Optimization of Energy through BIM in the Construction Industry

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A Thesis
submitted in partial fulfilment of the

requirements for the degree of:

Master of Science in Construction Management

University of Washington
2023

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Program Authorized to Offer Degree

Construction Management

University of Washington

Abstract

Optimization of energy through BIM in the construction industry

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The construction industry is experiencing rapid technological advancements with Building Information Modeling (BIM) and Building Energy Modeling (BEM), which have the potential to revolutionize how buildings are designed, constructed, and operated. These technologies are not well practiced and there is lot of confusion regarding the use of these technologies.

This research is conducted to explore the current state of BIM and BEM in construction industry, data exchange between BIM and BEM, the need for enhanced education and training in these domains, Tools and methods used for BIM and BEM and the impact of integrating BIM and BEM closely on time and resources.

The study also emphasizes difficulties associated with the adoption of BIM and BEM, emphasizing the obstacles to data exchange such as compatibility, integrity, and standardization.

Despite these challenges, the study highlights the benefits of integrating these systems, including improved collaboration, decision-making, and building efficiency. In addition, the thesis highlights the importance of education and training in BIM and BEM and underscores the

significance of acknowledging the benefits of integrating these systems to improve building energy performance and promote sustainable development.

While the advantages of implementing BIM and BEM are open to debate, there are some participants who expressed that the investment of time and money may not be justified. Overall, BIM and BEM are becoming critical in achieving building energy goals in the construction industry. However, challenges exist in exchanging information between the design and simulation domains, time and cost that must be addressed to ensure their continued relevance and usefulness in the long-term.

Acknowledgement

By embarking on my thesis journey, I was able to deeply delve into the field of research and construction industry, allowing for extensive exploration and learning. I would not have been able to accomplish this without the unwavering support of Prof. Carrie Sturts Dossick. I express my sincere gratitude to Prof. Carrie Sturts Dossick for her invaluable guidance,encouragement and mentorship throughout this journey. Your Patience and careful assistance at every step helped me to complete my thesis. I would also like to thank Prof. Hyun Woo Lee for his valuable feedback and input as a member of my thesis committee.

I would like to thank to all the interviewees who generously shared their time and knowledge for this research.

I extend my heartfelt appreciation to the Construction Management department faculty for recognizing my thesis efforts with the John E Schaufelberger Endowed Fund for Student Research, and for encouraging me to continue my academic journey. Lastly, I would like to thank my family and friends for their consistent encouragement and support.

Dedication

Dedicating my thesis to my family and my partner is an important way for me to express my gratitude and appreciation for their unwavering support throughout my academic journey.

Their constant encouragement and understanding have been instrumental in helping me to overcome challenges and achieve my goals. My family has been my source of strength and inspiration, and I am forever grateful for their sacrifices and love. Likewise, Deepanshu my partner has been a constant pillar of support, offering his unwavering love and encouragement every step of the way. Dedicating my thesis to them is a small token of my appreciation for everything they have done for me.

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Chapter 1

Introduction

Approximately 20%–40% of world's energy consumption is attributed to the building sector, accounting for one-third of all greenhouse gas emissions [4]. Climate change caused by global warming poses a significant threat to the survival of humanity by bringing about catastrophic weather changes. This phenomenon, attributed to human activities, has far-reaching consequences on the energy consumption, carbon footprint, and indoor climate of buildings. Additionally, it may result in sick building syndrome. As a result, building experts and regulatory bodies acknowledge the significance of constructing energy-efficient buildings to mitigate the detrimental effects of climate change on buildings [5].

Analyzing the energy performance of buildings during the design phase has become increasingly important due to the greater awareness of its effects on both the environmental impact and lifespan costs of a building. As more people recognize its significance in terms of building life cycle costs and environmental impacts, evaluating energy performance in building design is gaining importance [4]. Even though most energy analyses still utilize statistical estimates or simplistic static calculations (the conventional method), assessing energy efficiency in building design is now more critical than ever, given the significant influence of energy consumption on a building's environmental impact and life cycle [4].

Energy simulation software has been around for many years, with popular programs like TRNSYS, ESP, DOE-2, and BLAST having existed for almost half a century. However, newer tools like Energy Plus and IDA-ICE have been developed to offer more precise energy analysis outcomes [4]. Academics have mainly utilized these tools in construction projects instead of practitioners. However, when it comes to energy analysis in building design, it is crucial to meet the financial and schedule demands of actual projects. The major obstacle preventing the widespread adoption of dynamic energy analysis methods is the substantial amount of manual input work required..

Energy analysis using traditional building methods has limitations in terms of information sharing and energy evaluation result due to the risk of misinterpretation of 2D/3D CAD data by the energy analyst [4].

Building Information Modeling (BIM) can provide the majority of the information required for energy simulation of building elements. If BIM is used as a data source for energy analysis, data input will become more effective and the data will be easily reusable. This will allow for the utilization of spatial whole building models, which is a departure from the zone-based models that are currently prevalent in energy simulation. Energy simulation can obtain a significant amount of building element data from Building Information Modeling.

To fasten the energy analysis process, yield more detailed and accurate results, and generate energy-efficient building designs, it is advantageous to employ an energy analysis tool in conjunction with a BIM model [5, 6]. Over the past few years, numerous scholars globally have focused on utilizing Building Information Modeling (BIM) to evaluate energy usage in constructed surroundings.

The perfect generation of a building energy model from a BIM model can enhance the integration of the energy simulation process in design, increase its efficiency and efficacy, and save time. Recently, multiple studies across Europe, America and Asia have studied BIM impact in respective local contexts [7].

