenance (SHM2) is extensively performed as an amalgamation of decision-making and information processing as the background underpinning construction and remedial activities (Fig. 1).

SHM involves:

1. Structural observations and measurement: Observations, be them visual or ones taken through utilizing a variety of instruments and transducers, to provide data on structural conditions.

2. Information management: Information from future usage plans, structural observations, construction documents, finances from a diverse range of data, and maintenance records, and mining, storing, and managing the data could produce information that is useful.

3. Condition assessment: A rapid assessment of condition is capable of being provided through a swift processing of the data, either by using the human mind,

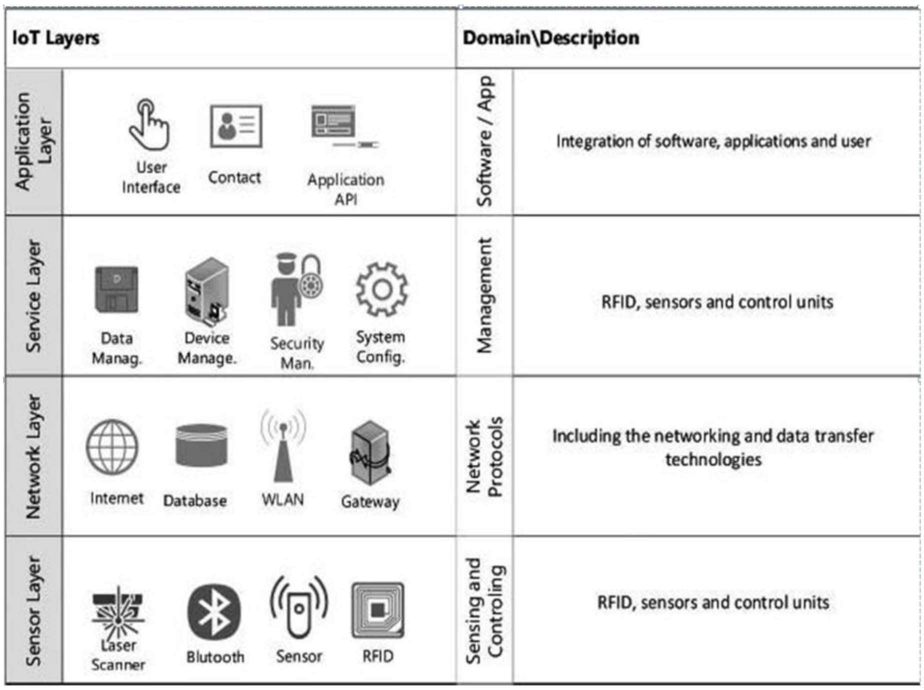

Fig. 4 Layout of IOT layers, adopted from (Atzori *et al*. 2010)

and/or being aided by machine intelligence.

4. Decision-making and planning: Which strategies, including a possible analysis of short lifetime and short duration costs of ownership, are ideal to maintain structural health? Options such as but not limited to minor and major repairs, scheduling more assessments and observations and reconstruction.

5. Implementation of repairs: Replace, reconstruct, and repair the structure. Scheduled attempt in order to minimize and reduce costs, for example trying to circumvent emergency repairs.

6. Assessment of repair and maintenance performance: Determining the performance of the repairs made (Huston 2010, Huston *et al*. 2016).

In the past decade, SHM has appeared to be an effectual method to observe structural health. SHM refers to an ongoing structural performance assessment employing the use of various kinds of sensors in order to assess the safety and integrity of structures and to assist engineers in deciding upon measures for rehabilitation when a structure experiences unexpected changes such as excessive deformation, deflection, strains etc. Sensors embedded or attached to structures are also used for economic applications other than SHM, such as indoor air quality monitoring, smoke detection, energy efficiency, quality assessment of the precast elements, etc. They are used to control the ongoing situation and performance of the buildings.

Principally, SHM techniques are supposed to identify states of damage that are to eventually take place within the structural system (diagnosis) and accordingly characterize their development (prognosis) based upon the interpretation and analysis of the data received from a sensory network installed in the structure. The integrity condition is capable of being depicted by a number of alternative parameters and the interpretation phase requisites the availability of a numerical model for the structural system (Del Grosso 2017).

6. The role of IOT

As of late, there has been a considerable increase in the number of articles and research papers on the Internet of Things (IoT). Observing the trends in searches on ProQuest, there were nearly 400 Papers released in 2010 whereas the number of released papers exceeded 16000 in 2016, and this accordingly posits the increased attention garnered by the topic (Papaoikonomou and Nejad 2017, ProQuest 2017, Keshtegar *et al*. 2018).

