

SURVEY OF BUILDING INFORMATION MODELING INTEGRATION WITH HVAC SYSTEM DESIGN

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ABSTRACT

Building information modeling (BIM) has become a revolutionary digital approach to improve collaboration, precision, and productivity of the entire building and infrastructure lifecycle. BIM, through the development of 3D models that are data-rich, intelligent, allows the integrated planning, design, construction, and facility management of a shared and interoperable information environment. The paper will describe the basics of BIM and give a brief description of the main elements of this technology, including: 3D modeling, parametric design, data enhanced representation, visualization, simulation, and life-cycle management, as well as the key principles that ensure interoperability and collaboration, and the standard of information exchange. Simultaneously, the paper analyzes the design of heating, ventilation and air conditioning (HVAC) system with an emphasis on the critical role of appropriate system sizing to guarantee comfort, energy efficiency, cost-effectiveness and long-term functionality of the system. The recent trends in HVAC design, such as intelligent and adaptive systems, integration of renewable energy and BIM-based design processes, are also addressed. In addition, the paper discusses the modeling of the HVAC system with the help of BIM, which allows for designing the system correctly and analyzing its work, as well as coordinating the work of different disciplines using Revit MEP, AutoCAD MEP, Carrier hourly analysis program, and MagiCAD. Finally, the issues that are relevant to the BIM-based HVAC design are examined, such as the problem of data interoperability, the inability to integrate software, the regulatory void, and the shortage of unified component libraries. The paper highlights how BIM-based HVAC design can enhance building performance and sustainability and identifies the main research and implementation issues that need to be tackled to realize high adoption.

Keywords: Building information modeling, Heating, ventilation, and air conditioning, Energy efficiency, Construction, Revit.

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INTRODUCTION

Building information modeling (BIM), often known as BIM, is one of the most significant aspects that is driving the continuous revolution in the building and construction industry. BIM takes a holistic approach to both the management of projects and the design of buildings. BIM is a strong tool that is used across the entirety of the life cycle of the construction industry. It comprises a variety of vital tasks. BIM enables the production of accurate 3D models in the early phases of a project [1]. These models may capture the geometric characteristics of the building and incorporate helpful information about the materials, components and spatial linkages. This digital portrayal serves as the basis for the project and provides all of the stakeholders with a distinct visual framework within which to collaborate and make decisions. BIM is proving to be an invaluable asset as the project moves forward.

The ability to utilize BIM to virtually construct a building before construction of the actual building provides an effective means to check its constructability in the real world and to resolve any uncertainties during the process. This allows for more efficient, better-designed structures that limit waste of resources, optimize energy usage, and promote passive design strategies [2]. This study investigated the perceptions among attendees at a design/build conference of the use of BIM for sustainable design and construction. The objectives of the research were to (1) analyze the current trends of BIM application in sustainable design and construction, (2) assess application of BIM as a mechanism for sustainable practices, (3) understand application of BIM as a building performance analysis tool, (4) determine potential interoperability problems with BIM software, and (5) determine at what stage in the design development process BIM becomes a useful tool in facilitating sustainable design and construction practices.

Heating, ventilation, and air conditioning (HVAC) systems provide a desirable indoor environment and are an essential element in almost all buildings. Residential buildings are often equipped with air conditioner

packages that are standardized and can be directly produced from factories. However, the HVAC systems of large commercial or office buildings are typically built-up systems that require design and are significantly more complicated than standardized air conditioner units [3,4]. There have been many studies on automated architectural, engineering, and construction design processes that provide efficient and convenient technical means for HVAC system design. On this basis, adding artificial intelligence technology can make the traditional design process more streamlined and reduce engineers' repetitive work [5]. In this paper, it propose a technical framework for automated HVAC system design [6]. The framework splits and simplifies the traditional complex HVAC system design process, and can initially realize the automated calculation, design and result generation of simple office buildings based on the existing technical methods.

Buildings account for one-third of worldwide energy consumption, while HVAC systems consume half of all building energy. HVAC-related issues can decrease energy efficiency by as much as 15%. In addition to lowering energy efficiency, HVAC problems can cause discomfort for building occupants and drive-up operating expenses. A building's annual energy costs can be reduced by as much as 10% when automated fault detection and diagnostics models are used to restore functionality to its original state [7].

Structure of the paper

This paper is structured as follows: Section II covers the fundamentals of BIM. Section III examines an overview of HVAC system design, while Section IV focuses on BIM-enabled HVAC system modeling. Section V provides significant conclusions and suggestions for the future, while Section VI provides a survey of the literature.

