# Utilising Latent Data in Smart Buildings: A Process Model to Collect, Analyse and Make Building Data Accessible for Smart Industries

Zohreh Pourzolfaghar
Dublin City University, School of Computing
Dublin, Ireland
Zohreh.pourzolfaghar@dcu.ie

Markus Helfert
Dublin City University, School of Computing
Dublin, Ireland
Markus.helfert@dcu.ie

***Abstract*— Smart buildings are embedded with large amounts of latent data from different sources, e.g. IoT devices, sensors, and the like. Integration of this latent data with the buildings information can highly impact efficiency services provided by various industries such as facility management companies, utility companies, smart commerce, and so forth. To enable the integration of buildings information, diverse technologies such as Building Information Modelling (BIM) have been developed and changed the traditional approaches. Notwithstanding a plethora of research in this area, potential users of this information such as facility management companies are still unable to fully benefit from the building information. This is due to this fact that various information and data have been heterogeneously scattered across various sources. To overcome this challenge, this research follows the design science approach to propose a process model to address facility management concerns in terms of the ability to access the combination of building information with live data captured from various sources. The presented process model is introduced thoroughly by explaining the required steps to collect and integrate this information with the live data. The Artifact evaluation of the process model was undertaken via the employment of a focus group session with the construction professionals, the IoT experts, and the data analysts. Also, this paper elaborates on two industrial use-cases to demonstrate how having access to the building information effectively affects the other industries. The outcome of this research provides an open access to the integrated building information and live data for diverse range of users.**

***Keywords*— *building information management, data capture, IOT devices, sensors, building Information Modelling (BIM)***

## I. INTRODUCTION

The smart buildings information is a valuable asset which can be utilised by various types of stakeholders in the smart cities (e.g. city councils for urban and infrastructure planning, maintenance/facility management companies to speed up their services and utility companies to estimate energy consumption). Smart buildings describe "a suite of technologies used to make the design, construction, and operation of buildings more efficient [28]. To enable smart buildings, [29] believed that a wider range of information should be available from a broader range of sources. By utilizing the building information in combination with the live data, the exact means of smartness can be realized. In this regard, numerous researches have described various advantages gained from such information. For instance, [6] stated that it is exceedingly important to have the capability of quickly and reliably estimating the buildings' energy consumption, especially for public authorities and institutions that own and manage large building stocks. Moreover, [2] claimed that estimating and predicting the building energy consumption depend on multiple variables, among which the building characteristics, the energy systems characteristics, etc. Other researchers like [8] introduced sensors as the devices for the extraction of the relevant smart environmental context, maintaining that the sensors would further improve the potential of the context-aware services. However, many researchers have stated that there are some challenges involved in utilising this valuable asset by the construction industry and other industries. Some of these challenges are related to the vast complexity and volume of the data and information generated during the buildings' life cycle [14], fewer advances in the information management methodologies and fragmented models in the construction industry [17] and [21]. Nonetheless, during the last two decades, many smart technologies and devices have been developed for the environmental monitoring applications [23] or for the combinational usage of different context data from different sources [8]. However, this information is scattered across the separated data storages and in heterogeneous formats. As [1] proclaimed, these issues contribute to some key challenges in the construction industry in terms of the manual driven process to utilise the building information through the hard copy-based format, lack of proper quality control procedures, and obsoleteness of the information.

With regard to the abovementioned challenges, this research proposes a process model with the aim of integrating the building information with the captured data from different sources. In the subsequent parts of this paper, first we will review some related research work in the building information field and then the proposed solution is explained thoroughly. The evaluation section includes four sub-sections to provide more details on the evaluation steps, including the focus group session, exploring the two use-cases, and discussing the focus group results and the show-cases.

