Hamidreza Alavi
Soheila Kookalani
Farzad Rahimian
Núria Forcada

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Hamidreza Alavi
Department of Engineering
University of Cambridge
Cambridge, UK

Soheila Kookalani
Department of Engineering
University of Cambridge
Cambridge, UK

Farzad Rahimian
School of Computing, Engineering
and Digital Technologies
Teesside University
Middlesbrough, UK

Núria Forcada
Department of Project and Construction
Engineering
Universitat Politècnica de Catalunya
Barcelona, Spain

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Chapter 1
Introduction

Abstract This chapter introduces the book, which explores the implementation of Building Information Modeling (BIM) during operation and maintenance (O&M) phases. It starts by outlining the main problem the book addresses and underlines the critical importance of the O&M phases in a project's lifecycle. The chapter then outlines the research aims and objectives, which center on enhancing building performance and occupant comfort through the interoperable integration of BIM and Decision Support Systems (DSS). Moreover, the chapter offers a comprehensive overview of the study's scope. It specifies the aspects of building performance under examination, particularly in relation to maintenance efficiency and the management of building systems such as HVAC, which have a significant impact on energy usage and occupant health. It also outlines the research limitations, including the specific focus on certain building types and the use of particular software tools for risk analysis and BIM. Furthermore, the chapter presents the overall structure of the dissertation, guiding the reader through subsequent chapters that elaborate on state-of-the-art facility management practices, the development of the DSS, and the integration of BIM with these systems to enhance operational strategies. This introductory chapter paves the way for a comprehensive discussion of BIM's potential to streamline data integration and support decision-making processes in building maintenance, ultimately aiming to optimize both operational efficiency and occupant comfort.

1.1 Problem Statement

In the life cycle of a project, the operation and maintenance (O&M) phases are critically important. Compared with other phases, the highest costs occur during the O&M phase [1, 2], which shows the importance of Facility Management (FM) activities. In the broad context of FM, building maintenance is generally recognized as the main activity, since more than 65% of the total cost of FM comes from facility maintenance management [3, 4]. In O&M phase, the FM team and owners are responsible for the upkeep of building elements/systems to prevent functional failures by

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applying corrective and preventive maintenance plans with the aim of achieving energy efficient and improving occupants' comfort [5–7]. For buildings to remain in appropriate conditions for use and to meet a minimum standard or level of performance, they require continuous operating expenses, including periodic maintenance [8]. A poorly maintained building will deteriorate even faster in the long run [9]. Hence, the lack of a proper maintenance plan along with the building's natural aging accelerates the degradation of existing buildings [10, 11].

Among the building systems, the HVAC systems have a significant impact on thermal comfort and, if it is improperly maintained, may result in health problems, and discomfort for occupants [12, 13]. The occupants' comfort within buildings is essential in terms of environmental, social, and economic aspects [14], since people spend approximately 90% of their time indoors [15–17]. In addition, the HVAC systems account for one of the highest percentage of energy use in a building [18, 19]. The use of HVAC energy in unoccupied spaces is sometimes higher than in occupied spaces in commercial buildings [20]. Moreover, standards based on indoor environmental quality (IEQ) factors are used to define the acceptable ranges of comfort [21, 22]. However, due to the variations in individual sensation levels, there is a poor relationship between the comfort conditions defined in the standards and those perceived by the occupants [23]. It is therefore necessary to put occupants at the center of maintenance decisions through the implementation of an occupant-centric approach by collecting occupants' feedback to improve building performance, including occupants' comfort and productivity [24].