FUNDAMENTALS OF BIM

BIM is a comprehensive and collaborative approach to the design, construction, and management of buildings and infrastructure in Fig. 1.



Fig. 1: Building information modeling architecture

At its core, BIM involves creating and managing a digital representation of the physical and functional characteristics of a facility [8]. This digital model serves as a shared knowledge resource for information about a building, providing a platform for stakeholders to collaborate and make informed decisions throughout the entire lifecycle of a structure.

Key components of BIM

BIM is a sophisticated and collaborative approach to design, construction, and facility management that involves the creation and use of intelligent 3D models [9]. These models serve as a comprehensive digital representation of a building or infrastructure project. BIM encompasses a wide range of processes and tools, and its key components are included in Table 1:

- **3D modeling:** The core of BIM is the creation of detailed, three-dimensional models of a building or infrastructure project [10]. These models go beyond traditional 2D drawings, providing a more comprehensive and accurate representation of the physical and functional aspects of the project. 3D models include information about geometry, materials, spatial relationships, and more.
- **Parametric design:** BIM uses parametric design principles, allowing elements in the model to be defined by parameters and rules. This means that changes made to one part of the model automatically update related elements, ensuring consistency and reducing errors throughout the design and construction process.
- **Data-rich models:** BIM includes a wealth of information embedded within the 3D models. This information can range from basic data, such as dimensions and materials, to more advanced data, such as cost estimates, construction schedules, and performance specifications. This data richness facilitates better decision-making throughout the project lifecycle.
- **Collaboration and integration:** BIM promotes collaboration among various stakeholders involved in a project, including architects, engineers, contractors, and facility managers. It enables seamless integration of data and workflows, breaking down traditional silos between disciplines and allowing for real-time collaboration.
- **Visualization:** BIM models provide powerful visualization capabilities, allowing stakeholders to better understand the design intent and project details. This not only aids in the design phase but also enhances communication among team members, clients, and other stakeholders.
- **Simulation and analysis:** BIM supports various simulations and analyses, such as energy performance, structural integrity, and clash detection. This helps identify potential issues early in the design process, reducing the likelihood of costly changes during construction.
- **Life cycle management:** BIM extends beyond the construction phase and supports the entire life cycle of a building or infrastructure. This includes maintenance, renovations, and eventual demolition. The data-rich models provide valuable information for facility management, helping optimize operations and maintenance activities.

Table 1: Key components of BIM

Component	Short description
3D modeling	Creates intelligent three-dimensional representations of building elements with geometry and spatial information.
Parametric design	Automatically updates related model elements when design changes occur.
Data-rich models	Stores detailed information, such as materials, dimensions, cost, and performance data within the model.
Collaboration and integration	Enables real-time data sharing and coordination among project stakeholders.
Visualization	Provides clear and realistic views of the building design for better understanding.
Simulation and analysis	Supports performance analysis, clash detection, and design validation.
Life cycle management	Assists in managing building operations, maintenance, and future modifications.

Principles of BIM

Construction professionals can benefit from BIM in both theory and practice, with an understanding of the ideas underpinning allowing them to have client and colleague discussions that are well-informed, addressing the fundamentals of BIM, its contemporary application in practice, and how things might change in the future [11]. BIM is utilized for exchanging, creating, and collating shared structured and intelligent information and data across a project [12]. To understand the principles behind it and how work methods will need to adjust to accommodate it as its use develops, more construction professionals will be needed. The heart of BIM is well-structured data, which will enable massive efficiency in the construction industry, that across the entire project team and standardized, there is a full collaboration. To aid in the comprehension of BIM is the intention of Practice and the Principle of BIM.

- Emphasizes the data and model interoperability and relevance of integrated practice and collaboration.
- To understand the aims and objectives of the BIM, provide the project team with a road map, its rules, and how it may gather, provide the information that a typical protocol document might include.
- The legal problems that surround the deployment of BIM on a project are thoroughly examined.

Throughout the building's life cycle, BIM models can be thought of as a repository of information that has been generated and managed, as well as the quality of that information and the high quantity were characterized.

OVERVIEW OF HVAC SYSTEM DESIGN

HVAC systems are integral to maintaining comfortable and healthy indoor environments. However, the effectiveness of these systems heavily relies on proper sizing and design [13]. An accurately sized and well-designed HVAC system ensures optimal comfort, energy efficiency, and longevity. Conversely, improper sizing and design can lead to discomfort, increased energy consumption, and premature system failure.

