Mixed Reality Approach for the Management of Building Maintenance and Operation

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Abstract

Building Information Modelling (BIM) has been indicated as the right tool to provide the construction industry with the productivity boost that has been lacking in the last 40 years. This momentum finds its highest fulfilment in the support provided by BIM models to knowledge management and the automation of process. However, the management of information flow is still far from its automation breakthrough and, as far as operation and maintenance are concerned, knowledge about procedures is often incomplete. Moreover, processes are often do not undergo optimisation and the individual steps to be performed are not communicated, but in facility management (FM) the transmission of know-how is fundamental particularly because some operations are dangerous or risky. In this framework, Mixed Reality (MR) represents a powerful means to communicate the correct data concerning both geometric features to be considered and the standard procedure to be followed. The aim of this paper is to investigate the possibility of exploiting the benefits provided by these technologies to achieve automation in the transmission of information and optimisation of procedures, improving efficiency and productivity thanks to a better understanding of the operations to be carried out and the reduction of errors. With the support of a head-mounted display (HDM) device with a see-through screen capable of presenting 3D virtual objects, this research tries to combine information from a BIM model with reality to study the benefits for maintenance personnel.

Keywords –
Mixed reality, BIM, Operation and Maintenance

1 Introduction

Facility Management is the phase in the entire building life cycle with the highest costs and yet to date little attention is still being paid to it. Nevertheless, there would be plenty of room for improvement for various aspects of operations and maintenance. The possibility of performing assisted diagnoses, automatically detecting components, avoiding surveys for the collection of information are all scenarios that offer great opportunities for improvement, particularly in terms of automation, since the automation of procedures is the benchmark for the improvement of efficiency and productivity. This research starts from an analysis of the needs which are still not being satisfied in the maintenance industry. Once the goals are established, the aim is to test the effectiveness of a system that collects together some technologies that, when considered separately, have already been demonstrated to increase efficiency in the construction industry. The BIM paradigm, which is rapidly spreading and establishing itself as a guarantee of efficiency, cloud systems for data management and mixed reality, which is the most interesting version of virtual reality since it allows human interaction with the digital environment created. This work aims to demonstrate the feasibility of this system and lay the foundation for its implementation by analysing its architecture and identifying all its components. Finally, on the basis of the needs identified, three scenarios the system could be used to bring benefits to and improve efficiency by reducing time and costs are proposed.

2 Scientific Background

The operational phase of a building is the main contributor to the cost of the building's life-cycle. Studies show that this cost is five to seven times higher than the initial investment costs and three times the cost of construction [1]. It is, therefore, crucial to identify increasingly efficient methods for managing the life-cycle of buildings.

At the same time, Building Information Modelling (BIM) has become the new international benchmark for improved efficiency and collaboration in the different phases of the life- cycle of a building [2].

One of the first necessities when performing commissioning or preventive and corrective maintenance is to identify building components (equipment, materials and finishes) and related information for quick identification and solution of possible problems [3].

Several studies state that building maintenance requires a comprehensive information system that captures / retrieves information about those components that may need intervention [4].

But building inspections are time and cost consuming, both with regard to on-site surveys and, even more, the subsequent BIM modelling of the data collected. In this regard, several researches have been initiated to facilitate this task by finding faster methods to retrieve information and communicate results, while other studies are focusing on the possibility of reaching automated reconstruction of 'as-built' building models [5, 6, 7].

After the surveying phase, one of the biggest challenges in the construction industry today is information management, both in the construction phase and in the building management phase. In order to manage buildings a huge variety of information are necessary [3]. As regards variety, to take maintenance decisions, facility managers require the integration of various types of information and knowledge created by the different members of a construction team such as maintenance records, work orders, causes and knock-on effects of failures, etc. Moreover, when it comes to information, besides the data that can be collected or the individual technical specifications of the various components of the building, a further aspect that needs to be kept in mind is the knowledge created from maintenance operations such as the lessons learnt from the investigation of the causes of failure, the reasons for choosing a specific maintenance method, the selection of specialist contractors, ripple effects on other building elements [4]. This knowledge also includes the fundamental know-how to train new personnel and therefore should be captured/retrieved in sufficient details. However Building Information Modelling is not tailored to individual processes and this makes it very difficult to enter the aforementioned kind of information if not already considered by the IFC structure [5, 8].