BIM is essential to validate energy efficiency at different stages of building construction. Some countries such as the USA, Denmark, and Finland are mandating the use of BIM in public building projects, providing more chances for thermal analysis advantages. Nevertheless, the widespread adoption of of BIMs in energy analysis is hindered by the absence of compatible data interfaces in thermal simulation tools and the absence of guidelines..

Although the potential benefits of the BIM-BEM process are significant, there has been relatively little research conducted in this area. Additionally, there is limited information available on the extent to which Building Information Modelling can enhance a building's energy efficiency.

1.1 Objectives of the Thesis

The objective of the thesis is to understand the concept of BIM with BEM in the construction industry.A literature review was conducted to identify gaps in the industry and explore the implementation of these technologies. The research gap identified was to explore the potential areas areas such as data exchange, enhanced education and training, and the impact of integrating BIM and BEM on time and resources,Tools for BIM and BEM as per the practitioners. The study also analyzed the benefits and future of using BIM with BEM. Six potential areas to explore were identified, including data exchange method, accuracy of BIM and BEM input data/results, tools for BIM and BEM, BIM and BEM expertise and the benefits associated with BIM based BEM. It is still debatable whether investing time in BIM-based BEM is worthwhile.

1.2 Thesis Outline

The rest of this thesis is organized as follows:

Section 1: Introduction

The first section is the introduction, which includes the background and motivation of the research on BIM and BEM, the research questions and objectives, the significance of the study, and the scope and limitations.

Section 2 : Literature review

A in-depth literature review was done to examine the integration of BIM and energy modeling in the AECO industry. The literature review was aimed to identify the current state of knowledge on the BIM and BEM, including the benefits and challenges of using BIM and energy modeling , the methods and tools used for BIM and energy modeling. Additionally , the review would aim to identify the gap in knowledge and potential areas for further research.

This was achieved by examining all the relevant articles published up to 2021 in various sources such as Science Direct,Web of Science, and the ASCE library. The articles were meticulously scrutinized and sorted into different categories such as BIM and BEM definitions, uses, benefits, and challenges, using Excel sheets.

Section 3: Methodology

The third section is the methodology, which outlines the research design, data collection and analysis methods.

Section 4: Results and Finding

The fourth section is the results and analysis, which presents the analysis of BIM and BEM findings , an evaluation of benefits and challenges, tools.

Section 5: Conclusion

The fifth section is the discussion and conclusions, which summarizes the findings of the research, discusses the implications and contributions, identifies limitations and future research.

Chapter 2

Literature Review

2.1 Building Information Modeling (BIM)

The National Building Information Model Standard Project Committee(NIBS) defines BIM as: "A digital representation of physical and functional characteristics of a facility."

Building Information Modelling (BIM) is an evolving technology that utilizes several software tools to aid in the design process, allowing developers, businesses, and government bodies to plan, design, and construct new buildings in a collaborative data environment with their consultants and contractors. It is a platform for sharing information on a building, enabling informed decisions to be made from its inception to its demolition.

The AGC, or Associated General Contractors of America, has defined *"Building Information Modelling (BIM) as the use of computer software to model and simulate the construction and operation of a facility"* [8].A building information model is a digital representation of a building that is rich in data, object-oriented, intelligent, and parametric. This model can provide data to meet a variety of user needs, and it assists planners in making decisions and improving project delivery by facilitating the extraction and analysis of data [6].

According to the US National BIM Standard, Building Information Modeling (BIM) can be characterized as a digital depiction of a building's physical and functional traits, providing a comprehensive definition of the term. As an information-sharing platform, BIM can be utilized to help with decision-making at every stage of the building's existence, from its initial construction to its eventual demolition. At different points throughout a project, stakeholders are able to utilize the BIM system to obtain, revise, and alter data, with the intention of reinforcing and demonstrating their collaborative

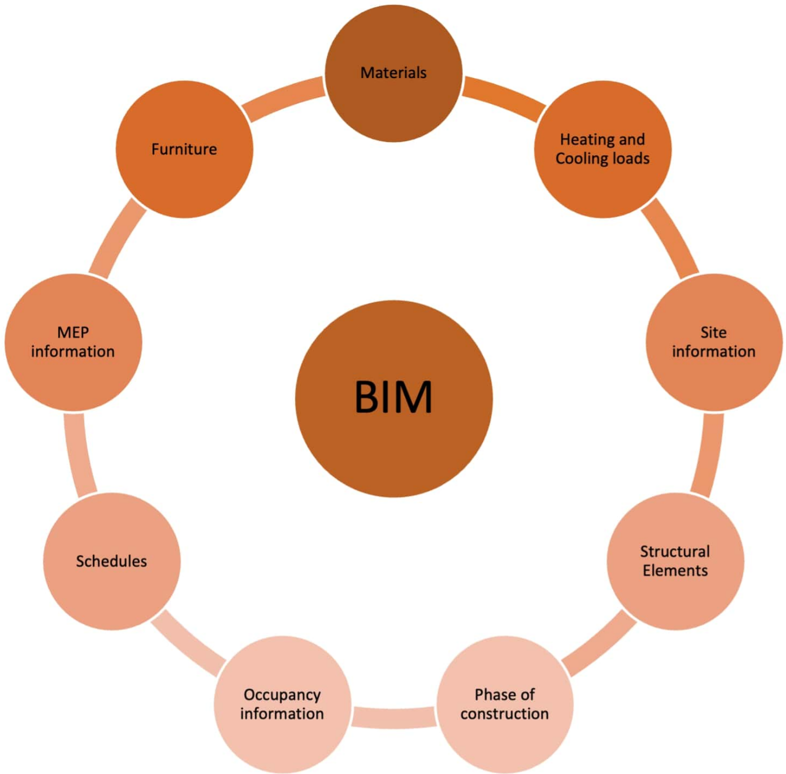

Figure 2.1: BIM inputs [1]

duties.