The importance of proper HVAC system sizing

There are many important factors in HVAC system sizing are as discussed in below or in Fig. 2:

- **Comfort and indoor air quality:** An appropriately sized HVAC system maintains consistent indoor temperatures and humidity levels, ensuring occupant comfort. Oversized systems may cycle on and off frequently, leading to temperature fluctuations and inadequate dehumidification. Undersized systems may struggle to meet heating or cooling demands, resulting in discomfort.
- **Energy efficiency:** Properly sized systems operate efficiently, consuming energy proportional to the building's needs [14].



Fig. 2: Heating, ventilation, and air conditioning system sizing importance

Oversized systems consume more energy due to frequent cycling, while undersized systems run continuously, leading to higher energy bills.

- System longevity: Accurate sizing reduces wear and tear on system components. Oversized systems experience short cycling, which can lead to pre-mature component failure. Undersized systems operate under constant strain, reducing their lifespan.
- Cost-effectiveness: While larger systems may seem advantageous, they come with higher initial costs and increased operational expenses. Proper sizing ensures that the system is cost-effective over its lifespan.

Emerging trends in HVAC sizing and design

HVAC Sizing and Design based on emerging trends are as follows:

- Smart HVAC systems and adaptive sizing: With the rise of smart homes and commercial building automation, HVAC systems are becoming increasingly responsive and intelligent. Modern systems now utilize sensors and adaptive algorithms to adjust output dynamically based on real-time occupancy, indoor conditions, and weather forecasts [15]. While traditional sizing is based on fixed assumptions, smart systems introduce a more flexible approach, effectively resizing their output within defined parameters.
- Integration with renewable energy systems: As sustainability becomes a driving force in building design, HVAC systems are now being paired with solar panels, geothermal systems, and energy recovery ventilators (ERVs). This integration demands a more nuanced approach to system sizing.
- Use of BIM: BIM tools are revolutionizing the HVAC design process by offering a 3D, data-rich representation of building systems.

BIM-ENABLED HVAC SYSTEM MODELING

BIM integration with HVAC automation marks a transformative alliance that leverages digital intelligence to enhance the design, installation, and operational phases of HVAC systems [16]. This section provides an overview of the seamless integration between BIM and HVAC automation, elucidating the ways in which these technologies collaborate to optimize building performance.

The integration involves embedding BIM-generated data and insights into the HVAC automation process, fostering a continuous flow of information from the design and construction phases to the operational life of the building. By bridging the gap between the static digital representation of BIM and the dynamic controls of HVAC automation, this integration unlocks unprecedented opportunities for precision, efficiency, and adaptability in building management.

BIM-enabled HVAC system design and analysis

BIM enables an integrated and data-driven approach to HVAC system design by supporting accurate modeling, coordination, performance analysis, and interdisciplinary collaboration [17]. BIM-enabled HVAC tools enhance design efficiency, reduce clashes, and improve system performance across the entire building lifecycle. In Table 2, discuss the purpose and features of BIM Tools and Software for HVAC system design.

Table 2: BIM tools and software for HVAC system design

BIM tool/software	Purpose in HVAC design	Key features
Revit MEP	Detailed HVAC system modeling and coordination	3D modeling of ducts and equipment, clash detection, and multidisciplinary collaboration
AutoCAD MEP	HVAC drafting and layout design	Parametric HVAC components, 3D system creation and editing
Carrier HAP	HVAC load calculation and performance analysis	Hourly load analysis, climate and occupancy modeling, BIM integration
MagiCAD for revit	HVAC equipment selection and placement	Manufacturer-specific libraries, accurate system sizing, seamless Revit integration

HVAC: Heating, ventilation and air conditioning, BIM: Building information modeling

- BIM tools and software for HVAC system design: BIM has catalyzed a paradigm shift in HVAC system design, offering advanced tools and software that facilitate precise modeling, coordination, and analysis [18]. This section provides an overview of the BIM tools and software specifically tailored for HVAC system design.
- Revit MEP Autodesk's: Revit MEP is a widely used BIM software that provides specialized tools for HVAC system design. It enables the creation of detailed 3D models of HVAC components, including ducts, pipes, and equipment [19]. The software supports accurate spatial coordination and clash detection, enhancing collaboration among different disciplines involved in the project.
- AutoCAD MEP: AutoCAD MEP is an extension of AutoCAD designed for mechanical, electrical, and plumbing (MEP) professionals. It includes features specifically geared toward HVAC system design, such as parametric components and specialized tools for creating and editing HVAC systems in 3D.
- Carrier hourly analysis program (HAP): Carrier HAP is a BIM-compatible software used for accurate load calculations in HVAC system design. It allows designers to model building systems and analyze their performance, considering factors, such as occupancy, lighting, and climate [20]. The software seamlessly integrates with BIM platforms to enhance data exchange and collaboration.

