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A framework for integrating BIM and IoT through open standards

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ABSTRACT

The built environment provides significant opportunities for IoT (Internet of Things) deployment, and can be singled out as one of the most important aspects for IoT related research. While the IoT deployment in the built environment is growing exponentially, there exists a gap in integrating these two in a systematic way through open standards and systems. From technological perspective, there is a need for convergence of diverse fields ranging from Building Information Systems and Building Services to Building Automation Systems, and IoT devices and finally the end user services to develop smart, user oriented applications.

This paper outlines the efforts to develop a platform that integrates the built environment data with IoT sensors in a campus wide, web based system called Otaniemi3D that provides information about energy usage, occupancy and user comfort by integrating Building Information Models and IoT devices through open messaging standards (O-MI and O-DF) and IFC models. The paper describes the design criteria, the system architecture, the workflow and a proof of concept with potential use cases that integrate IoT with the built environment. Initial results show that both the end users and other research groups can benefit from such platforms by either consuming the data in their daily life or using the data for more advance research.

1. Introduction

Recent advances in technologies such as Internet of Things (IoT), wireless sensors, data processing and analysis, and Building Information Modelling (BIM) have the potential to transform how we interact with the built environment and improve the experience for end users and service providers [1–7]. The IoT devices and sensors are increasingly being deployed in the built environment and industrial applications. The number of connected devices have already overtaken connected human beings and are estimated to be around 9 billion. The sensor nodes are being deployed in various application areas such as the industrial, transportation, health and wellbeing, building automation, automotive and retail. The number of sensor installation is increasing at an exponential rate and some estimates suggest that there will be around 50 billion connected devices by 2020 [8].

As majority of the IoT devices are deployed within the built environment, the integration of built environment information and IoT becomes a prime challenge [5,6,9,10]. The built environment represents almost all aspects of human life, from healthcare to education and industries, where the field of BIM is rapidly expanding as an information delivery and management platform. BIM models are used across the entire project lifecycle including design and construction to operations and maintenance [11,12]. With the emerging popularity of the BIM platforms, there is an opportunity to leverage this technology so that it can be used to build open platforms that synchronise with diverse information sources such as wireless sensors and building automation systems. However, there is a gap in research in integrating built environment data with IoT standards that shows tangible open systems which are built upon open standards. The need for open standards become acute due to plethora of protocols and information exchange standards being used in both the built environment and IoT domains [13]. Moreover, the IoT domain is siloed with many researchers highlighting the need for cross cutting applications built from user centric perspective. There is also a growing consensus that future “smart” applications should be more human centric and support bottom up innovation rather than being technology centric and supporting top-down decision making. This research attempts to address this gap by providing the details of a proof of concept development that a) integrates built environment and IoT data; b) provides tangible, intuitive and open user interfaces and c) is situated in the real-world rather than being lab based. One of the motivations behind this study is to support distributed, cross cutting and bottom-up innovation by supporting both consumption of data provided by the system and development of applications and further research by utilising the APIs (Application

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Programming Interfaces) provided by the platform.

The paper begins by providing a background on the key technologies followed by the design rationale that explains the main factors that influenced the design of the proof of concept and the underlying framework. A description of the system architecture follows that outlines the main components of the system. Subsequently, the proof of concept implementation, Otaniemi3D is described in detail followed by a real-life use case, discussion and conclusion.

2. Background

The field of built environment is plagued by information silos and lack of standardization that affects the information flow [3]. The industry which touches upon almost every aspect of human activity, is one of the most important at both the micro (things, spaces and buildings) and macro levels (campuses, cities, and regions) for IoT deployment [7,14]. Where context is important for almost all IoT deployments, spatial nature of the built environment provides a natural and important platform that plays an important role there [5,6,10]. As a major platform emerging to host built environment data, BIM is an important technology to consider from IoT integration perspective. This section provides a state-of-the-art review in the area of BIM-IoT integration, Open standards within both BIM and IoT domains and the IoT deployment.

2.1. BIM and IoT

BIM now extends itself to cover many technological advances the industry is witnessing and is the natural interface for IoT deployment [11]. Several researchers have started to explore the potential synergy between these two platforms. There has been research that demonstrates the usefulness of IoT in breaking traditional silos in the built environment for the entire lifecycle, from design to construction to handover [16].