To improve building performance based on occupant-centric approach Decision Support Systems (DSS) can be used, making decisions in an early design development stage and during the O&M phase. The former helps designers to identify multiple technical and commercial options that are compliant with pre-determined specifications and the latter help facility managers to optimize building operations techniques [25]. The DSS for maintenance activities with the appropriate information, modeling, and planning can have a significant impact on occupants' comfort as well as building performance, allowing buildings to maintain serviceability before deterioration propagates, prevent defects and failure of the building elements, extend their service life [26–28]. Various types of historical data, including inspection records, and sensor data, are frequently used by the FM team to make decisions on building condition assessment, HVAC problems analysis and occupants' comfort evaluation [29, 30]. Some building maintenance systems, like computerized maintenance management systems (CMMS) are typically used for capturing such data to perform maintenance activities [31–33]. However, the current systems are based on deterministic models [34, 35] and do not take into account the effects on occupants' comfort of building information (e.g., building characteristics) and spatial information (e.g., occupancy density) [36, 37]. Some factors such as climate conditions and building operational conditions are intrinsically uncertain, making accurate predictions of building performance difficult [38]. It is therefore essential to increase predictability by incorporating these uncertainties in order to identify strategies and methods to improve the performance of buildings and occupants' comfort [6, 39].

To incorporate these uncertainties, Bayesian Networks (BN) can be used. BN are a type of probabilistic graphical model that provide a formalism for reasoning about partial beliefs under conditions of uncertainty [40]. It is considered a powerful tool by which to model risks with uncertainty data [41–43]. BN can model building comfort as a probabilistic process, to give the most probable performance level of a building using probability distributions [44]. In addition, it can model a building's condition as a probabilistic process, contrary to deterministic models [45]. Bortolini and Forcada [45] developed a probabilistic model based on BN that covers several interconnected elements for assisting decision-making on building maintenance and retrofitting measures to improve building conditions and support occupants' comfort [44, 46]. Although the models can handle uncertainty and make predictions, the data that is required is dispersed among platforms. Besides, the data is transferred manually, which is a laborious, inefficient process [6, 47, 48].

To address the challenges of data reliability and automatize the data transfer process, a Building Information Modeling (BIM) has been emerging as a potential solution [48, 49] for guiding decision-makers concerning building maintenance [50]. BIM is "an approach to design, construction, and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format" [1]. BIM constitutes an effective platform by which to depict high-quality information and integrate different platforms. BIM utilizes 3D, parametric and object-based models to create, store and use coordinated and compatible data throughout the life cycle of a facility [51, 52]. Acting as a central resource for decision-makers, BIM has the ability to provide better documentation, improved collaboration and work flexibility, and updated information through the building life cycle [6, 53, 54]. BIM integrated with a DSS, may constitute a powerful tool to support the selection of effective maintenance strategies [55, 56]. Nevertheless, the greatest obstacle of the integration of BIM with a DSS is the lack of interoperability in the O&M context [57, 58]. The interoperability issue caused a delay in transferring the FM information into DSS during O&M phase even though the required data is available in the BIM model [59, 60]. It is estimated that inadequate interoperability and incompatibility between systems result in a $15.8 billion total increase in project costs, according to a study conducted by the National Institute of Standards and Technology [61].

To address the interoperability issues, this book presents a conceptual model to integrate BIM models into DSS (e.g., the probabilistic models based on BN). This book focuses on improving both maintenance efficiency, and occupants' comfort by integrating DSS into BIM to optimize building operation strategies and support decision-making on FM activities. This integration facilitates data transfer and reduces the time and effort that the FM team spends on manual input. It also allows BIM tools to visualize in an integrated, interactive way for decision-makers. Moreover, the FM team can make decisions on building operational problems centered on occupant comfort with minimal effort, overcoming a key barrier to collecting required information during the O&M phase.

1.2 Aim and Objectives

The primary aim of this book is to facilitate the interoperability between DSS and BIM specifically during the operation and maintenance phases of building management. This interoperability is crucial for enhancing building performance and supporting effective facility management (FM) activities. By integrating these systems, the book seeks to improve the efficiency of building operations and ensure that facilities meet both operational standards and occupant needs.