## II. RELATED RESEARCH WORKS

The building information modelling technologies have become more common to manage the building information during the last ten years. However, these technologies confront large number of challenges, e.g. updated data for the as-built BIM models [4], the pertinent semantic format for the maintenance stage [22], and unsystematic use of the building information on the virtual models [16], the related procedures [5], the established standards [10], and the computerised facility management system integration [3]. Some other researchers have reported challenges facing the maintenance stage. Later, [18] presented a critical synthesis and evaluation of the benefits derived from the BIM for the maintenance stage and reported several corresponding obstacles, including: The available data are not necessarily the required data for maintenance stage; and the data is not necessarily stored in usable format. Similarly, the COBie has been criticised for its inability to ensure the comprehensive semantic data for the maintenance stage [5]. Similarly, some researchers have reported some challenges for the maintenance stage. As [26] and [22] stated, some identified challenges relate to interoperability, interfaces with other systems, integration of wired and wireless sensor networks to enhance the live data collection during the construction phase, and controlling the access to the project information. As such, [15] proclaimed that the building maintenance requires a comprehensive information system that captures/retrieves the information about the building maintenance components and all their related building components. In this regard, they proposed an integrated information/knowledge system which was limited to capturing and retrieving the data during the maintenance phase. The data integration was defined by [7] as: “the combination of data from different sources with unified access to the data for its users”. Obviously, many researches have proposed methods and models to integrate the building information with the captured data to facilitate the maintenance of the buildings. However, inadequate data integration is a current challenge faced by the building information models, stemming from differences in the data syntax, the schema, or the semantics [18]. Regarding the reviewed literature, integration of data from diverse sources has been introduced as a challenge. As a result, the users cannot benefit from the values of the integrated data. Therefore, this research aims to present a process model to collect, analyse, and integrate the building information with the live data captured from IOT devices and sensors.

## III. RESEARCH APPROACH

This paper follows [19] the design science research approach to define the problem in terms of unavailability of a combination of the building information with the live data. To define the problem, an extensive literature review has been conducted in the area of the technologies to manage the building information, e.g. the BIM. To support the problem in practice, the authors conducted meetings and workshops with the facility management teams as the potential stakeholders of this combination. Based on the evidences from the literature review and practice, the problem was defined as the inability to take advantage of the combination of BIM models with the live data. Therefore, this research proposed a process model to combine the building information and the live data from heterogeneous sources and store them in an open access storage. For the conceptual evaluation of the proposed solution, this paper follows the approach proposed by [25] and discusses the obtained results from a conducted focus group session for this study’s purpose. To conduct the focus group session, the focus group session passed through an eight steps procedure by [24] with the practitioners from the construction industry, the IOT experts and the data analysts. The different phases of the process and their steps have been discussed painstakingly. The results of evaluation section provide evidences on relevancy of the proposed process model for the explored field.

## IV. PROCESS MODEL FOR BUILDING INFORMATION AND LIVE DATA INTEGRATION

Buildings information is known as a priceless resource for various smart industries. For instance, utility companies can utilise building information to estimate energy consumption and promote energy saving [20]. For instance, utility companies can compare live captured data for building consumptions with the predicted energy usage estimation. For this purpose, they need access to the cumulative information of electrical devices, while detailed buildings information may not be accessible. Similarly, retailers can predict and manage market demands with regard to the technical specification for building components and materials [20]. However, building information is not openly available for this type of industries. To provide such an ability, the initial overall idea to integrate building information with live data, as well as making buildings information accessible for all potential users, is presented in Fig 1.