Cloud database systems represent a tool for connecting information of different disciplines that is not placed in building models and information related to processes [8]. Furthermore cloud computing has the ability to support construction projects in the sharing of documents and information despite the fragmentation of the construction industry [9, 10]. In particular, the power of cloud computing lies not only in making the sharing of documents and information possible, but also in improving it and allowing it to be exchanged in real time. [11,12] In fact, one of key challenges in operation and maintenance processes is always the need to have sufficient information about products readily available.

The Cloud-BIM system not only provides an information display service, but also provides information manipulation services for users located anywhere and at any time [13]. A link from BIM models to FM databases could help detect and diagnose construction equipment based on the necessary information such as specifications and maintenance history, which could be automatically associated with the equipment located and delivered to the staff on site [2]. Effective and immediate access to information during operations minimises time and labour and helps avoid ineffective decisions made in the absence of information [14].

This system for the management of large information flows can also find the necessary support for on-site visualisation thanks to a head mounted display that supports mixed reality. Starting from the definition by Milgram and Kishino [15] of mixed reality as a "spectrum of reality" ranging from pure "reality" (seen by a user without computer intervention) and pure "virtual reality" (a computer-generated environment where the user has no interaction with the physical world), it can be said that MR is any environment that incorporates aspects of both physical reality and computer-generated reality, for example, by overlapping virtual objects over a user's field of view of a real space. As far as augmented reality (AV) is concerned, it is a predominantly real environment with some virtual elements. Milgram et al. also gave other details about MR, which is also defined as a special class of Virtual Reality-related technologies for creating environments wherein real world and virtual world objects are presented together in a single display [15].

Thanks to these characteristics, mixed reality has already found application in on-site support to operators, especially with regard to the need for a good training of operators and access to large amounts of information about equipment management . In these circumstances, in fact, the capability of AR to involve construction personnel in increased workspaces allows a user to work with the true 3D environment while visually receiving additional computer generated or modelled information about the activity in progress. Mixed Reality can improve the user's perception of the real environment, showing information that he could not directly acquire without help [16].

Despite the great successes of BIM-based VR and cloud computing in improving the performance of AEC activities, it is still necessary to examine methods and systems to integrate both BIM virtual reality and cloud computing for advanced project communication among remote project stakeholders with a shared immersive virtual experience [11].

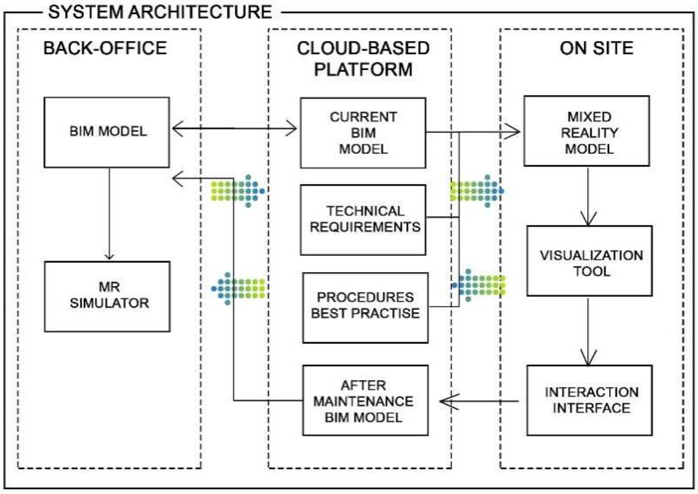

Figure 1. System Architecture

Indeed the research presented in this paper is mainly focused on:

- integrating the BIM virtual model, the real environment and operators;

testing the mixed reality approach in three novel scenarios (inventory/survey support, diagnosis, remote support to operations).

3 Research Methodology

This research starts from the study of FM needs. The identification of these challenges leads to a huge set of data requirement which become the starting point for the creation of a BIM model of the building. Following a survey with maintenance expert personnel additional information and procedures are collected. Since the management of all the maintenance data must be real time, therefore fast and efficient, the study foresees the use of cloud platforms for the management of large amounts of data and consequently the creation of interfaces between the model and virtual data. Finally to verify the proposed approach, simulations of the three different scenarios are carried out with both preliminary and real world test.

3.1 Requirement analysis

In literature it is widely recognised that FM includes and involves multi-disciplinary activities and, as a consequence, has extensive information requirements. [2] Operation and maintenance are a substantial part of the FM and can be related to structures or facilities which may be very different from each other. Many references about the most important needs to be met in order to best perform maintenance interventions can be found in literature.

In this research the analysis will be enhanced by also considering the opinions of experts in the maintenance sector.