IoT can be elucidated as a network of data collectors, machines, sensors and computers that have been connected to one another via the internet to analyze, process, and store data upon a cloud-based server for different types of clients (Papaoikonomou and Nejad 2017, Da Xu 2011, Miorandi *et al*. 2012).

The IDC's 2015 survey estimates a market of 1.7 trillion dollars in 2020, IoT is a concept considered old (Baracho *et al*. 2018). attributes the term to the British researcher Kevin Ashton of the Massachusetts Institute of Technology (MIT-1999) and explains that "with the Internet everything will be connected: Smartphones, refrigerators, fire alarms, tablets, computers, garage doors, traffic lights, road signs and more" and the need for security and that this is a discussion that is just beginning.

As a result of the convergence of several technologies, IoT is part of the large number of devices that have been proliferating. It is estimated that by 2020 (Baracho *et al*. 2018). There will be more than 40 billion connected devices, a fact associated with the miniaturization and popularization of the most varied types of sensors and the advancement of wireless for the growth of the concept and dissemination of its economic applications.

7. IOT structure and layers

A range of paradigms should be linked in order to better comprehend the concept of Internet of Things. Atzori's Case Study posits a trinary paradigm consisting of sensors, a middleware, actuators network, and finally a knowledge-based system. Whereas, an Opentechdiary specialty article (2015) examines four layers of gateways, economic applications, sensors, and processors. In accordance with the Opentechdiary (2015) article, He and Li have suggested four layers encompassing a majority of the abovementioned layers (Atzori *et al*. 2010, Da Xu *et al*. 2014).

A. Sensing layer: Regarding the sensing layer, the wireless smart systems with sensors or tags are now capable of automatically exchanging and sensing information among disparate devices. These advancements of technology have significantly improved the capacity of IoT to identify and sense the environment or things (Wu *et al*. 2013, Da Xu *et al*. 2014).

B. Networking layer: The role of the networking layer is to bridge all things together and permit the sharing of information with other connected things. Additionally, this layer is able to aggregate information from existing IT infrastructures (such as ICT systems, healthcare systems, business systems, transportation systems, power grids, etc.) (Atzori *et al*. 2010, Da Xu *et al*. 2014).

C. Service layer: The service layer is dependent upon the middleware technology that supplies functionalities to seamlessly integrate economic applications and services in IoT. The middleware technology provides a cost-efficient platform, whereby the software and hardware platforms are capable of being reused, to the IoT. In the service layer, a main activity involves the specifications of service for middleware, which are being developed by a variety of organizations. (Atzori *et al*. 2010, Guinard *et al*. 2010, Miorandi *et al*. 2012, Da Xu *et al*. 2014).

D. Interface layer: An Interface Profile (IFP) could be regarded as a subset of service standards that supports the interaction with economic applications deployed on the network. A decent interface profile is related to the implementation of Universal Plug and Play (UPnP), which explicates a protocol for the facilitation of an interaction with services provided by various things. The interface profiles are utilized to describe the specifications between services and economic application s. The services on the service layer run directly on limited network infrastructures in order to effectively identify new services for an economic application, upon connection to the network (Guinard *et al*. 2010, Gama *et al*. 2012, Da Xu *et al*. 2014).

Simply, the Internet of Things is realized when physical objects within our daily lives are linked to information systems that are capable of being utilized to facilitate one's regular activities. IoT has capabilities which, according to some commentators and researchers, may develop to have radical implications upon the world we live in. One of these capabilities comes with the ubiquity of the Internet and through the use of sensors to embed objects to systems which assist the communication among networks of devices and people. Atzori defined IoT in an overview survey, as the combination of three paradigms (as visualized in Fig. 1) (Atzori *et al*. 2010):

- Semantic-oriented (knowledge)
- Thing-oriented (sensors)
- Internet-oriented (middleware)

With a more user-centric and visionary description, IoT is recognized as interconnection of actuators and sensors providing the capacity and capability of collecting and analyzing data, then representing and sharing information across platforms through a unified framework for supporting the creation of further innovative economic applications (Gubbi *et al*. 2013).

8. Sensor networks

Sensors are devices which possess the capability to measure a range of parameters within the physical realm, for example pressure, lux level, humidity, temperature, carbon dioxide, movement, gas, water, electricity meter readings (Gokce *et al*. 2010). Traditionally, sensors relied on wired connections like using USB cables which are not flexible for sensor placement positions.