MagiCAD for Revit: MagiCAD is a BIM solution that integrates with Revit, offering specialized tools for HVAC system design. It includes a comprehensive library of manufacturer-specific product models, facilitating accurate equipment selection and placement within the BIM environment.

Challenge analysis of BIM-based HVAC design

In the field of building design, it is expected that "virtual building" design based on BIM technology will become the mainstream of computer-aided building design in the future [21]. The relevant regulations and standards are imperfect, and there are still many problems in engineering applications.

- An optimized design of a building thermal system based on Revit and the trade-off load judgment method can determine the optimal combination of the building envelope and the energy efficiency design of the building thermal system.
- Data are the core of BIM technology. A variety of software is required to implement a complete BIM project. The continuity and consistency of data when the BIM model is exchanged between different software is an important premise for the successful application of BIM technology. At present, BIM-related software supports mutual model identification and data transfer, but in the actual application process, the continuity and consistency of the data transferred between different software cannot be guaranteed.
- Building HVAC system design based on BIM technology enables designers to understand the project intuitively, through the display and analysis of 3D models. Meanwhile, BIM technology can reduce the error rate, reduce the rework, and improve the design efficiency

in professional collaborative design. Although building HVAC system design based on BIM technology brings many conveniences to designers, the lack of ‘families’ is the biggest deficiency in the current applications of BIM technology in the field of building HVAC system design.

LITERATURE REVIEW

This section highlights related studies on BIM Integration with HVAC Systems.

Xie *et al.* indicate that LSTM outperformed other models in multi-room scenarios due to its superior context awareness and data fusion capabilities. In contrast, GRU demonstrated the highest real-time performance in single-room setups due to its lower computational complexity and faster convergence. LSTM achieved moderate accuracy with acceptable latency. Hence, LSTM is best suited for multi-room digital twins, and GRU is preferable for single-room digital twins. These insights inform ML algorithm selection for real-time DTs, enhancing sustainable, energy-efficient building management [22].

Espejel-Blanco *et al.* present the design of a control system using Python to control the operation of HVAC equipment in a BEMS (building energy management system). The main objective of this project is to control the turn on and turn off of the compressor used in the HVAC equipment for the cooling stage, trying to reduce the amount of energy used for this task. BEMS is an automatic control system to manage the amount of energy consumption of an entire Building with the objective of achieving energy savings without sacrificing the comfort of the occupants [23].

Xinru and Wei aim to solve the problems of incorrect physical connections between equipment and pipeline in the BIM model, and it is difficult to automatically extract the logical association of equipment. And research a new idea of automatic repair and efficiency optimization of the physical association between equipment and

pipeline for a construction site. Three types of problems, such as breakpoint, misalignment and wrong direction in cross-document, are precisely defined. Then, this paper studies the efficiency of mechanical and electrical integration automation repair, and realizes the batch extraction of BIM modeling and the efficient automatic extraction of information association [24].

ElMansy and Baraka establish a framework utilizing managed BC in the built environment FM. The scope of this system is to integrate the benefits of BIM and BC to manage data from an IoT platform gathering ambient conditions information. The flow of information is regarded in the established framework through the integration of four modules, namely, (1) the data collection module, (2) the data processing module, (3) the data storage module, and (4) the data visualization module. Furthermore, the developed framework is tested and applied for the validation of the approach. Results of the system are shown and are established by the system to be continuously updated and stored [25].

Srisurapanon and Banjerdpongchai present the design of supervisory model predictive control (MPC) for HVAC systems and two zones. The supervisory control (SC) is designed to find the optimal reference temperature of each zone. The design criteria consist of the total operating cost and the thermal comfort cost. Then, the MPC is designed to track the optimal reference signals. When SC and MPC are designed for two zones simultaneously, they are referred to as centralized SC and centralized MPC. On the other hand, when SC and MPC are designed for two zones separately, they are referred to as decentralized SC and decentralized MPC [26].