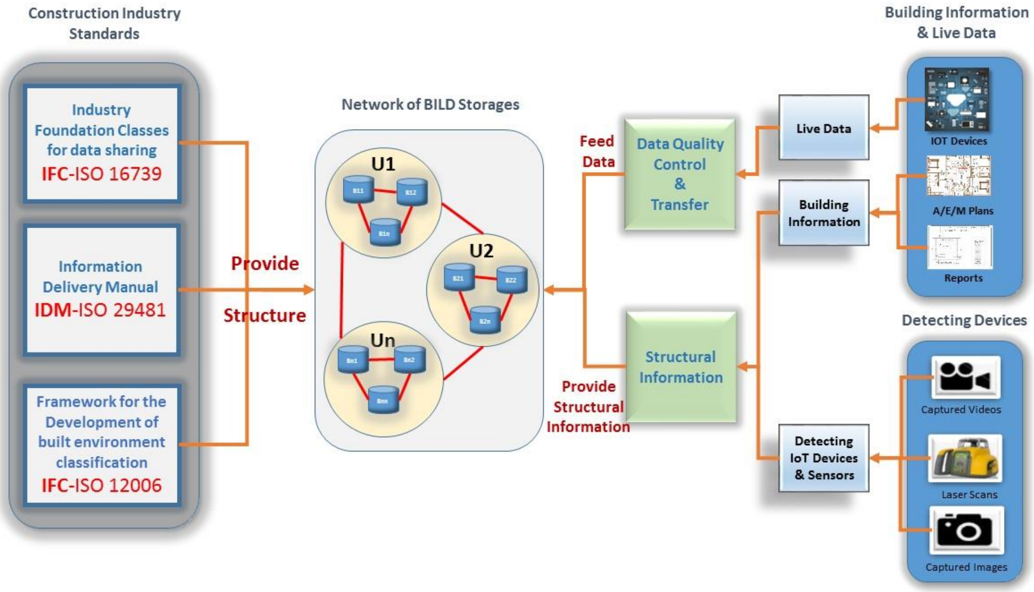


Fig. 1. The overall view of the Process Model

Establishing on this overall view, this study proposes a process model to capture the data from various source and integrate them into a Building Information and Live Data (BILD) open storage. Consequently, four phases have been defined for the proposed process model. In the following sub-section, the above mentioned phases of the process model are described thoroughly.

### A. *Structuring BILD Open Storage*

The first phase of the proposed process model is structuring the open storage in which integrated and qualified building information and live captured data are stored. This open storage should comply with the construction industry standards, (i.e. ISO 16739, ISO 12006, ISO 29481 and any other related standard). To develop such an open storage, the first phase of the process model comprises the following steps. The first step is exploring Building Information Modelling (BIM) and COBie standards are the European standards for the construction industry. Based on these standards, all the data should follow the corresponding rules describing the data format and the data exchange. Based on the explored standards, some structural and semantical requirements are specified. Regarding these requirements, an initial version of the open storage structure is defined, accordingly. Another important requirement for this phase is standardizing the coding system for building spaces. Later, the assigned codes are used to link the collected live data from various sources to the buildings information. The presented process for this phase is shown in Fig. 2.

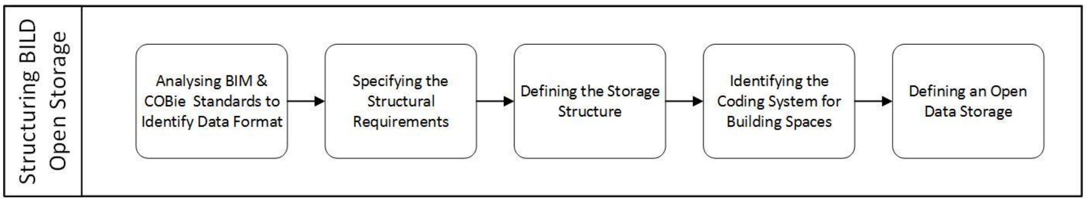


Fig. 2. The process of structuring BILD open storage

Structuring the BILD storage is completed progressively, by accomplishing the second and third phases. This is due to the fact that the required fields to preserve the information and collected data should be defined regarding their correspondent sources.