Some popular BIM authoring tools include Revit by AutoDesk, ArchiCAD by Graphisoft, Tekla by Trimble, Allplan by Nemetschek, and Microstation by Bentley. These tools are commonly used by architects, engineers, and construction professionals to design, plan, and manage building projects [9].

2.1.1 BIM technical features

Visualization

BIM visualization is the process of presenting a building or infrastructure project in a visual format that gives viewers a realistic impression of the constructed facility. This technique employs advanced 3D imaging technology to create a virtual model that accurately depicts the real-life project. By establishing a direct link between the visual representation and the actual facility, BIM visualization facilitates virtualization and simulation during the design, construction, and operation phases of the project [10].

Coordination

BIM building information models offer a valuable tool for identifying and resolving

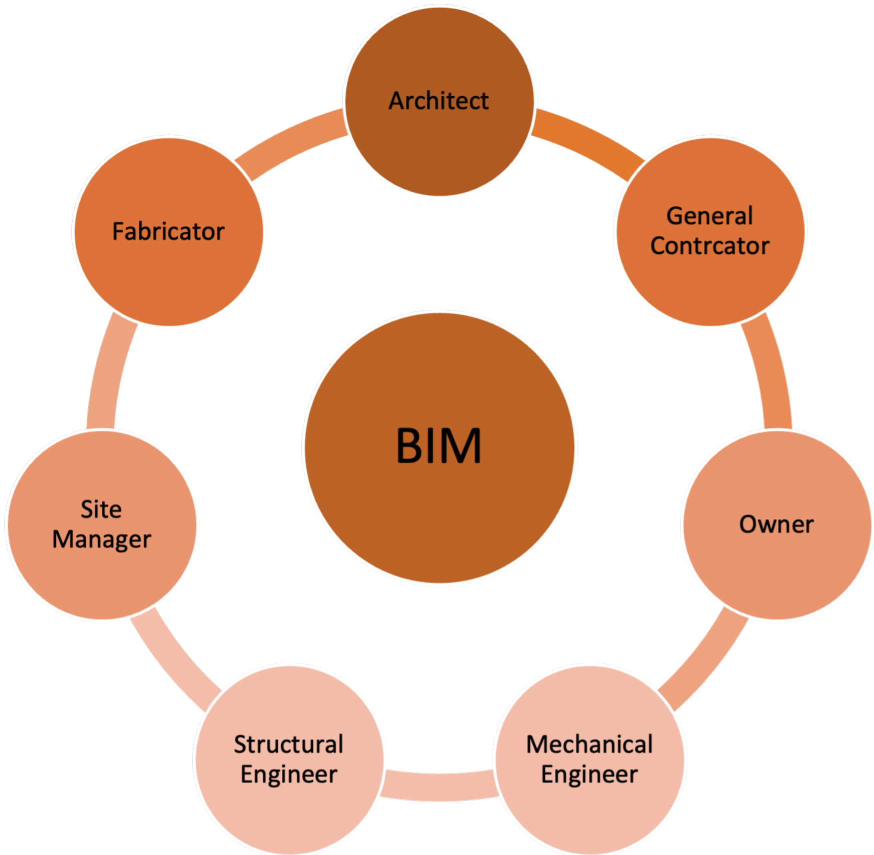

Figure 2.2: BIM promotes collaboration between various AECO participants

potential conflicts, known as clash detection, among various construction professionals in the early stages of a project. They can also be utilized to generate coordination data that promotes effective collaboration and information sharing [10].

Optimizing a project's design and scheme requires a comprehensive analysis that balances the project's value with the expected return on investment, while also meeting the needs of the owners. For specific design projects, such as podiums, curtain walls, roofs, and large spaces, that may represent a small proportion of the entire building but require significant investments and pose construction challenges, optimizing the design and construction scheme can result in significant time and cost savings [10].

Simulation

During the design phase, various simulations such as energy, emergency evacuation, sunlight, and heat conduction are conducted. In the bidding and construction stages, 3D or even n-dimensional models are used to manage project development time, construction organization design, and cost control, and to determine a reasonable construction plan to guide construction. During project operation, simulations are conducted for daily emergencies based on typical scenarios such as earthquake and fire evacuation [10].

The completeness of information

In BIM technology, parametric primitives serve as digital building blocks that contain all the relevant information about engineering objects. This includes three-dimensional or even multi-dimensional geometric data, descriptions of topological relationships [10].

2.1.2 Application of BIM in construction industry

BIM 3D Models

During the site planning stage of building construction, Building Information Modeling (BIM) 3D models are particularly valuable. These models allow construction engineers to simulate the relationship between facilities and equipment in a virtual space, allowing them to plan and prepare for potential issues before actual construction begins. Additionally, BIM 3D models facilitate the visualization of site components, enabling easy identification and resolution of site planning issues. A review of relevant studies [11] indicates that BIM 3D technology has been widely applied in pre-construction stages, allowing for the creation of parametric objects that can be used to design a rich information model.

BIM's ability to integrate, visualize, and parameterize information can reduce repetitive work and interface difficulties. BIM is no longer a simple reference file; it has become a platform for integrating collaborative design among various professionals and their information.

BIM 4D Models

The traditional method of construction schedule management relies on 2D drawings, which can lead to poor visibility and difficulty in communication among different project participants.By using BIM visualization technology, it is possible to simulate the construction process and create a 4D management system that can monitor the entry time of construction resources such as manpower, materials, and equipment.

According to Abiodun et al. [12], BIM has the capability to manage the schedule throughout the construction process. The BIM 4D function helps to guide the work sequence during the construction period and serves as a powerful tool for visualization and communication among project participants. With this feature, all participants can easily comprehend the construction schedule and keep track of the critical path of the project.

