Next-Generation Integrated Asset Management System with Building Information Modelling

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Abstract: By leveraging the conceptual framework of Building Information Modelling (BIM) in information interoperability and reusability, the Electrical and Mechanical Services Department (EMSD) has proposed a novel architecture for exploiting BIM in integrating asset management (AM) and other operation and maintenance (O&M) systems/tools, including Building Management System (BMS), Closed Circuit Television (CCTV) system, Radio Frequency Identification (RFID) scanning tool and Real Time Location System (RTLS). This was done with a view to streamlining building O&M services. An integrated BIM-AM system has been developed to implement the novel architecture, and the results have successfully demonstrated the system capabilities and potential for next-generation building O&M services.

1. Introduction

As the largest Mechanical, Electrical and Plumbing (MEP) maintenance agency for the public sector in Hong Kong, EMSD is always on the lookout for better solutions to provide quality and cost-effective O&M services to its clients. BIM technology has rapidly emerged in recent years in the construction industry to reduce construction and design efforts/resources for building design and MEP engineering works. By facilitating early coordination among different disciplines, BIM significantly reduces variation orders for rework, hence shrinking construction schedules and project costs. However, BIM application in the O&M stage of the building lifecycle is yet to be explored, and whether or not directly applying BIM to AM could benefit O&M much is still a question. While there are many research studies and real-world applications of BIM in facility management (FM), most of them tend to focus on information transfer from BIM to FM software [1,2,3,4]. For instance, the population of FM/AM database to FM/AM software from the as-built BIM by such means as developing Revit Add-ins, exporting BIM model in IFC format [5], or delivering COBie as a spreadsheet or an XML file [4,6,7]. These real-world applications are, in essence, generally not considered as full integration among BIM, FM/AM software and multiple O&M systems in terms of their integration diversity and extent, as compared with EMSD's integrated BIM-AM system.

BIM is conceived as an object-oriented (OO) computer-aided design (CAD) system that supports the representation of building elements in terms of their 3D geometric and functional attributes as well as their inter-object relationships. This paper aims to show that, by leveraging the conceptual framework of BIM in facilitating effective storing, exchanging, sharing and managing O&M information in an interoperable and reusable way, a novel architecture for exploiting BIM in integrating AM and a variety of O&M systems/tools has been successfully implemented by EMSD with the view to streamlining building O&M. Such a BIM-AM system application has been piloted in EMSD Headquarters since April 2014 to evaluate its O&M effectiveness. The pilot results have broken new ground in the application of BIM and could potentially fill a void in the market. An integrated BIM-AM system has been successfully developed and such a system is considered viable for next-generation building O&M services. The BIM-AM system features multiple O&M tools in a single integrated application, offering real-time O&M information sharing/retrieving and exchange capabilities, thus making system handover and O&M much more efficient and effective. It enables pre-diagnosis for fault handling, among other benefits.

2. Integrated BIM-AM System

The use of BIM should not be limited to building design and construction processes, but also be extended to FM/AM and O&M stages by seamlessly conveying the necessary asset information from an as-built BIM model. Undoubtedly, there is enormous potential in BIM's value. By its OO nature, BIM is also an effective and powerful tool in capturing and reporting defects at the as-built handover stage.

Owing to the utmost importance of information accessibility for efficient O&M, the asset related information that can be obtained by maintenance staff should not be limited to static asset attributes of each building element residing in the BIM model. To close the gap between direct adoption of BIM and day-to-day O&M practice, EMSD has investigated the appropriate integration/interfacing between BIM and a variety of O&M systems/tools that can assist

and streamline O&M workflow together with FM/AM system for asset and service order management. The idea behind featuring multiple O&M systems/tools in one single integrated system lies in the very concept of BIM that its every building element is represented as an object with its own geometry, relations and attributes.