To achieve this primary aim, the book sets out several specific objectives:

Objective 1: Identify and analyze shortcomings of the implementation of BIM in the O&M phase. This objective involves a thorough investigation into the current uses of BIM during the O&M phases, pinpointing areas where BIM may fall short in addressing the needs of facility management. This includes assessing how well current BIM implementations support the ongoing maintenance and operational challenges of buildings, and identifying gaps where improvements are necessary.

Objective 2: Identify and devise a solution for generic interoperability problems. The focus here is on overcoming common barriers to interoperability between BIM and other systems used in building management. This involves designing solutions that can facilitate seamless data exchange and integration, thus enhancing the functionality and usability of BIM in real-world applications, particularly in scenarios involving multiple software platforms.

Objective 3: Develop a conceptual model to enable interoperability between BIM models and probabilistic models. This objective aims to create a conceptual framework that integrates BIM with probabilistic models, which can predict and optimize building performance under varying conditions. This model would leverage the detailed information from BIM and the predictive power of probabilistic approaches to enhance decision-making processes in building maintenance and operations.

Objective 4: Establish an effective platform for data visualization. The goal here is to develop a platform that can visually represent data in an intuitive and actionable manner. This platform should enable facility managers and decision-makers to easily interpret complex data derived from integrated BIM and DSS, facilitating better understanding and quicker decision-making regarding building operations.

Objective 5: Evaluate the conceptual model. The final objective is to rigorously test and evaluate the conceptual model developed in Objective 3. This evaluation will assess the model's effectiveness in real-world scenarios, its usability, and its impact on building performance and occupant comfort. This step is critical to ensuring that the model not only theoretically integrates BIM with DSS but also practically improves building management practices.

Through these objectives, the book intends to bridge the gap between theoretical research and practical application, making a significant contribution to the field of building information management and operational efficiency. In addition, the book explores the application of Augmented Reality (AR) to improve the usability and accessibility of BIM data. AR has the potential to offer facility managers a revolutionary method for visualizing and interacting with building data overlaid onto physical spaces.

1.3 Scope of the Research, Limitations, and Delimitations

The research outlined in this book primarily focuses on the development and application of a conceptual model designed to facilitate interoperability between BIM systems and DSS for enhancing building performance management. This involves both the integration of these systems and the visualization of data concerning building conditions and occupant comfort during operation and maintenance phases. The visualization tools developed as part of this research are engineered to be user-friendly, enabling facility managers to easily interpret complex datasets and apply these insights to make informed, strategic decisions about building maintenance and management.

However, it is important to note that the scope of this research does not encompass all facility management activities. Specific areas such as emergency management are excluded to maintain a focused investigation into the interoperability of BIM and DSS and their impact on building performance and occupant comfort. This delineation ensures a targeted approach, allowing for a deep dive into specified areas without the confounding variables introduced by broader facility management tasks.

Facility managers play a crucial role in evaluating and prioritizing building renovations and maintenance actions. They, along with other stakeholders such as building owners and occupants, are involved in a variety of building types, including business, educational, and mercantile sectors. However, residential buildings and specific non-residential buildings like hospitals are excluded from this book due to their unique operational requirements and stringent regulations.

One notable limitation identified in this research is the use of a specific integration model that only employs AgenaRisk for risk analysis and Autodesk Revit for BIM. This limited implementation could hinder the generalizability of the research findings across different platforms and software environments. To address these software-specific limitations, it is recommended that additional Python code blocks be developed to facilitate the implementation of the model across various other software systems.

The research also acknowledges limitations in handling complex building elements. While the model can define and manage data at the level of building facades, it encounters difficulties with finer details such as individual room performance, which would require additional scripting, possibly through tools like Dynamo, to enable room-specific performance evaluations.

The integration methodology is semi-automated, requiring manual oversight to ensure data is correctly named and stored in appropriate locations. This semi-automation may introduce human error and inefficiencies that could impact the effectiveness of the system.