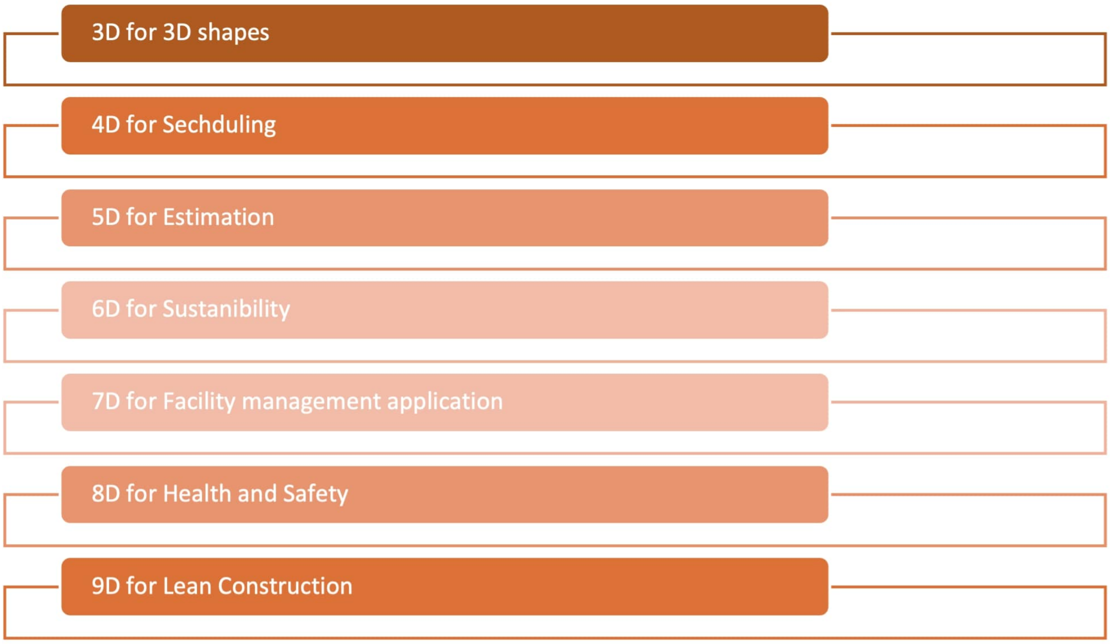

Figure 2.3: 9 Dimensions of BIM

The Integration of BIM with the construction schedule combines process and time information to create a visual 4D model that precisely portrays the construction activity. BIM 4D is a useful approach for managing the construction process's site assembly requirements. [13]

BIM 5D Models

The conventional quantity surveying process involves manual calculations that depend on CAD documents, which may have limitations in the data they hold. This makes it difficult for a computer to automatically calculate and leads to a high need for manpower and potential for deviation.

Ismail et al. [14] found that BIM can provide more reliable cost estimates through its 5D reliable database information. The traditional method can be invalidated by changes in design, but BIM's engineering information database provides various quantity information that allows for quick statistical analysis. The BIM 5D function allows for the rapid updating of quantity summaries and reduces potential for manual errors.

BIM 6D Models

The traditional way of gathering construction information often involves fragmentation from various contractors and suppliers, leading to a reliance on manual records and a high chances of errors. With the implementation of BIM, project management can be more effective by developing new competencies for building handovers [15].

Lin et al. (2018) [16] a system called Final As-built BIM Model Management (FABMM), which utilizes BIM models to merge construction information with operation and maintenance data for building management. FABMM enables owners to conduct inspection, modification, and confirmation activities before project closeout, potentially leading to decreased errors, lower costs, and enhanced building performance.

2.2 Building Energy modelling

BEM (Building Energy Model) is a robust software-based instrument that enables the study of building performance and evaluation of the environmental implications of diverse design alternatives.It allows the design team to optimize building design by evaluating the environmental impacts of different options and can also be used to solve complex design problems. Using BEM, it is possible to compute building loads and energy consumption, which can help to determine the energy properties of the building and its systems, as well as determine the maximum design loads for equipment and plant sizing. Additionally, it can evaluate the building's daylight performance [17]

The National Renewable Energy Laboratory (NREL) conducted a study which demonstrated that BEM can predict a building's energy performance with a high degree of accuracy, exhibiting an average deviation of only 2.5% between projected and actual energy usage.

Traditional energy consumption analysis faces several issues, such as obtaining information being difficult, the complexity of analyzing energy consumption, and inaccurate results. There are two main methods for analyzing building energy consumption: using a static algorithm and manually inputting data into simulation software. However, the first method doesn't account for heat transfer delays and attenuation effects, leading to significant deviation in results. The second method requires extensive manual input and professional knowledge, making it difficult for non-experts to conduct the analysis without proper training [18].

A technique to decrease the need for energy consumption is by utilizing building energy simulation, which employs software to calculate the energy usage of a building. Building energy simulation software can establish key parameters for different parts and components of a building, and it should incorporate virtual displays, like building models and energy simulation models, to interact with energy variables. [6]. In order to conduct a thorough analysis, building energy models need to be created to carry out more accurate simulations. Simulation software can be tailored to the requirements of a building and can make projections about monthly energy consumption, annual en-