2.1. Significance

Full integration of BIM with an AM system as well as a variety of O&M systems/tools including BMS, CCTV system, RFID scanning tool, and RTLS has not been realised, despite a number of real-world projects involving information exchange between BIM and FM/AM system [4,7,8] or even with BMS integrated in the same system [4,8]. EMSD is the first to propose and implement a novel architecture for the aforesaid full integration as depicted in Fig. 1. The dotted line in Fig. 1 indicates the integration that may have been implemented in some other FM/AM software applications whereas the solid line indicates the full integration that was first proposed and implemented by EMSD in 2014. Under this architecture, AM software is considered an O&M software application for asset management, preventive maintenance and corrective maintenance management including workflow for fault reporting, handling and monitoring. It is worth noting that EMSD's BIM-AM system is at the forefront of BIM integration in terms of the integration diversity and extent as compared with other researches and relevant real-world applications. The BIM-AM system allows locating and visualising any particular asset with its latest and real-time asset information by manoeuvring freely throughout the BIM model in one single integrated BIM-AM system, instead of mere data exchange between BIM and AM systems.

Moreover, EMSD has established its own BIM-AM asset hierarchy for MEP installations by modifying the current EMSD MEP asset hierarchy for Heating, Ventilation, and Air Conditioning, Fire Services Installation, Low Voltage Switchboard, and Lift and Escalator, etc. To facilitate MEP contractors to input asset information and particularly asset relationships in efficiently populating the data to the BIM-AM system, spreadsheet templates of BIM-AM MEP asset register as shown in Fig. 2 were also specially designed.

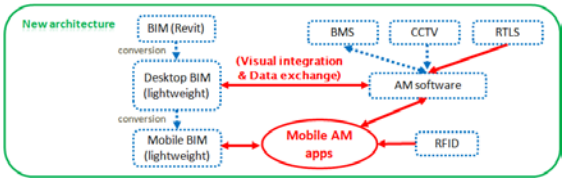

Fig. 1. The novel architecture for an integrated BIM-AM system

Equipment No.	Equipment type	Parent Equipment 1	RFID No.	Switchgear No.	Type of Circuit	Rating (A)	Make	.....
123456	Switchgear (ACB)	111122	ABCD0001	6N1	Incomer	3200	Ellison	.....
123457	Switchgear (MCCB)	111121	ABCD0002	6N2	Sub-main (Normal)	400	Merlin Gerin	.....
123458	Switchgear (MCCB)	111121	ABCD0003	6N3	Sub-main (Normal)	800	Merlin Gerin	.....
123459	Switchgear (MCCB)	111121	ABCD0004	6N4	Sub-main (Normal)	400	ABB	.....
123460	Switchgear (MCCB)	111121	ABCD0005	6N5	Sub-main (Normal)	800	Federal	.....

Fig. 2. Sample spreadsheet templates of BIM-AM MEP asset register for switchgears

2.2. Static Asset Information

Cross-platform mobile and desktop solutions were developed for the integrated BIM-AM system in this pilot. Static asset information such as asset attributes, maintenance records, manuals, as-built system drawings, asset relationships and system topologies can be accessed anytime and anywhere. It should be noted that the feature of displaying system topology was purposely developed in this system to visualise the asset relationships of any selected asset within a particular system for efficient O&M. The mobile screenshot of asset relationships as shown in Fig. 3 indicates the parent assets, dependent assets and related assets of a VAV box whereas the system topology as shown in Fig. 4 provides a graphical view of the asset relationships of the VAV box within the overall system.

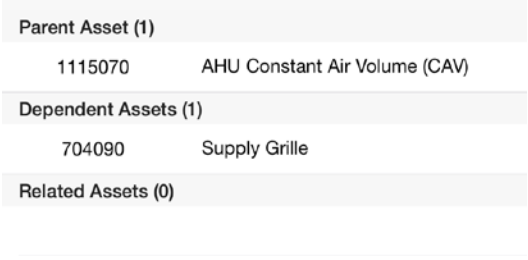

Fig. 3. Asset relationships displaying the parent assets, dependent assets and related assets of a VAV box

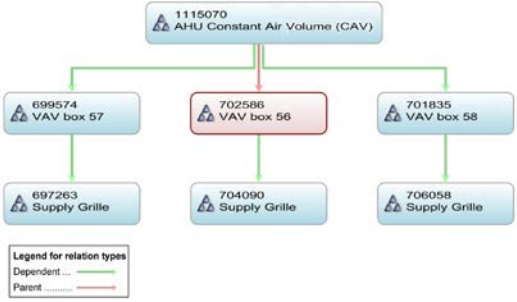

Fig. 4. System topology visualising the asset relationships of a VAV box within the overall system

