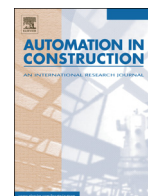




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A framework for the utilization of Building Management System data in building information models for building design and operation

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ABSTRACT

Research on digitizing the various aspects of a typical building project has been on the increase since the advent of Building Information Modelling (BIM). Most efforts build on information technology capabilities already achieved in the various professional domains associated with different stages of the building life cycle. It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs. As such BIM is now being utilized in the various professional domains and project stages. However, research suggests that the building operation and management stage is being left behind despite the abundance of data collected using building management systems (BMS) of varying degrees of sophistication. It is therefore important to consider exploring BIM applications that encompasses the building operation phase. This will enhance the evaluation of building performance in use and provide feedback to the design stage which could help eliminate design-related performance issues. A framework for utilizing feedback loops from building energy consumption to inform and improve design and facility management in a BIM environment is therefore proposed. A prototype illustrating the framework is implemented in. NET framework interfaced with a BIM-enabled tool and tested in the refinement of a pre-designed school using data from the operations phase of another school delivered previously. We conclude that the framework developed in this research can contribute to bridging existing gaps between the design, construction and operation phases of a building's life-cycle.

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1. Introduction

The advent of BIM promises to greatly reduce the seeming complexities inherent in the facilities manager's tasks as well as those of other professionals in the construction sector. Current research on building information modelling (BIM) focuses on digitizing the various aspects of a typical building project as part of the design and perhaps construction stages. Hence, research efforts towards addressing BIM use in the operational phase is still at its infancy [1,2].

Most of the current research efforts are built on the BIM/computer-aided capabilities already achieved in the various professional domains associated with the different stages of the building life-cycle such as planning, design, construction and, perhaps operations. For example, the object-based features and parametric modelling capabilities displayed by contemporary BIM-enabled systems are improvements on CAD systems and the earlier achievements made in the graphical representation of solid geometry [3,4]. Similarly, domain-specific tools

(e.g. for structural analysis and design, architectural drafting) have been in use and improved over the years as advances were made in information technology and communication. Perhaps this approach to software development resulted in persistent issues with interoperability, and thus barriers to seamless information exchange. The overall aim of the developing contemporary BIM approach is to provide consistent digital information that can be reused by stakeholders throughout the building life-cycle [4,5]. It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs, as well as assisting with asset management.

As the scope of BIM gradually expands towards asset management, there is the need to learn from building performance by establishing and utilizing feedback loops to the appropriate stages in the project life-cycle. This can be achieved through the establishment of frameworks such as the one implemented in this research. The envisaged benefits of using BIM for asset management include providing instantaneous results on anticipated building performance and identifying areas (such as energy modelling and sustainable material selection) of weaknesses in design and specifications so that they can be improved in forthcoming projects. Although sustainability (including energy) analysis tools for early planning and design purposes exist, the performance data they generate are disconnected and separate from their

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Table 1
Building energy management tools.

Tool	Functional description
Building energy performance tools for design purposes	
Autodesk Ecotect	Sustainable design analysis software that offers a range of simulation and building energy analysis functionality to improve performance of existing buildings and new building designs. Its capabilities include Whole-building energy analysis, Thermal performance, Water usage and cost evaluation, Solar radiation, Daylighting and Shadows and reflections
Autodesk Green building studio	Cloud-based energy-analysis software used for whole-building analysis optimization of energy consumption and carbon-neutral building designs in early project phases. Functions include Whole-building energy analysis, Detailed weather data, Energy Star and LEED support, Carbon emissions reporting, Daylighting, Water usage and costs, Natural ventilation potential
DOE-2	A building energy analysis programme that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.
eQUEST	A building energy use analysis tool that allows comparison of building designs and technologies by applying sophisticated building energy use simulation techniques.
BEopt	The BEopt™ (Building Energy Optimization) software can be used to evaluate residential building designs and identify cost-optimal efficiency. It can be used to analyse both new construction and existing home retrofits. It provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, vintage, location, and utility rates.
Facility Management tools	
Artra (Trimble)	Artra provides seamless information links between the multiple engineering systems. It enables information to be provided in the relevant format for jobs and has mobile capability for delivering complex data.
Onuma Planning Systems	A web-based Building Information Modelling (BIM) tool that can be used for early planning, Project Program Development, Charrettes (BIMstorms), Schematic Design, Connect to other BIM applications, Cost estimating, Energy Analysis, Life Cycle Costing, Facility Management, Portfolio and Program Management
Autodesk Project Dasher	Project Dasher is a web-based application that helps to augment existing Autodesk® Revit® design models with real-time building sub-meter and sensor data on electricity and occupancy. It presents a comprehensive framework for monitoring building performance using a visualization hub where collected data from various sources is intuitively aggregated and presented in 3D to enhance the ability to infer more complex causal relationship pertaining to building performance and overall operational requirements.