### B. *Multi-sources Building Information Capturing*

In this section the required steps to capture the buildings information from various sources (e.g. building plans, reports, IOT devices, sensors, etc.) are explained. To this goal, two different sub-processes are proposed in this section. The first process is to digitalise building information from architectural/mechanical/electrical plans as well as project reports. Building plans contains essential information about building spaces and their associated technical specification. Likewise, project reports comprise useful information on mechanical/electrical and structural aspects, e.g. building energy and water consumption. As the first step for this process, all this information are required to be digitalised. Then, the next step is using a coding system (defined in 4.1) to assign unique code to the building spaces. Further, there is a need to provide a link between the digitalised building information from plans and from the project reports. Later, this information is stored in the structured data storage in section 4.1. The defined process in this stage is shown in Fig. 3.

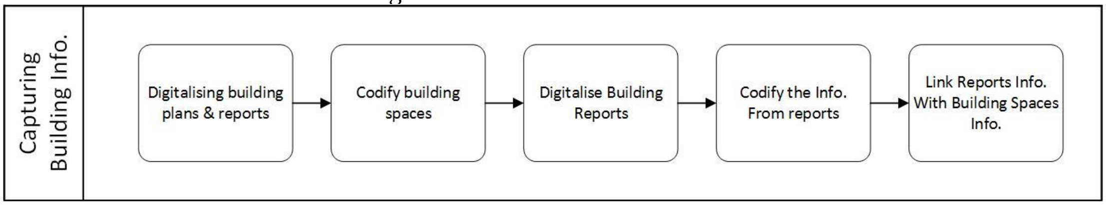


Fig. 3. The process of capturing building inforamtion from plans ad reports

The second process for this stage is detecting all the IOT devices and sensors installed in the building spaces. To do so, all these devices are detected using laser scans, captured images and video records. The outcome of the detecting devices is in the form of point cloud data and they need to be converted into the objects. Moreover, some additional information e.g. coordination and location are utilised to link this information to the previous building information. The second process is presented in Fig. 4.

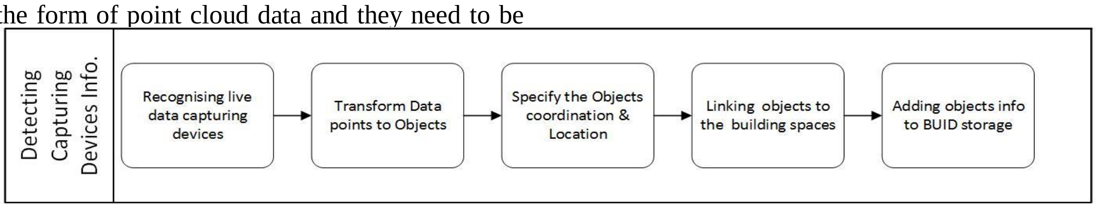


Fig. 4. The process of detectind IoT devices and sensors information

During this phase, some structural information is provided to construct the data storage in phase 4.1. These types of information are extracted from building plans and reports from one side, and from detecting devices for IOT devices and sensors, from the other side. The iterative process of feeding live data into the BILD storage is presented later, in section D.

### *C. Establishing a BILD Storages Network*

By providing a network of data storages for the buildings, an opportunity is appeared to use live data for the urban planning purposes (e.g. infra structure planning and waste water management based on energy consumption in an urban area) in smart cities. To establish such a network, the required steps are explained as follows. In the first step in this process, locational information fields are needed to be defined for the buildings. This information includes geographical and urban information as the key fields to link to other existing applications (e.g. GPS, urban districts, etc.). Then the codifying system should be identified to develop a unique code for every building in the urban areas in the cities. This unique code is the reference number for each building. In this regard, all the buildings in the urban areas could be referenced with their unique code. For instance, if 'U1' is a part of the buildings' code located in 'U1' urban's area, total water consumption in all the buildings in this area can reflect an estimation for the waste water infrastructure. Finally, appropriate fields should be allocated to all the above mentioned information, in the storage structure. The proposed process for this section is presented in Fig. 5.