2.3. Integration with BMS and CCTV Systems

It was found that real-time asset related information is crucial for effective and efficient fault diagnosis and rectification in MEP systems. When such real-time information could be made available together with the live site images from remote-eye CCTV cameras before fault attendance on-site, it would enable frontline staff to carry out pre-diagnosis so that they may bring all necessary spare parts/tools to the site in one go. Our BIM-AM system has been integrated with BMS and CCTV systems to made such real-time information available at the mobile terminal for frontline staff, so that he/she could remotely access not only the system status by the BMS sensors and live view of the site, but also may attempt to clear the fault by remotely controlling/configuring some of the major MEP equipment, if appropriate, simply via the keyboard at his/her fingertips. Fig. 5 is the screen-shot of the mobile terminal showing the captured real-time BMS monitoring sensor values of an Air Handling Unit (AHU). In some instances where suspected system components causing potential system breakdown are required to be closely monitored, ad-hoc wireless sensors were developed for prompt installation and monitoring of any abnormal change of equipment/ambient temperature, sound pressure or power consumption. The hyperlink of sensors data could easily be appended to the particular asset in the BIM-AM system as part of its ad-hoc attributes. The data collected from the ad-hoc sensors /and the existing BMS can be further analysed for on-going condition monitoring, generation of pre-fault alerts or energy management.

Similarly, an ad-hoc wireless mobile pan-tilt-zoom CCTV camera was developed for incident handling. It can easily be installed at any strategic location not covered by the existing CCTV system and the live feed hyperlink can also be appended to any particular asset in the BIM-AM system as part of its ad-hoc attributes, such that supervisor /and frontline staff can visualise the real-time incident situation and closely monitor the contractor's work progress when necessary. Fig. 6 shows the live feed of an ad-hoc camera available at the mobile terminal for monitoring the subject plant room area.

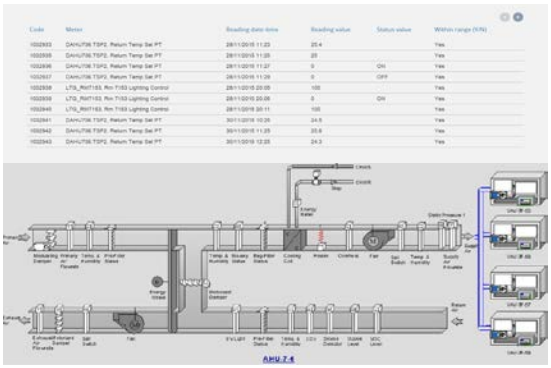

Fig. 5. Real-time BMS monitoring interface of an AHU in the BIM-AM system

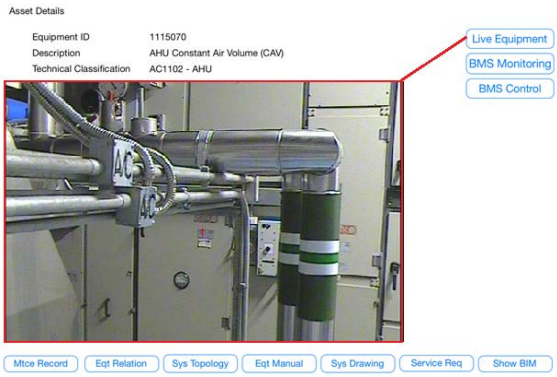

Fig. 6. CCTV live feed in the BIM-AM system at the mobile terminal

2.4. Integration with RFID Scanning Tool and RTLS

For years, RFID has been considered as a practical methodology in FM/AM application such as managing and tracking inventory and assets. Having integrated with the RFID scanning tool, the BIM-AM system as shown in Fig. 7 would facilitate frontline staff to efficiently and effectively locate critical equipment for further enquiry of asset information such as maintenance record, static and dynamic O&M manual, the afore-mentioned real-time sensor data and site image, etc., even if the equipment is hidden above a false ceiling or underneath a raised floor. By quickly manoeuvring and cross-referencing the related area in the BIM model, details of the connected pipe work and upstream/downstream equipment locations can be easily traced, making all that is invisible visible.