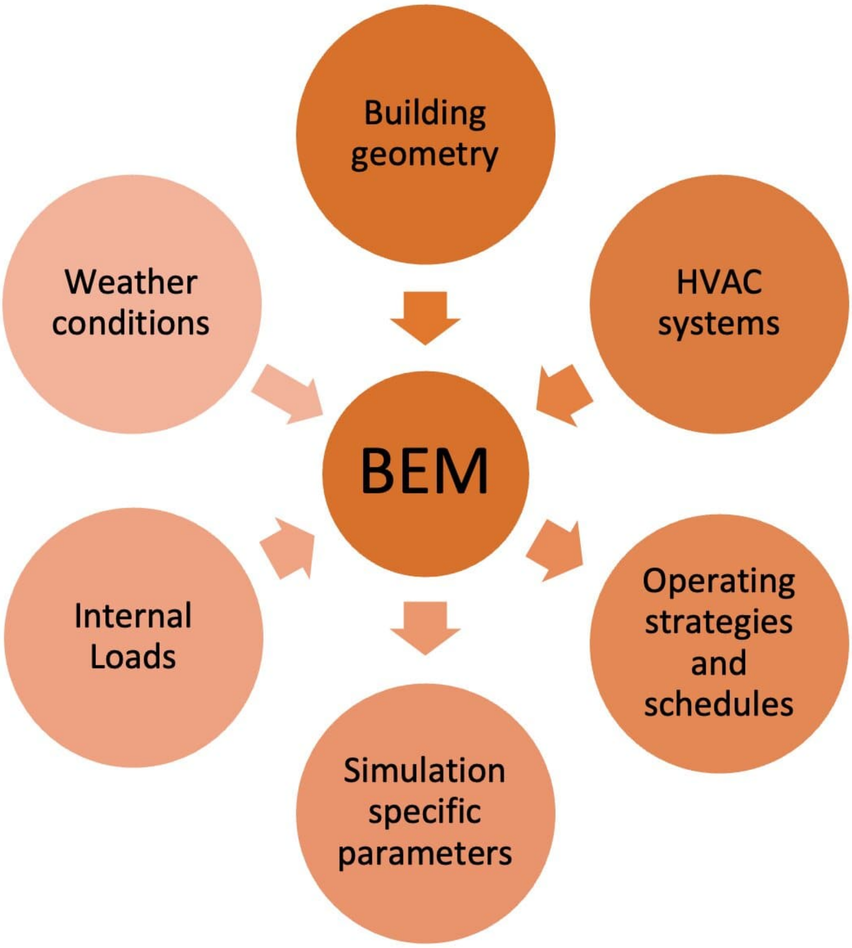

Figure 2.4: Inputs for BEM tools [2]

ergy expenses, yearly carbon emissions, assess various efficiency measures, and assist in cost-saving decisions.

To analyze an EM case study of a building, crucial information includes the building's structure, features, energy usage records, and climate data. Moreover, various intricate factors such as productivity traits, thermal efficiency, and energy management can also influence the building's energy performance [19].BEM is an effective tool as it enables design teams to obtain concise details about the efficiency and ecological effects of various design alternatives, thereby contributing to the advancement of building energy assessment and thermal comfort. [7].

As per Dong et al. [20], BEM tools can be broadly classified into two groups. The first group includes tools that use the calculation engine by Department of Energy (US-DOE) such as eQUEST, DesignBuilder, EnergyPlus, and Autodesk Green Building Studio (GBS). The second group includes tools that use their own calculation engine, such as IES Virtual Environmental (IES-VE) and Trace 700. Different BEM tools may have different capabilities based on the input data and simulation assumptions they use.

For example, EnergyPlus allows for user-configurable heating and cooling equipment components, making it more adaptable to actual conditions compared to DOE-2 and BLAST, which only allow for the use of hardwired template HVAC systems.

In the past, researchers have conducted comparisons of various BEM tools. In their study, Crawley et al. [21] comprehensively evaluated 20 prominent building energy modeling (BEM) tools based on a range of criteria, including general modeling capabilities, zone load analysis, building envelope, daylighting and solar performance, infiltration, ventilation and multi-zone airflow, renewable energy systems, electrical systems and equipment, HVAC systems, HVAC equipment, environmental emissions, economic analysis, availability of climate data, results reporting, validation, and user interface. Other works such as [2] [22] [23] also provide summaries of the input, assumptions, features, and limitations of these BEM tools.

BEM technologies have been used for a long time in building design, optimization, construction, operation, and research. Most commercial BEM tools (use physical models, which are good at predicting performance over a wide range of conditions without needing extra data. However, physical models have limitations when it comes to modeling dynamic performance, such as the lack of controller development and the inability to include advanced controllers or mathematical models for new materials, which can lead to inaccurate energy modeling [24].

BEM should be used throughout the design process, as it is necessary for completing various tasks at different stages. The energy model starts as rough, and becomes more detailed as the design progresses. The US General Services Administration (GSA) has broken down the design stage into three parts: preliminary concept design, final concept design, and design development and also outlined how BEM should be used during each stage as follows [17]:

During the preliminary concept design stage, a basic energy model is created using simple thermal zones. This rough model allows for evaluation of initial design ideas, such as the building's location, shape, orientation, and use of alternative energy sources. This helps the design team make important decisions [17].

As the design process advances to the final stages, more specific information about the building is established and a more precise energy model is developed to assist the design team in evaluating different design options, including layout, HVAC systems, fuel options, construction materials, and architectural elements, in relation to the initial design choices made earlier.

Although Building Energy Modeling (BEM) technology is useful and beneficial for building design, the limitations of conventional BEM are undeniable. As a result, the full potential of BEM cannot be fully utilized in practice. According to Bazjanac [25], the limitations of conventional BEM include:

1.Simulating the energy performance of buildings is a challenging task that demands considerable time, resources and effort, which can result in high costs and a prolonged process, thereby making it difficult to produce speedy results.

2.The results of BEM are not reproducible due to the arbitrary decisions and assumptions made in the simulation model definition, and can only be trusted under specific circumstances.

3.The BEM process cannot begin until certain key design decisions have been made, such as architectural and HVAC design, in order to provide enough information for the model.

4.The long time consumption of traditional BEM means that its results are always behind the timing of design decision making.

5.The process of preparing building geometry in simulation tools is inconsistent, as it is based on the personal thermal view of whoever is preparing the simulation and analysis.