9. Wired sensor networks

There are two types of sensors collecting information: outdoor sensors and indoor sensor as below:

- Outdoor- sensors are installed on the roof of the building with the purpose of capturing measurements of outdoor environment factors such as sunshine and wind flow from different sides of the building. These data are mainly used for steering the indoor environment accordingly after the outdoor weather conditions. One example might be the activation of blinders when lux from sunshine exceeds the contracted conditions.
- Indoor sensors, as planned at the design phase of the building, are approximately 2000 wired sensors embedded to the building objects on the ceilings strategically arranged. It is arranged so that the sensors systematically cover all space of the floor. With the aim of collecting indoor climate data, the factors captured are the level of indoor lux, temperature, humidity, carbon dioxide and movement.

10. WSN

With wireless technology, the emergence of Wireless Sensor Networks (WSN) has benefited the users as flexibility and cost-efficiency in comparison to wired installation (Malatras *et al.* 2008). Underwood and Isikdag (2011) see a potential future of WSN when expanding the use of BIM throughout buildings life-cycle.

The emergence of WSN has facilitated the connection between the physical world and the digital by making the

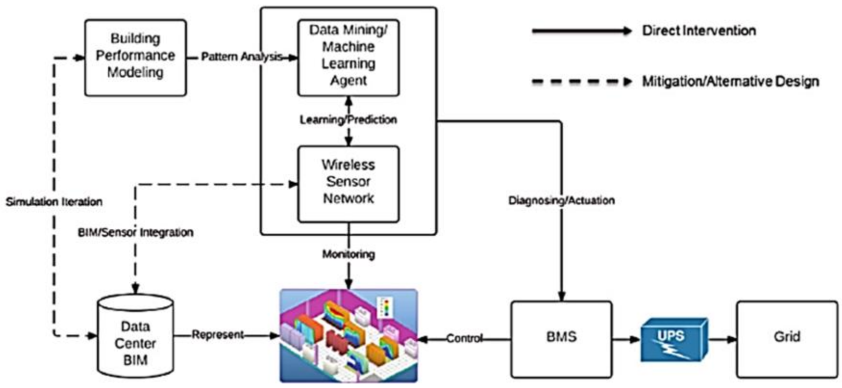

Fig. 5 BIM-WSN framework

large number of tiny sensors connected to each other by wireless protocols (Malatras *et al*. 2008). Using wireless communication, WSN is defined as a web of distributed autonomous sensing devices that sense, measure and collect information in the physical environment (Gokce *et al*. 2010).

Moreover, choosing types of sensors, wired or wireless, would depend on the building itself and occupants' perspective. For example, with existing buildings, wireless sensors might be more convenient to set up, install due to the flexibility and mobility of wireless connection. Therefore, it also could be used in the short term for temporary purposes. Whereas wired sensors are usually adopted with permanent purposes, which is planned at the planning and design stage of the project.

11. Comparison of wireless and wired sensors network

WSN brings several advantages compared to wired sensor networks that might be reasons for the more widespread adoption of WSNs, especially in building management. However, when compared to the traditional way in detail, wired network, WSN still embodies some drawbacks (Malatras *et al*. 2008, Calis *et al*. 2011, Li and Becerik-Gerber 2011, Kaur and Monga 2014, Nguyen 2016).

12. Discussion

BIM technology focuses on supporting the construction of buildings, mainly in the concept, design and construction phases. Designers and builders, architects and engineers use BIM models to design projects and building functions. Also is an appropriate tool for data management, data storage, damage detection and data retrieval are needed for effective monitoring.

BIM models work on the relationships between modeled objects and components and space. These relationships are linked to four main strands: level, discipline, family and environment. Each object of the model is linked to a level, which can be a real or conceptual habitable floor. One level is created for each floor or other required building reference such as the first floor, top of the wall or bottom of the foundation. Each object is linked to a discipline.

Another link relates to the family that contains the geometric definition and the parameters used by each element of the model. An element inserted into a template is an instance of a type of family. Each instance of an element is defined and controlled by the family. These elements can have properties, which control their appearance and behavior, common to all elements of their family or properties that may vary in each instance. Finally, and perhaps more important for the integration, that links to the environments, which are subdivisions of space in a BIM model, based on dividing elements such as walls, floors, roofs and ceilings, which are Defined as environmental delimiters. In addition to the obvious use of the environments in a model to calculate distances, areas, and volumes, the sharing of information from environments.