To extend the locating feature from fixed assets to movable assets, such as certain mission critical mobile medical devices deployed inside a hospital, for timely preventive maintenance, two advanced RTLS over WiFi as well as Ultra-Wide-Band (UWB) technologies were piloted in EMSD Headquarters. This aimed to help optimise the use and distribution of valuable assets and thus increase equipment availability. As shown in Fig. 8(a), RTLS over WiFi was integrated with the BIM-AM system for locating movable assets in zone level of approximately 3-meter radius. UWB-based RTLS as shown in Fig 8(b) has been successfully examined as a viable solution for applications demanding higher positioning accuracy in the order of centimeters, such as patient tagging. Though these electronics

systems are standalone O&M systems/tools in themselves, their capabilities would be much enlarged via their synergy with BIM for O&M application.

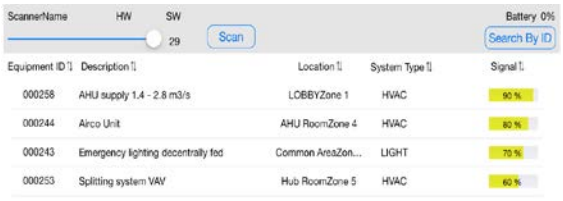

Fig. 7. RFID scanned results listing nearby assets in order of signal strength

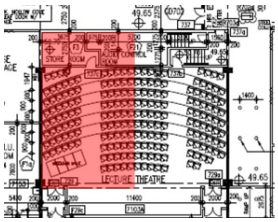

Fig. 8(a). RTLS over WiFi

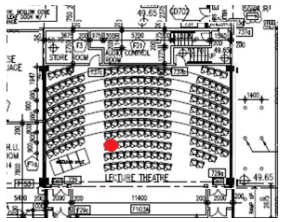

Fig. 8(b). RTLS over UWB

2.5. BIM Visualisation and Associating Assets in BIM-AM System

RFID scanning tool has its limitations in accurately locating a particular tagged asset due to its fundamental constraints of electromagnetic radiation and orientation of the tag being installed. RFID tag detection is hardly feasible when the tag is installed behind a metal surface. Under such circumstance, cross-reference to the related BIM model could be an effective alternative. The BIM model provides abundant visual information of any MEP installations down to detailed piping and ducting works. Such visualisation is of paramount importance for effective pre-planning and site preparation in alterations, additions and improvements (AA&I) works, such as by using design simulation over the BIM model. This is particularly useful when the site is not easily accessible or the concerned asset is installed in a concealed area. If the improvement work is to take place in a public area, pre-planning using BIM simulation is so accurate and effective that it can eliminate the need for pre-planning visits and on-site site preparation, thus significantly reducing interruption and inconvenience caused to the public. Overall, BIM enables a greater degree of creativity in the implementation of AA&I works via visualisation that takes all relevant factors into consideration.

BIM is also superior to 2D/3D CAD drawings for AA&I works, as its visualisation corresponds more closely to the depth and quality of building information. 3D views formulated by 2D CAD drawings of facilities such as elevations, plans and sections are difficult to be visualised. Even 3D CAD images are only composed of graphical entities supplemented with separate document files. Hence, when editing 3D CAD views, checking and updating all related drawings and document files are still required and such operations are error-prone and inefficient.