6.Preparing input for the simulation and analysis is a time-consuming, resource-intensive and arbitrary process.

2.3 BIM applications to Energy Modeling

One of the main issues with traditional BEM is that the process of setting up the energy model is both time-consuming and repetitive. For instance, the shape of the building from a CAD program needs to be manually converted and reconstructed within the BEM tool [26]. Architects and engineers often struggle with using BEM tools due to a lack of understanding of simulation. Even the most user-friendly simulation tools require a significant amount of input and expertise to be used effectively [27].

In the traditional design process, BEM is typically only brought in during the final design phase because of the limited input variables in earlier stages. However, this often leads to conflicts between building design choices and BEM analysis when changes to the design can no longer be made [28]. This means that the simulation results obtained after significant time and expense may end up being pointless [27].

The Building Energy Model based on Building Information Modeling provides solutions to the limitations of the conventional Building Energy Model approach and enables the seamless integration of Building Energy Modeling with digital design. An emerging technology known as Building Information Modelling based Building Energy Modelling (BIM-based BEM) has appeared in recent years, which is based on the foundation of BIM and enables more streamlined building energy modelling. [6] By utilizing pre-designed BIM models to generate input for BEM tools, BIM-based BEM creates a more efficient, accurate, and consistent process that is also low-cost, easy-to-use, time-saving, and practical. [7]

The integration of Building Information Modeling (BIM) and Building Energy Modeling (BEM) has generated considerable interest among academics and professionals alike. Unlike the conventional approach of manually constructing building energy models based on design documents, BIM-based BEM employs pre-designed BIM models that already contain architectural design, mechanical loads, properties, and systems. These models are used to automatically generate the input required for building energy models [29].

The creation of building energy models is simplified by BIM-based BEM, which directly accesses building design information and automates the data transfer process from the original sources, eliminating the need to re-enter geometric information from the design model. This saves time and reduces the chances of errors due to human intervention, which can lead to subjective and arbitrary decisions [30].

According to Bazjanac et al [31], the inclusion of particular guidelines in BIM-based BEM prevents erratic modifications to the data, guaranteeing the energy model's accuracy and consistency for different users.

Pezeshki et al. [19] conducted research on the progress of BIM-based Energy Modelling and examined the use of EnergyPlus as an energy modeling software. They determined that a graphical interface is necessary for the widespread implementation of BIM and GIS integration, enabling non-IT professionals to conduct data queries effortlessly. Additionally, they analyzed several factors that impact the adoption of BIM-based tools, including inaccurate export from open exchange formats such as IFC and gbXML. Furthermore, they observed that the expense of software and training required to extract relevant information leads to small-scale projects exceeding their budget.

Maile et al. [2] created an optimal workflow chart for BIM-based BEM, as demonstrated in Figure 2.5. The initial stage entails identifying the building's location, which can then be linked to a weather file. Then, the geometry, construction and thermal properties of materials, and space types should be imported from the BIM model. It may be necessary to simplify the geometry to enable translation into a thermal view and compliance with the geometry definition of the relevant thermal performance simulation tool.. The

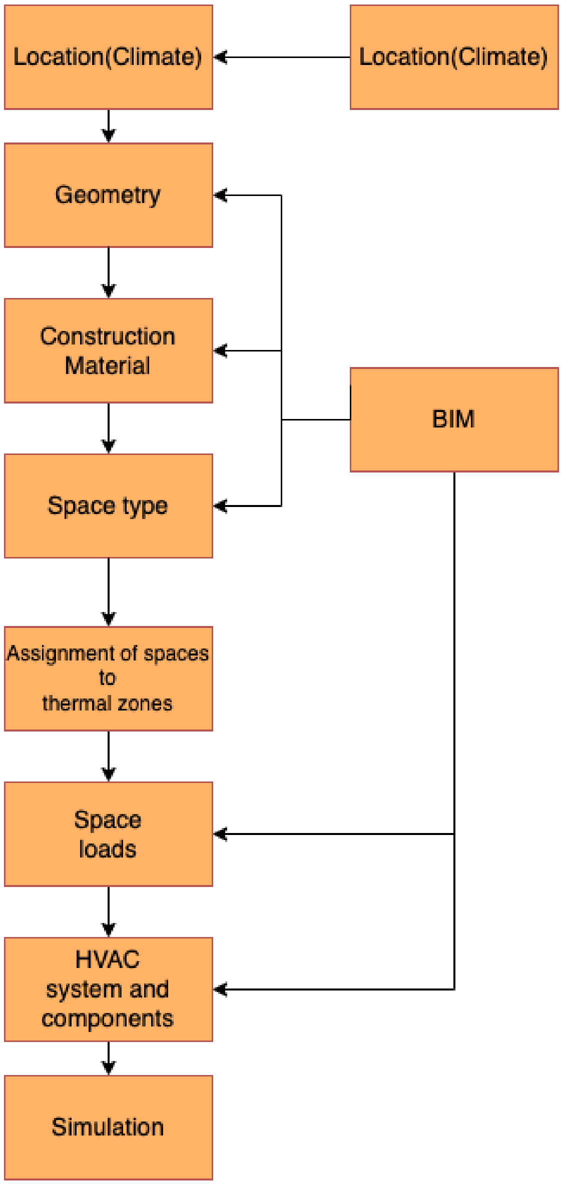

Figure 2.5: Workflow from BIM to BEM

user interface should also allow for the aggregation of spaces into thermal zones and the subdivision of a space into thermal zones based on geometry definition.The subsequent phase involves assigning space loads to specific space types, which should also be provided by BIM.Finally, the information for the HVAC system and components should also be provided by BIM.