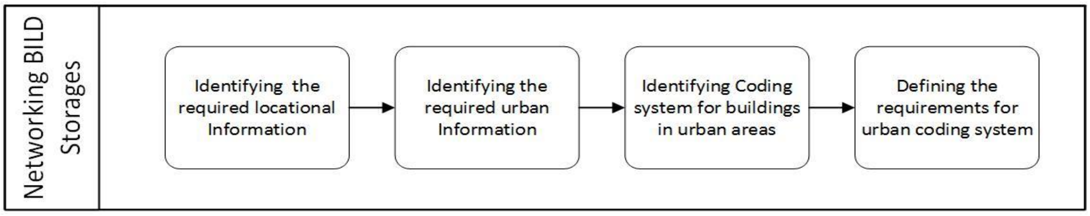


Fig. 5. The process building network of BILD storages

### *D. Multi-sources Live Data Capturing*

The last phase of the proposed process model is transferring the qualified live data to the BILD storage. As the first step in this process, the live data are captured from the detected IOT devices and sensor. This captured data are stored in the databased associated with their software. In this condition there is a need to define an interface to obtain the data from these devices and sensors software. Then this data is utilised through the further steps. Referring to the second phase (i.e. 4.2), some fields have been defined to store the live data for the installed devices in the building spaces. Therefore, the capture data can be transferred to their related fields in the BILD storage. However, before this step there is a need to ensure about the quality of the captured data. In case of passing the quality control step, data is ready to be transferred to BILD storage. This process is shown in Fig. 6.

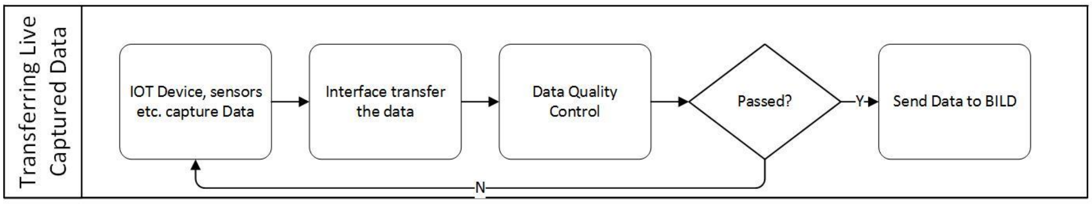


Fig. 6. The Qualifying and Transferring the live data to BILD storage

Indeed, this is the only iterative phase in the whole process model. This phase is responsible the most updated data on the status of the installed devices in building spaces.

The abovementioned phases have been defined to collect, qualify, integrate and store building information and live data in an open storage. This storage will be accessible by all industries. The relations between these four phases are shown in Fig 7.