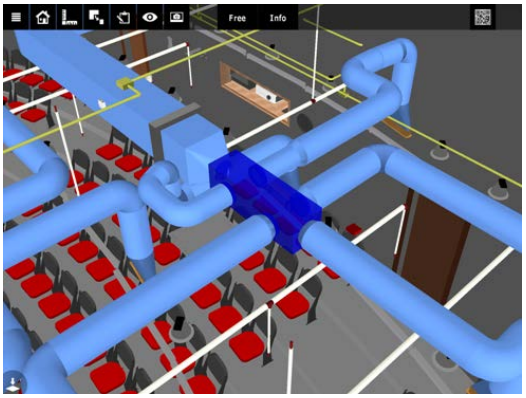

Fig. 9. Georeference of a VAV box in a BIM model

Fig. 10. Georeference of a VAV box in a 2D CAD layout drawing

On the contrary, BIM is a centralised database model with all documents interdependent and carries coordinated information in an effective and efficient way. It allows full BIM integration in EMSD's BIM-AM system, which was achieved by associating individual assets with its Global Unique Identifier (GUID) in the BIM model such that each individual asset could be tied to its 3D geometric location. This is far superior to the non-geometric information exchange between BIM model and BIM-AM system in other FM/AM software applications. As shown in Fig. 9, a VAV box can be visualised and quickly located in its approximate real-world physical location. This facilitates not

only on-site system handover from an as-built BIM model, but also enables easy cross-referencing to a BIM model when carrying out O&M activities on-site. Our BIM-AM system also supports association between an asset and its location in 2D CAD layout drawing. Fig. 10 shows the georeference of a VAV box in a CAD drawing generated by our BIM-AM system. In relation to the value and practicality of georeferencing assets and assets information for O&M applications, a mobile application showing floor plans in JPEG format has been developed and used by EMSD for streamlining fault attendance and site performance measurement activities [9]. In future, Geographic Information System can also be integrated with the BIM-AM system to enrich the features in managing multiple buildings in a holistic view based on geographical locations.

2.6. O&M Workflow Management

The integrated BIM-AM system provides a comprehensive and coordinated O&M workflow management platform for fault reporting, handling and monitoring. In the BIM-AM system, the entire maintenance workflow from service request creation to service order management can easily be achieved. In real-life building O&M service situations, the interaction among different parties in the client, contractor organisations and EMSD is dynamic and versatile. BIM is able to cater to these highly dynamic interactions by assigning different roles to different parties on its platform to facilitate efficient and effective O&M service, supervision and communication at all times.

Features of integrated BIM-AM system	Online/Offline	Client	Helpdesk	Supervisor	Frontline	
					Pre-site	On-site
1. Make service requests	*^ Online submission (*^ Offline input)	X	X			
2. Enquire service request's status	*^ Online	X				
3. Create service orders	*^ Online		X	X		
4. Check and record for **repeated call**	*^ Online		X	X		
5. Attach additional information & remote support to frontline (e.g. mobile CCTV)	*^ Online		X	X		
6. Assign service orders	*^ Online		X	X		
7. View service orders for the **same venue**	*^ Online		X	X	X	
8. Retrieve service orders	^ Online				X	
9. Monitor and control BMS and ad-hoc wireless sensors	*^ Online			X	X	
10. View the live feed of fixed-installed and ad-hoc mobile CCTV cameras	*^ Online			X	X	
11. View the locations of movable assets from RTLS	*^ Online			X	X	
12. RFID scanning for quick search of asset and its further O&M information	^ Offline					X
13. View asset details, maintenance record, asset relationships, system topology, manual & system drawing	*^ Offline			X	X	X
14. Georeferencing assets in BIM model	*^ Offline				X	X
15. Input service orders details	^ Offline				X	X

*: Desktop solution; ^: Mobile solution
Pre-site: back-office with Internet connection; On-site: incident site without Internet connection

Table 1. Features of the BIM-AM system for O&M of EMSD Headquarters

In EMSD's BIM-AM system, we have identified four key generic user models, namely Client, Helpdesk, Supervisor and Frontline. Respective user interface design with system features have been specifically developed for each user model to carry out their role activities effectively at either a desktop or mobile terminal. To make the BIM-AM system design truly generic and versatile, we have worked to ensure that the system can cater for different user operational modes and requirements at different venues. Taking EMSD Headquarters as a showcase building, Table 1 shows the wide variety of features that the BIM-AM system can carry out under the four different user models. The Helpdesk role, for instance, can be carried out by EMSD's in-house facility management unit staff. At the same time, we can also assign the Helpdesk functions to our team of customer service officers working at our

7x24 Customer Service Centre to maintain over 2,000 government buildings in EMSD's O&M service portfolio, using the same user design interface. This is just an example of the versatility of the BIM-AM in real-life service situations. Fig. 11 to Fig. 14 capture some of the screenshots of the generic user interface design.