In literature, requirements can be split into:

aided document/information retrieval

components localisation

procedure management automated support

personnel training

automated identification and modelling of components

Aided document and information retrieval is based on the use of BIM software for modelling buildings. The digital model of a building could, in fact, contain information on the maintenance operations carried out, the level of deterioration and technical specifications, making this data easily retrievable and providing an immediate localisation in the building. Furthermore, the digital model could be supported by cloud data storage systems for procedures or extended information that cannot be inserted into the model. [17,18,19]

In literature, research attempting to identify, in a more or less detailed way, the information needed for buildings maintenance management can also be found. This depends largely on the type of facilities and on the operations to be carried out. Among the necessary data, Hamledari et al. indicate the details associated with the inspection process, such as the person/organisation responsible, defects, as-built type, as-designed type, data capture tools, time/date of the inspection, the inspector's notes and the images captured [20]. Gao et al. begin, instead, from a more detailed analysis of the components to be detected on-site, starting from the OmniClass classification and integrating it with data fields in a COBie worksheet [21].

A further informative requirement concerns the localisation of the component which is an expensive activity in terms of time and effort. Conventionally, maintenance personnel on-site rely on paper-based blueprints or on their experience, intuition and judgment in finding and locating equipment,such as HVAC systems and electrical, gas and water lines, which are usually in places that are not easily visible, e.g. above ceilings, behind walls or under floors. This task becomes of great importance especially during an emergency, or when newly assigned personnel takes over responsibility for the facility or when the equipment has been replaced or removed. Also in this case, the BIM as-built model can be of great help, also considering the clear visualisation that the 3D model provides. [2,22]

It is crucial to organise and have information regarding also the procedures to be followed always available : which maintenance and repair works must be performed, when these works must be done, how work can be undertaken safely and which works are most needed. [17]

These initial information requirements are all included in the training of personnel, who are currently managed through presentations, on-site visits, hand-hand demonstrations and self-study, which requires intensive preparation, takes a long time and depends largely on the skills and experience of the trainers. [2] This would certainly benefit from organised data management and advanced visualisation and support tools. [23,24]

Lastly, the real geometry of buildings often differs from the original plans and for this reason the reconstruction of a precise 3D model is a common requirement. The efforts in automated modelling have so far focused on the segmentation and recognition of large structural components and more strongly for the exterior rather than for internal components. However, modelling should also include small-sized indoor items for different purposes (scheduled maintenance, storage and documentation, FM, security, feeding of building information models). In addition to this, recent research focused more on capturing geometric data rather than semantic representations of buildings and feeding point cloud data into BIM software [5, 25, 26, 27, 28, 29] This requires, on the one hand, a certain work of interpretation of the data collected, on the other hand, it omits a series of information that goes beyond the geometry of the elements and which is necessary for process management. In general, although this proves to be a demanding task, so far relatively few studies have turned their attempts to reduce modelling/ conversion efforts from construction data acquired into BIM objects with a high semantic meaning. [23,24,30]

3.2 System architecture

This research proposes a framework that integrates the information flow from office to operation site and vice versa. The architecture of the system proposed is actually composed of three different fields of action: the back-office, a cloud-based platform for big data management, and the operation site (Fig.1).

Starting from the back-office, this is the place where operators work. They have access to all the documents (BIM model, data sheet, etc.) and give support to the operators on site. The back office contains also the BIM model and the MR simulator necessary to enrich the virtual environment.

The cloud-based platform is the place where the BIM model updates are shared. At first, the model of the current state is shared, so that the information packages and procedures can be connected to objects. Then, following the maintenance operations, also the updated BIM model is shared to allow the back-office model to be updated.

The on-site part of the system makes available equipment to provide the technician with the MR view, the visualisation of the virtual reality on top of the real one and an interface that allows the interaction and transmission of information to the cloud system.

3.3 Cloud-based Platform

The BIM model of a building needs a deeper range of information in order to be usable for MR applications. All this information can be integrated through cloud systems for big data management. The choice of the use of a cloud based platform to support data flows depends on the need of having a schema that allows fast and efficient queries among data coming from different technologies or with different purpose and, as other researches have shown, IFC is not a suitable choice for real-time applications [3]. The maintenance operation data to be included in a cloud system concern, on the one hand, a specific in-depth analysis of the components, containing all the technical information necessary for the interventions, and, on the other, the procedures that the personnel must follow to complete the operations.