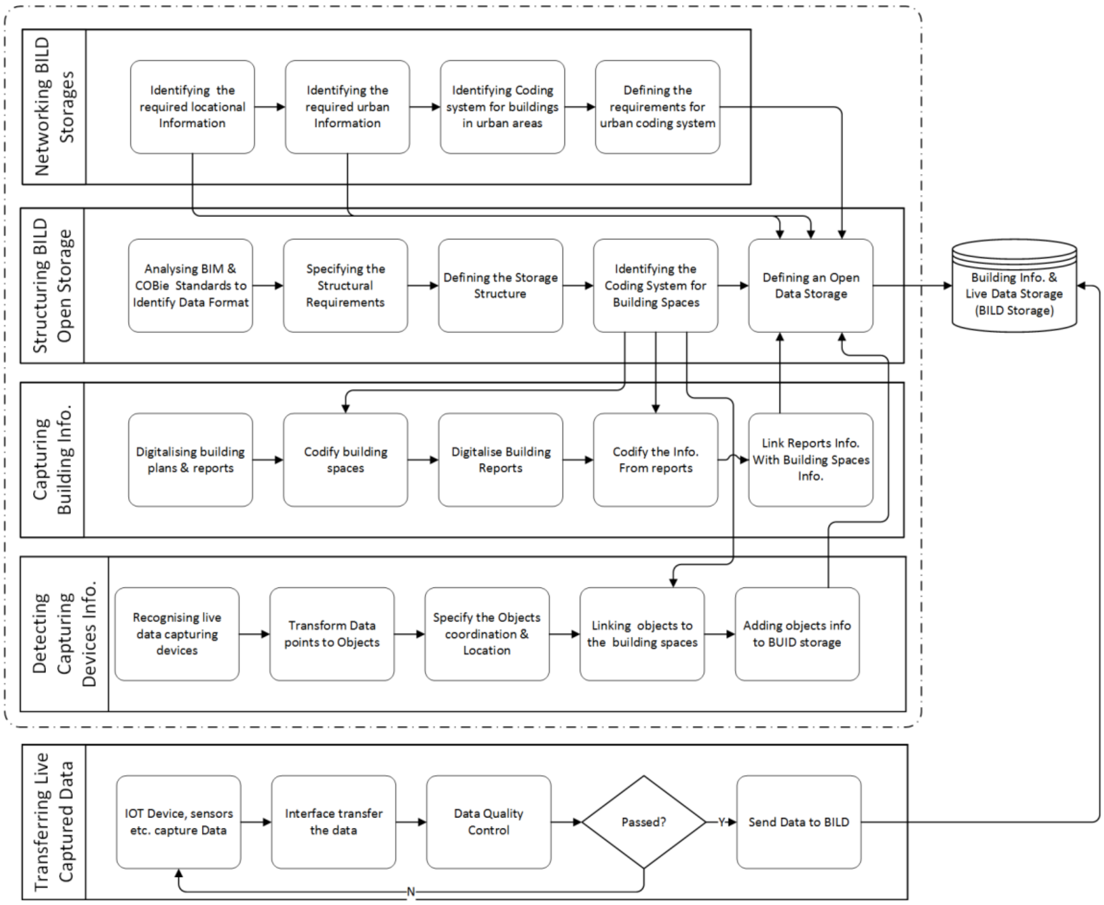


Fig. 7. The overall process model and relations between sub-processes

Based on the above process model, the defined sub-processes for four phases are interacting to build up the structure, as well as feeding the information into the BILD storage. The first four sub-processes in the process model are happening once (to construct the BILD storage structure), while the last phase is the iterative sub-process which continuously feed live data into the storage. Indeed, this phase is responsible to update installed devices status. The proposed process model has been demonstrated to the experts in construction field, IOT devices and sensors for validation purpose. In the next section, more details is provided on validation of the proposed artifact by this study.

## V. Validation

For evaluation purpose of the proposed process model, this research follows [25] ex-ante evaluation approach. To do this, first a focus group discussion was conducted for conceptual evaluation of the proposed process model in terms of relevancy of the process model to the challenges in building information area. Later, two different use-cases are explained as the evidences to prove that this information are current in this field. In the following three sub-section more details are provided on focus group discussion and two use-case. Later, in the fourth sub-section, a discussion is conducted on two evaluation aspects, i.e. relevancy and current information.

### *A. Focus Group Discussion with Professionals*

According to procedure stated in [24], to apply focus groups in in the design science context, some steps are needed to be considered. The sequence of these steps are: 1) formulating the problem; 2) Identifying sample frame; 3) Identifying a moderator; 4) Developing and pre-test a questioning route; 5) recruit participants; 6) conduct focus group; 7) analyse and interpret data; and 8) report results. Based on this requirements, the defined problem for the focus group session defined as: 'whether the proposed model is relevant to the current challenges facing building information management, in terms of data integration'. The focus group attendees were six practitioners from construction industry professionals, IOT expert and data analysts. This focus group session has been conducted with the aim of providing some evidences from participants on how good this process model may fit into its defined goals. The main two goals are integration of building information and captured data and also storing this information in an open access format consistent with construction industry standards. The main objective for this session was getting a consensus on to how extend this process model may achieve its defined goals. Therefore, we invited two participants for each of three different areas in the process model, i.e. construction practitioners, IOT experts, data analysts. The moderator of the session was the main author of this paper who has a background in construction industry. For developing and pre-testing the questioning route we first defined questioning route. For this purpose, this research followed [12] to conduct a conceptual evaluation we. Based on this approach the questions should be in the form of "*This information is relevant to our work"*, "This information is sufficiently current for our work". Then, we had an interview with two invited practitioners and revised the questions based on their expertise. In the following two sub-sections two use-cases of using building information are described as the evidences for usefulness of building information to other smart industries. Then, in sub-section 5.4 the results of focus group session and two use-cases are discussed altogether.