Here is how the four roles function on the BIM-AM system in real life. A user-friendly interface has been designed to allow the Client to select the related MEP system and raise a service request at the mobile or desktop terminal as shown in Fig. 11. To stay well-informed of work progress, the Client can also enquire about the latest status of its service requests raised in the BIM-AM system. Alternatively, the service request can be created by the Helpdesk directly as shown in Fig.12 where the Client simply makes a phone call to the Helpdesk to do so or enquiries the latest status later on. The Helpdesk will create and issue respective service orders directly to the available frontline staff who will then carry out the works in some cases, or to the Supervisor for subsequent service order assignment. The Helpdesk will record the repeated service order status in the system as shown in Fig. 13(a) so that the Supervisor can be easily notified or alerted of the status, and prioritise the service orders received. The Supervisor can also oversee the status of all service orders of venues under his/her charge on a dashboard as shown in Fig. 13(b), depending on his/her level of authority. This may range from the level of a work supervisor, an engineer and all the way up to directorate, depending on the specific situation. The Frontline's mobile device terminal can also be given to an outsourced contractor who will view and take action of service orders assigned, as shown in Fig. 14(a). Just like our in-house frontline staff, the contractor's staff can also make use of the BIM-AM system as shown in Fig. 14(b) to carry out their work effectively.

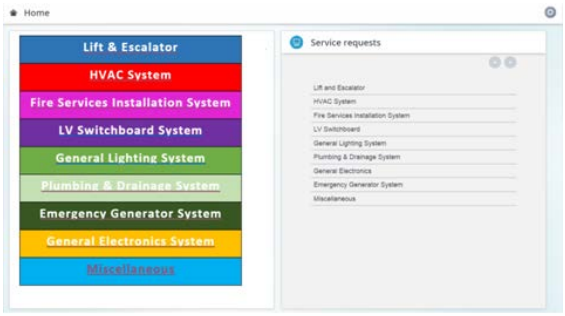

Fig. 11. User interface for Client:
Creation of service request by system type

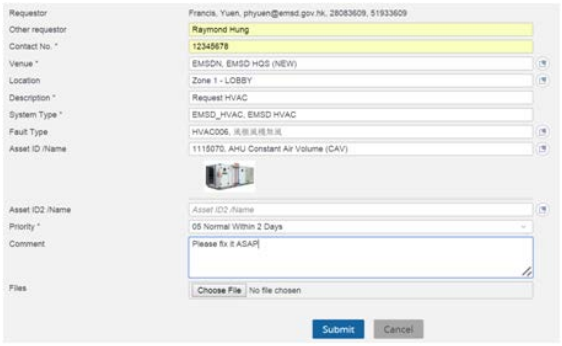

Fig. 12. User interface for Helpdesk:
Service request input upon receiving phone calls from clients

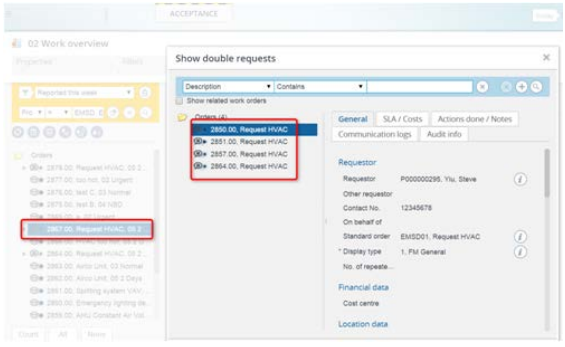

Fig. 13(a). User interface for Helpdesk/Supervisor:
Automatic recommendation for repeated order

Fig. 13(b). User interface for Supervisor:
Dashboard showing total pending orders, total repeated orders, orders by system type, and orders by status etc