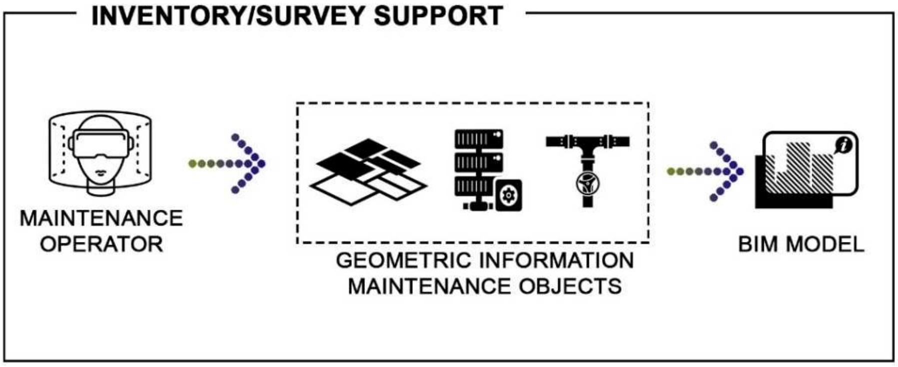

Figure 2. Inventory/survey support scenario

3.4 Design of workflow management

The information data will flow through the different components of the system by means of the cloud platform. Depending on the applications, it will be decided how and which interfaces to use to guarantee interoperability and allow the different users (back-office operators, designers, technicians) to collaborate. The flow will move in both directions, from the office to the site and vice versa, thus allowing a continuous exchange of data, which will make it possible to have continuously updated documents and the perfect knowledge of the asset status.

3.5 Development of on-site technology

The on-site part of the system proposed is developed with the support of a head-mounted display device with a see-through screen capable of presenting 3D virtual objects on top of existing physical surfaces. [31] This technology enables maintenance personnel to interact with the building and with virtual building objects, thus, pushing mixed reality towards a necessary goal so as to promote its widespread use [11].

The MR functions provided by this device include the possibility of displaying virtual objects and performing automated localisation in the building without markers.

This interaction brings also the possibility of capturing real-time data (e.g. updating maintenance operation results) which, in turn, allow constant updating of the model leading to having the updated version of the digital building all the time.

3.6 Preliminary and real world test

The tests to determine the reliability of the system will be performed, at first, in a predefined environment, the basis for the creation of the system itself. This experiment will have the purpose of calibrating the system and verifying the system's main functions based on the intervention scenario taken into consideration. Secondly, the test will be carried out in the real world, in a new environment. That is where the possible sources of interference will be evaluated and the remote support function will be tested.

4 Three interventions scenarios

Following the requirement analysis, as far as the management of maintenance operations, scenarios with criticalities only partially solved have emerged. These are the usage scenarios which are the basis of three frameworks that have been developed for information flow management and on-site support.

4.1 Inventory/survey support

Existing building data collection is the necessary basis for asset maintenance management and it is a challenging step. Recovering all the necessary information on all the elements of a building could indeed be difficult or sometimes impossible [19,24]. A series of new or more advanced technological applications are emerging to make information acquisition faster and more efficient (Scan-To-Bim for small building components), but often these applications are not related to the creation of a BIM model [30]. The first intervention scenario is therefore the automated acquisition of data on the status of fact (Fig. 2). To make the creation of a BIM 3D model of the building as automated as possible, this collection of data should be based not on point clouds or generic surfaces but on objects, which are the basic elements of BIM digital modelling.