According to this workflow, BIM-based BEM methods can be broken down into 6 steps: geometry (Step 1), constructions and materials (Step 2), building or space type (Step 3), thermal zones (Step 4), space load (Step 5), and HVAC system and components (Step 6). It may be possible to overcome the shortcomings of conventional BIM by making the seamless data transfer process between BIM and BEM [32].

2.3.1 BIM-based BEM methods

To establish model interoperability in BIM between software, the usual approach involves utilizing Green Building XML (gbXML), Industry Foundation Classes (IFC), or direct plug-ins. These open-standard data schemes for information exchange are the most commonly employed techniques between BIM and BEM tools.

Gao et al. [6] investigated the degree to which data is transmitted from BIM to BEM via two methods: the IFC-based method and the gbXML-based method. In their study, Kamel et al. [33] distinguished between gbXML and IFC with regards to energy simulation, identifying differences between them. The data transformation levels include geometry, material, space type, thermal zone, space load, and HVAC system. According to their findings, most IFC-based methods are still at the geometry transformation stage, while gbXML-based methods have progressed to space type transformations. BIM-based building energy modeling techniques can manage up to the third level of transformation, whereas other techniques, such as Design Performance Viewer and some commercial software, are still focused on the geometry transformation. Despite the benefits of the BIM-BEM process, interoperability remains a primary concern, and more research is needed in this area.

Several BIM-based BEM methods are developed and are in practise. The Industry Foundation Classes (IFC) method is a common approach.

Industry Foundation Methods (IFC)

Most of the research on the integration of BIM and BEM has been focused on the initial step of data interoperability, which is the transfer of building geometry from BIM to BEM. Different research groups have developed various conversion tools and methods for this purpose, and most of these methods convert the IFC format used in BIM software to the Input Data Format (IDF) that is used as input for EnergyPlus [27] [34] [35].

IFC, a 3D object-oriented exchange format, was created in 1996 by the International Association for Interoperability and is currently managed by the buildingSMART alliance. It serves as the sole open and standard format utilized for BIM and was intended to enhance information exchange and processes within the construction and facilities management sectors [36]. IFC enables the transfer of data between teams with varying expertise and can depict building geometry of any form [37].The production of BEM through BIM using IFC as a medium has been the subject of much research in recent times.

At present, the majority of techniques that merge BIM (Building Information Modeling) and BEM (Building Energy Modeling) via IFC (Industry Foundation Classes) solely emphasize transferring the geometry from BIM to BEM. This means that the remaining necessary BEM data must be entered manually or chosen by default. However, these approaches are still in their initial phases and cannot guarantee precise and mistake-free translations since complications like absent items, replicated surfaces, and conflicting boundaries might arise during the conversion phase. [38].

Green building XML (gbXML)

Green building XML (gbXML) based methods are another approach used in BIM-based BEM. A gbXML file is a format that uses Extensible Markup Language (XML) and was developed by Autodesk Green Building Studio. This format is robust, non-proprietary, persistent, and verifiable, making it useful for storing and transmitting text and data both online and offline [39]. Many popular BIM software such as Revit and ArchiCAD, as well as energy analysis applications like EnergyPlus and e-QUEST, can exchange data using gbXML through the Green Building Studio web service [35].

gbXML is primarily used for energy simulation and allows users to obtain a properly formatted file from BIM tools and transfer it to relevant BEM tools to generate building simulation results rapidly with specific assumptions. While IFC is a comprehensive approach to representing a whole building project, gbXML is focused on simplifying the transfer of data from BIM to engineering analysis tools, especially for BEM tools.The gbXML format is limited to rectangular shapes in its geometry representation, which is typically adequate for simulating most building structures. [37].Around the gbXML data schema, several BEM approaches that incorporate BIM technology have been constructed.

Building Information Modelling (BIM) based Modelica Building Energy Modelling (BEM) method

BIM-based BEM techniques that employ Object-Oriented Physical Modelling (OOPM) use a structured and equation-driven modelling procedure to simulate building energy consumption. Modelica is an equation-based OOPM language that is used to model complex, significant, and heterogeneous physical systems. This approach is used to model the component-level of a physical system's topology through component-connection representation [40]. Modelica-based BEM is a specific example of Modelica-based OOPM, in which the building is modelled and simulated in a Modelica environment. Using Modelica requires a Modelica library that provides model components, solvers, and a Modelica simulation environment. The LBNL Modelica library and Dymola are commonly used to provide model components and simulation solvers, as well as a simulation environment respectively.

2.4 Interoperability/ Data trasfer

Interoperability, the ability to seamlessly exchange data between different applications, is a crucial concern in the Architecture, Engineering, Construction, and Owner-Operator community (AEC0), particularly when working with multiple models and tools. This can help to eliminate data repetition, reduce the risk of human error, and allow for the rapid reproduction of models [41] [42]. As stated by Eastman [42], it is essential for a smooth workflow and automation of model transactions.

In a BIM-based BEM, interoperability is essential, as it enables two separate software programs to communicate and exchange data. The benefit of smooth data transfer lessens the likelihood of duplicate data generation or missing data in analytical models, and ensures the integration of sustainable features at the early design stage [43].

In BIM based BEM, transferring data smoothly between Building Information Modeling (BIM) and Building Energy Modeling (BEM) systems can be a challenge, as shown in figure 2.7. Although BIM is a tool used in many different fields, problems with compatibility can restrict its use in certain industries [44].These difficulties include the challenge of linking BIM models with energy simulation software, the need for repetitive manual tasks to create a BEM, and a lack of standardization in the process, which can cause problems with data loss and misinterpretation, especially during the early [45] [46].