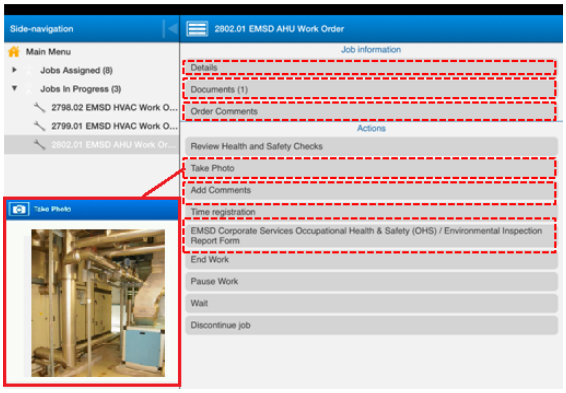

Fig. 14 (a). User interface for Frontline:
Service order management supporting viewing of order details, photo upload, and electronic form for safety compliance

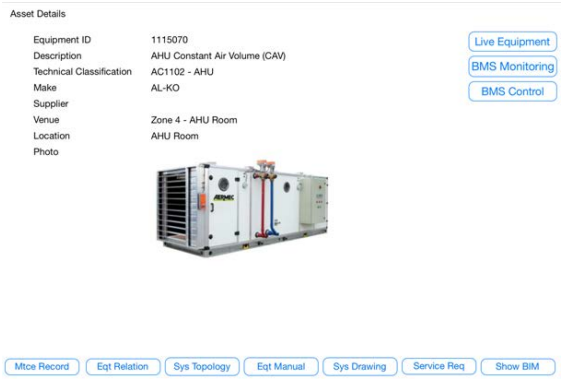

Fig. 14 (b). User interface for Frontline:
Asset management by viewing asset attributes, maintenance record, equipment relationship, system topology, manual, and system drawing as well as creating service request and cross-reference in BIM

3. Demonstration

To evaluate the O&M effectiveness and benefits of the integrated BIM-AM system, simulated O&M works scenarios using an AHU model and a fire sprinkler system model in the BIM-AM system were recorded in videos for demonstration purpose [10]. Together with several simulated storylines for cost and time benefit analysis, the results demonstrate that the integrated BIM-AM system can improve productivity in numerous aspects, such as faster fault response, better workflow management, higher safety compliance by interactive electronic forms, easy retrieval and appending of maintenance record, prompt access of asset details, relationships and manuals, clear visualisation of MEP system routings in 3D and so on. The benefits of the BIM-AM system differ according to venues and applications. One of the key benefits worth mentioning is that the integrated system can enable O&M staff to respond faster to incidents and emergencies, especially at mission critical venues such as hospitals and airports.

4. Conclusion

EMSD has proposed a novel architecture for exploiting BIM in asset management and realised the concept in an integrated BIM-AM system featuring multiple O&M systems/tools in one single platform. Results of our pilot project demonstrate that BIM-AM is a highly visual, real-time O&M and asset management tool that can enhance the maintainability and availability of MEP facilities in buildings. The integrated platform has proved effective in streamlining workflow, facilitating responsive incident handling and effective AM. The tool has great potential to bring major benefits including long-term cost savings in the O&M building lifecycle. Though the successes arising from EMSD's pilot BIM-AM architecture and system are only on a limited scale, EMSD hopes the integrated BIM-AM system would not only benefit its Trading Fund services in operating and maintaining over 2,000 government buildings, but also encourage and facilitate the construction industry in Hong Kong to better deploy this new technology for next-generation building O&M services, ultimately benefitting the public.

In this regard, EMSD has been collaborating with the Construction Industry Council (CIC) in designing and building a pilot BIM-AM system for its Zero Carbon Building, with the view to promulgating awareness of BIM-AM to the industry and assisting CIC to formulate the Hong Kong BIM MEP data and drawing standards. We have been sharing our BIM-AM project experience and transferring the technical know-how and technology via talks and seminars. Furthermore, the BIM-AM system for the Zero Carbon Building which we are building for CIC, once completed, will be used by CIC to promote BIM know-how to the industry. We are delighted to have the opportunity to support the construction industry via our BIM work and will contribute further via more knowledge sharing.

5. References

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