13. Conclusions

BIM is usually used as a static data source. Extending the BIM model from static to dynamic by SHM & IoT will prove to be of great use to owners and facility managers by providing accurate and updated information about the state of various parts of the building. On the other hand, a static data source compromises of limited design and as-built data.

Dynamic BIM models can work in capturing real time building information such as data obtained from different types of sensors attached or embedded in the building to reflect its existing condition.

Accordingly, sans the use of appropriate tools, the significant task of effective data management is unable to be implemented successfully. BIM has developed to be a powerful data management tool through sorting, recalling, sharing, and obtaining data and then providing a digital environment of said data. An effective method to solve data management issues would be through the implementation and use of BIM in monitoring systems, such as SHM. The process of rendering BIM dynamic by means of documenting the SHM data will be of significant utility for facility managers, engineers, and owners due to the provision of up-to-date data regarding the state and health of various portions of the building.

Table 1 Comparison between wireless sensor network and wired sensor network

Characteristics	Wireless sensor network	Wired sensor network
Infrastructure requirement	No need of a fixed infrastructure when setting up the network	Necessary for fixed infrastructure in order to install network
Deployed cost	More cost-efficient	Less cost-efficient, due to cost for cabling deployment and installation
Configuration	Quite easy with no cables	More complicated with cables connecting requirement to the network
Mobility	More flexible in positions to place sensors. Therefore, both deployments and removals are easier	Limited
Installation time	Less time	More time
Speed	Lower	Higher
Security	Weaker, due to the access points are easily to be entered and got information	Better
Energy supply	Power supply for WSN is limited. Due to given size constraints, the batteries normally cannot be large. It is required to change new battery periodically	Wired network guarantees for sustainable power supply for the sensor network working

BIM models can also use IoT devices. BIM and IoT systems are complementary technologies. The “things” connected to the internet generate accurate and reliable data about the systems of a building in a given “space”. This data will assist the BIM models giving them more utility.

Finally, more important for the integration between BIM, SHM and IoT technologies, are links to environments, which are subdivisions of space in a BIM model, based on dividing elements such as walls, floors, roofs and ceilings, which are defined as environmental delimiters. In addition to the obvious use of the environments in a model to calculate distances, areas, and volumes, the sharing of information from environments between BIM systems SHM and IoT equipment management systems is critical.

Future work will include the use of SHM and IOT that improves the monitoring and maintenance of a particular building or even entire urban systems, such as the use of sensors to control burned-out lights and the consumption and distribution of water or electricity.

With the adoption of Information Communication Technologies (ICTs), it is getting more frequent for emerging sensing technologies like sensors and sensor networks to be incorporated into the functionalities of the building, especially in the energy control and management fields.

WSNs are currently integrated in some existing Building Management Systems (BMSs), which manage, control and adjust the functionalities of building systems and services such as Heating, Ventilation and Air Conditioning (HVAC), security, electricity systems, lighting, access control, resource monitoring, etc.

Five main benefits of applying WSNs in building management:

a. Better facilities’ performance measurement: a WSN system could have the capabilities to measure performance of building facilities more detailed over time compared to the conventional way (using meters: thermometer or power meter) by collecting data of how well the facilities perform.

b. Real-time data access: With this function, data captured from sensor networks is able to be accessed anytime by building management personnel. Therefore, it is possible to keep track the status of all building facilities.

c. Providing occupant behaviors on using energy: Sensor data and energy consumption are correlated to understand the behavior of users and also the occupants’ physical needs that can be adjusted for time, seasons, etc.

d. Problem diagnosis: Gathering data from sensors and occupants’ behavior in a certain area after a period of time enables to reveal some problematic issues of facilities, and how it may be negatively affected by occupant behavior and use.

e. Automated energy control and management: The sensor data is also usable for Energy Management System (EMS) which can automate and optimize the energy management.

When these sensors are dispersed throughout the building, it could probably be more functional to in detail monitor the facilities in accordance with the changes of time, outside temperature and other exterior environment variation and physical comfort scale of occupants.

Finally, BIM is an effective tool used as a powerful data management tool through recalling, obtaining, sharing, sorting and storing data and making them intelligent. It can be used as a repository of all data captured or made during the building’s lifecycle. BIM is usually used as a static data source, but in this article we tried to talk about its dynamic dimensions.

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