Wang uses PVsyst, a PV system design software, to clarify key parameters, such as the installation and selection of inverters and PV modules, and then simulates the PV power generation. The information model of this residence is constructed using eQUEST software to analyze the building energy consumption in three aspects: PV power generation, air conditioning energy efficiency, and envelope structure. The results show

Table 3: Comparative analysis of building information modeling (BIM) integration with HVAC system

References	Study on	Approach	Key findings	Challenges/limitations	Future directions
Xie <i>et al.</i> (2025)	ML models for HVAC digital twins	Comparison of LSTM and GRU models in single- and multi-room scenarios	LSTM performs better in multi-room DTs due to contextual learning; GRU excels in single-room setups with lower latency	Trade-off between accuracy and computational cost	Hybrid or adaptive ML models for scalable real-time DTs
Espejel-Blanco <i>et al.</i> (2024)	HVAC control in BEMS	Python-based control system for compressor ON/OFF control	Reduced energy consumption while maintaining thermal comfort	Limited to basic ON/OFF control strategy	Integration of predictive and AI-based control mechanisms
Xinru and Wei (2024)	BIM-based HVAC pipeline and equipment coordination	Automated repair of physical and logical connections in BIM models	Efficient detection and correction of modeling errors (breakpoints, misalignment)	Complex cross-document BIM dependencies	Intelligent BIM validation with AI-assisted error correction
ElMansy and Baraka (2023)	BIM-Blockchain integration for FM	Framework integrating BIM, Blockchain, and IoT data	Secure, continuous data updating and visualization for FM	System complexity and scalability concerns	Large-scale deployment and real-time analytics integration
Srisurapanon and Banjerdpongchai (2023)	HVAC supervisory control for multi-zone buildings	Centralized and decentralized SC-MPC control strategies	Improved balance between operating cost and thermal comfort	Computational overhead in centralized control	Distributed and AI-enhanced MPC frameworks
Wang (2022)	BIM-based PV-integrated building energy analysis	PVsyst and eQUEST simulation with BIM integration	BIM-PV integration enhances energy self-sufficiency	Simulation-based validation only	Real-world BIM-renewable energy integration studies
Kia and Moradi (2022)	Optimal HVAC control	LQR-based control with Lyapunov stability analysis	LQR gains significantly affect energy use and control performance	Model dependency and tuning sensitivity	Adaptive and learning-based optimal control methods

HVAC: Heating, ventilation, and air conditioning, BIM: Building information modeling

that PV buildings can promote the realization of energy self-sufficiency and, combined with BIM technology, can play a role in promoting the development of green and energy-efficient buildings [27].

Kia and Moradi designed a control system based on the LQR optimal control method for this air conditioning system, including two heating and cooling operations. Then, after examining the stability of the system based on the Lyapunov stability criterion, and also a temperature control performance index is defined to express and compare the performance of the control system with different gains. Finally, by performing the simulation, the control and HVAC system performance is evaluated with the help of a defined performance index in the presence of a designed algorithm, which results show that LQR gains have a direct effect on energy consumption and control system performance [28].

Table 3 provides a summary of BIM Integration with HVAC System, including the study, Approach, Key findings, and challenges.

CONCLUSION AND FUTURE WORK

BIM has been found to be an effective and revolutionary paradigm in contemporary building design and construction, and specifically in the framework of HVAC system modeling and optimization. BIM supports the effective coordination of the multidisciplinary stakeholders, minimizes the design errors, and increases decision-making at each lifecycle stage of the building by combining a smart, information-rich 3D model with a collaborative workflow. BIM use in designing HVAC systems facilitates the correct determination of loads, effective sizing of the system, clash detection, and performance analysis, which translates to enhanced indoor comfort, energy efficiency, cost effectiveness, and life span of the system. More superior versions of the BIM, such as Revit MEP, AutoCAD MEP, Carrier HAP, and MagiCAD, make the design process even stronger as these versions provide smooth modeling, analysis and equipment selection. Although these benefits exist, there are still difficulties, such as the problem of data interoperability between various software platforms, the absence of unified libraries of HVAC components, and the interregnum in regulations and implementation standards. These limitations are fundamental to the realization of the full potential of HVAC design using BIM.

Future work

The implementation in the future will be done in enhancing interoperability between the BIM platforms by the use of a standardized data exchange and open BIM frameworks. A combination of BIM with new technologies, such as digital twins, IoT, and AI-based analytics can allow to conduct real-time monitoring, predictive maintenance, and adaptive HVAC control. The creation of standard libraries of HVAC components and the reinforcement of regulatory standards will contribute to the further development of the efficiency, precision, and popularity of the BIM-based design of HVAC systems.

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