ultimate downstream use by facility management systems [6]. This also means that there is a gap in the upstream flow of feedback from the building's operational phase. The general consensus from literature [1, 6] is that the building operations phase is disconnected from the earlier phases of the project life cycle in terms of delivering the product and information exchange. It is alleged as a tradition but also as a key obstacle against asset owners extracting maximum value from their investments [6]. Thus, the anticipated value of design-operation integration can only

be fully accrued if feedback loops from the building operations phase can be established.

In order to meet the relevant standards, design specifications usually identify materials and systems for production/construction according to anticipated performance mainly based on laboratory tests and manufacturers' claims on performance. The Literature suggest that the design stage offers a good opportunity to influence cost and sustainability [7, 8]. It is therefore important that performance information is verified from actual historical performance data collected during the operations phase. However, professional domains have not sufficiently explored this opportunity as identified in Oti and Tizani [9] and Wang et al. [10]. Alwan et al. [6] remarked that assets have been often made attractive by declarations of design aspirations while an ever expanding performance gap exists. In facilities management (FM), existing information gaps with design are partly because of the way projects are being delivered with little or no consideration for the integration of FM issues unless a Client consciously requires this to be done [6].

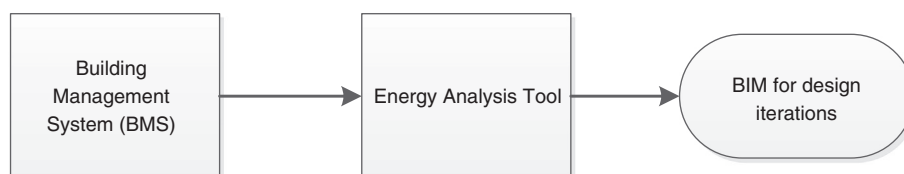
This paper aims to devise a framework for such integration. It illustrates how feedback loops from operations to design can be established by incorporating building management system (BMS) data into a federated BIM to inform the designer and the facility manager. Its objectives are to: (i) ascertain challenges in the integration of building operation and BIM (Section 2), (ii) identify building energy consumption data acquisition and feedback options to BIM (Section 2.2), (iii) establish a framework for BMS data utilization in BIM (Section 4), (iv) implement a prototype to link BMS data to BIM (Section 5.1) and (v) test the system implementation in a real-life project (Section 5.2).

The paper is divided into seven sections. An introduction and insight into the research problem is given in Section 1. Section 2 provides a background on the role of performance data acquisition in facility management with respect to BIM leading to the description of the adopted research methods in Section 3. Sections 4 and 5 respectively present the proposed implementation framework for BMS data utilization and integration in BIM and illustrate a test case using the developed prototype. Section 6 discusses the research limitations including likely areas of future expansion and Section 7 concludes the paper.

2. Operations data acquisition and integration in BIM

There are potential areas for BIM application in facilities management where feedback can be useful. Some areas already identified by Becerik-Gerber et al. [1] include locating building components, facilitating real-time performance data access, visualization and marketing, considering ease of maintenance, creating and updating digital assets, space management, planning and feasibility studies for noncapital construction, emergency management, controlling and monitoring energy consumption, and personnel training and development.

While the modalities of BIM implementation may differ in all these areas, what will perhaps be common to all is the process of harnessing feedback from the model to inform and improve asset performance and vice versa. This process will require more than just engaging the facility manager in the design stage as suggested in Wang et al. [10]. It will require careful planning, mapping and integration of the facility management operations into the BIM approach. This paper stems from this premise and evaluates the option of integrating building management system (BMS) into a federated BIM.

**Fig. 1.** BIM - Energy Analysis Tool link.

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