### *B. Building Information and maintenance*

As [9] believed, the proliferation of advanced computerisation throughout industry has revolutionised the way that buildings are designed, constructed, operated and maintained. According to [15] one of the key challenges in building projects is the need to have sufficient information on products ready available for any maintenance operation, such as product specifications. Also [16] believed that maintenance information of products installed into building during the construction phase should be available for maintenance stage facilities management. Likewise [16] stressed that detailed product data might be needed to respond to the demands from authorities or users to track the used products. Obviously, there is a high demand for integration of building information with installed devices in buildings. Therefore, the proposed process model by this study can be a solution for the recognised challenges for maintenance phase of buildings.

### *C. Building Information and Smart Energy*

Regarding the increased efforts for energy saving and energy cost reduction, utility companies attempt to find new ways to promote more effective ways of energy usage. In this regard, [6] stated that it is exceedingly important to have the capability to quickly and reliably estimate the buildings' energy consumption, especially for public authorities and institutions that own and manage large building stocks. For this purpose, many researchers utilised machine learning and data mining [27], regression models [11] to predict and estimate building energy consumption. However, some other researchers like [13] and [2] believed that building energy consumption highly depends on building information. Obviously, to estimate or predict the building's energy consumption there is an essential need to have access to the building information, while there has been no such possibility. This is due to this fact that building information is not accessible by other industries.

### *D. Discussion on Focus Group Results and Use-Cases*

During the focus group session, four different questions related to four phases of the proposed process model were discussed. According to the results, all the participants believed that different phases of the process model are relevant and necessary for data integration. Also they all stressed that this information is sufficiently current in their area. For instance, IOT experts stated that this is a new demand from their customers' side to have a list of IOT devices installed in the buildings and they are looking for a solution to respond to this need. Similarly, construction experts believed that the integration of live data with building information is an essential issue in this area. Therefore, they strongly believed that proposed process model has the ability to address data integration issues. As a result of this evaluation session, all the participants believed that this process model is an appropriate and exact approach to respond the current demands in the construction industry. From the other side, two explored show-cases realise that other smart industries may benefit from building information, if they have the ability to access to this valuable information. Examples of potential advantages of accessing building information explained earlier (in sub-sections 5.2 & 5.3). Therefore, these use-cases can be evidences on this fact that building information is current for smart industries as well. Therefore, this study believes that the proposed process model, by providing the ability to openly access to building information, can provide more added values to other smart industries as well.

## VI. CONCLUSION

The building information and the live data are a valuable asset which can be utilised by the construction industry users for the maintenance services, estimating energy consumption, capacity estimations for infrastructure planning and many other aspects. Although diverse technologies such as building information modelling have been developed to manage the building information, however, industry users are not unable to benefit from the combination of this information with the live data. Moreover, this combination of the information and the live data should be openly accessible needless of the skills to use specific professional environments like the BIM. Overcoming this challenge, this research proposed a process model to collect and integrate the building information with the live data. Then the integrated information is stored in an open storage consistent with the data exchange standards in the construction industry. This open storage has the ability to be accessed by all the potential users from different industries. The propose model by this paper has been prepared to apply be applied in a real case in the facility management industry. By going through the future steps to implement the proposed process model, more details will be provided to the readers.

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