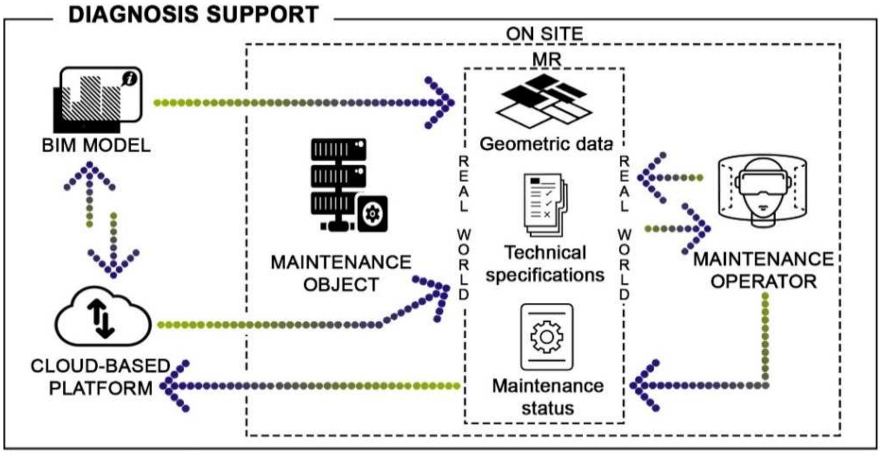

Figure 3. Diagnosis support scenario

In order to allow this type of recognition, it is essential to identify the objects' relevant features that will allow the operator to perform the recognition. This type of analysis involves the adoption of a precise and codified classification that makes it possibloe to detect all the elements involved in maintenance operations, at the same time collecting also the information necessary for the subsequent operations. The innovative contribution of this research work lies in its aim to provide a more efficient object inventory and a more rapid conversion of the elements identified during inspection into BIM elements by adding not only geometric but also semantic data and trying to minimise the post-collection work of the data acquired.

4.2 Diagnosis support

The second scenario this system could bring benefits to is that of diagnosis (Fig. 3). The prime set of information functional to diagnosis is undoubtedly the geometric one. Correct and immediate localisation of the objects on which it is necessary to operate certainly allows a reduction of possible misunderstandings, also thanks to the mixed reality display viewer that avoids having to rely on paper documents, thus making the possibility of error lower, keeping in mind that the overlapping of a virtual reality allows maintenance personnel to see hidden things (e.g.

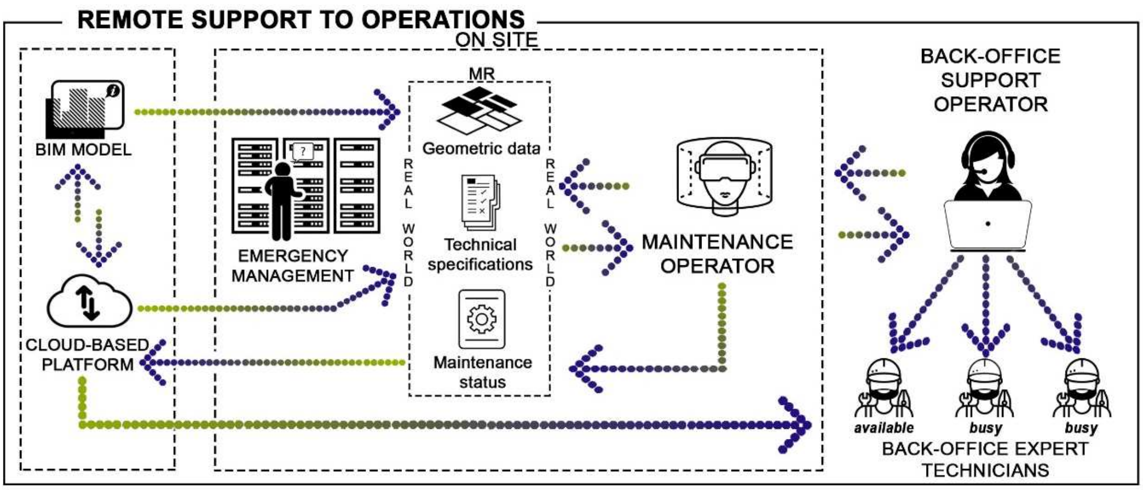

Figure 4. Remote support to operation scenario

steel in the concrete or cable paths in the walls or behind the floor). In addition to geometric data, there are also technical specifications and descriptions of components to be updated and stored and procedures to be followed in the operations. All these data start from BIM and cloud databases and can then be visualised thanks to a head-mounted display and be immediately available on site.

4.3 Remote support to operations

The last scenario taken into consideration is that of on-site operatios support from back-office (Fig. 4). Sometimes it is not possible to reduce maintenance operations to a standard procedure displayed as an object property. Therefore, in case of emergency, a standard procedure to be performed is not always available. These are the circumstances in which back-office support can be fundamental.

Moreover, sometimes not all information can be displayed automatically, because it would result in having a large amount of bulky data to be handled on site. In this case, remote support can be of great help for all the information that would be complicated/ difficult to find automatically, which is more efficient than asking a colleague working remotely (e.g. the pieces out of production in stock).

5 Conclusion

The aim of this research project is to provide support for the operation and maintenance phase during building life-cycle. This study focuses on the possibility of a combined use of three big technologies, the BIM paradigm for data management, a cloud-based system for managing information flows and mixed reality, to obtain an interaction between operators, digital model of the building and information flow.

A data set, not covered by this project, that could be developed in the future is that related to the building functional data and therefore the management of on-site safety, an issue that is always very important, since it aims at reducing risks at the workplace.

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