Teizer et al. [17] have proposed to integrate BIM data with IoT sensors, with a focus on making available performance, environmental and localisation data of workers in an indoor work environment. The goal of the research is to create a safe job site where information integrated from several sources such as production control and BIM can be synchronised with IoT sensors (lighting, proximity, etc.) to provide real-time feedback to workers. The researchers use off-the-shelf BIM technologies along with readily available Bluetooth beacons and RFID sensors to integrate BIM and IoT information sources. Rowland [6] proposes gamification as an entry point in integrating BIM and IoT, where the author proposes to bridge the vertical silos of BIM with the horizontal silos (or information flows) of IoT along with several use cases including wayfinding, spatial and context awareness and above all persistence of data for the project lifecycle. Alongside gamification, the author also puts forward the use of Augmented Reality to interact and visualize BIM and IoT information.

On a macro scale, Isikdag [10] conceptualises the integration of BIM and IoT in order to develop a GIS based city monitoring or management application framework. The author proposes to integrate information from physical IoT sensors with "virtual sensors" that represent BIM objects and their state (which can provide contextual and spatial information) through RESTful APIs.

From the literature review it emerges that the BIM and IoT integration research is in nascent stages where most proposals are at a conceptual stage. Except for Teizer et al. [17], none of the other research has developed/demonstrated any real-world applications or proof of concepts. It should also be noted that the aspect of open data and open communication standards has not been addressed sufficiently within the domain of BIM and IoT integration.

2.1.1. Open standards, BIM and automation

The fields of BIM and IoT are mired by proprietary file formats and closed ecosystems where information is still not shared openly amongst stakeholders [3,13]. BIM still remains a tool for the experts, and the information that can be used to improve the quality of life of the inhabitants hardly ever reaches them [6]. Within the subdomain of building management systems, which at the moment is the "low hanging fruit" from IoT deployment perspective since it already hosts majority of sensor deployments, there exist plethora of protocols and standards such as Zigbee, KNX, BACnet, LONWorks, DACI, Mobus, oBIX, OPC, etc) [3]. Achieving integration and developing user interfaces that improve the quality of life of its inhabitants remains one of the biggest challenges for IoT deployment in the built environment.

2.1.2. Visualization of spatial information in real-time

The quest for 3D BIM real-time visualization arises from the communication needs between various actors in engineering, construction and architectural businesses. A 3D visualization offers a natural representation that is useful in a range of applications along the design and construction processes. As a mediator of various data sources, an integration phase is required, typically collating CAD, BIM and GIS data sources to a multipurpose platform [18]. However, as the related data sets are typically very complex, real-time visualization thereof has become a severe challenge, easily exceeding the capacity of the computer [19]. The hopes often lie in future hardware; unfortunately, even the latest hardware always seems to become overloaded [20]. Hence, designers are forced to split the model to smaller parts. Despite this, commonly used software tools for BIM visualization would still either fail to load the 3D data or be unable to render it in real-time, unless the model is further remodelled and simplified [21]. For a mobile case, the situation becomes considerably worse due to the lack of resources [22]. The software engineering approach of the building walkthrough case has also been suited for large scale mobile urban visualization. In this case, it was shown that an improvement of two orders of magnitude can be reached without sacrificing model detail, achieving interactive rendering rates for otherwise too complex a model [23]. This kind of approach has not yet been applied to the BIM case.

2.2. IoT standards

As a rapidly growing area, IoT has become a technological focus for academia, industry, and even government organizations [8,24]. The IoT envisions a world of heterogeneous objects uniquely identifiable and accessible through the Internet [25–27], the whole forming a dynamic global network infrastructure with self-configuring capabilities. Nonetheless, IoT is entering a new phase with an increased focus on how to avoid the continual emergence of vertical silos, which hamper developers to produce disruptive and added value services across multiple platforms and sectors (data is "siloed" in a unique system, cloud, domain, and stays there). This vision of interoperability requires the mastery of protocols and standards to leverage system interoperability due to the large number of products, platforms, and competing applications that coexist in the IoT [16,28,29]. In lack of standardized solutions, it is likely that a proliferation of architectures and identification schemes will develop side by side, each one dedicated to a particular or separate use, which will lead to the fragmentation of the IoT [27,30]. At the time of writing, there are more than 250 reported IoT platforms available on the market [31].

2.3. IoT deployment

Most IoT deployments remain expert driven and cater to specialised use cases. Also, majority of sensors due to their inherent nature are hidden away from human interaction, which in turn make them an area reserved for top-down innovation. The IoT domain in general and its deployment areas such as Smart Cities have come under criticism for being top driven and self-congratulatory [32]. There is a growing concern that the entire area is driven by corporates, where greater