The connection between Building Information Modeling (BIM) and Building Energy

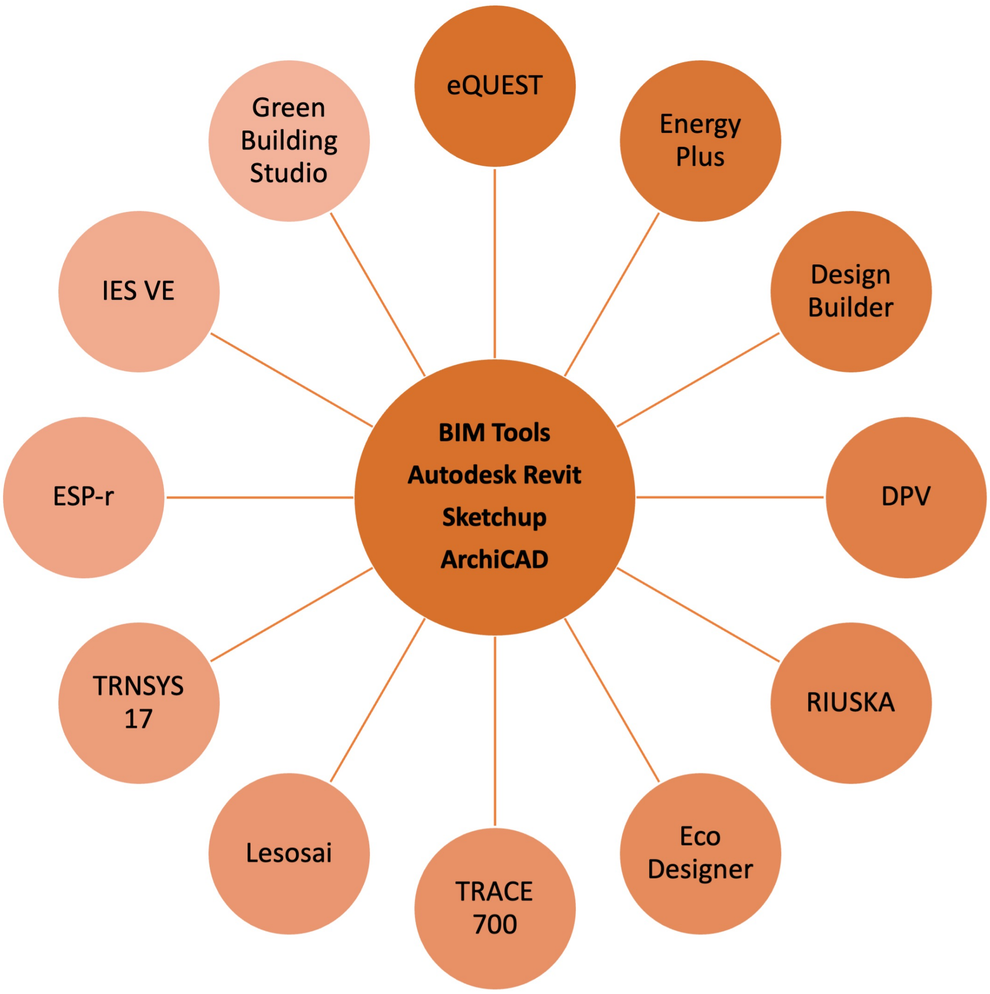

Figure 2.6: The data exchange between the design tools and the energy modelling tools [3]

Modeling (BEM) involves three parts: a BIM tool, a model schema exchange format, and BEM software [47]. Interoperability issues can arise in any or all of these components, not just in energy simulation applications.Therefore, the difficulties faced are not solely caused by BEM tools' inability to convert BIM input data. To transfer BIM information to building energy analysis software, various file formats are available, such as HTML, XHTML, bcXML, IFCXML, IFC, and gbXML. The last two, IFC and gbXML, are the main open BIM standards [48].These open standards enable and facilitate collaboration and integration among professionals from different parts of the world by providing a common basis for research, development, and deployment activities, . The BIM-BEM process has been a subject of ongoing debate for some time [49].

A continuous information exchange between the BEM and BIM is not possible due to inconsistencies between the two softwares. To avoid the require for manual information input and loss of data between both software , Kamel and Memari [33] introduced a middle ware remedial tool, created using python.

According to Carvalho et al. [7], the main challenge in implementing sustainable and energy-efficient measures in building projects is the incompatibility between BIM and BEM tools. To overcome this issue and promote building sustainability, designers require a dependable BIM-based system that can improve building energy performance and facilitate the creation of thermal projects.

According to Gao et al. [6], energy simulation software faces challenges in comprehending complicated data present in BIM models.

Pezeshki et al. [19] explains that the lack of compatibility between BIM and BEM software leads to obstacles in delivering sustainable and energy-efficient projects throughout their life cycle. Such projects often suffer from incomplete or inaccurate modeling of HVAC systems and insufficient information about controls.

Jin et al. [8] conducted a review of 60 studies on BIM integration with energy analysis, emphasizing on interoperability issues in BPA life-cycle, semantics, and sustainability rating systems. Through bibliometric analysis, they highlighted the difference between the energy performance of a building 'as-designed' and 'as-built.'

The interoperability issues between BIM (Building Information Modeling) and BEM (Building Energy Modeling) are currently a challenge in the industry, but it is expected that these issues will be addressed in future developments. The integration of BIM and BEM is a relatively new area of research, and advancements are expected to be made in the future.

2.5 Tools used for BIM and BEM

There are many softwares for BIM (ArchiCAD, Revit, Navisworks) but Revit is the most common. Revit® software is a powerful Building Information Modeling (BIM) tool that is designed to assist professional designers in creating and managing buildings with exceptional quality and improved energy efficiency. By utilizing the data from the models created with Revit, architects, engineers, and construction companies can make joint decisions at an earlier stage of the design process, leading to more efficient project completion [50]. Whenever any modifications are made to the design in any Revit plan, elevation or cross section, the entire model gets automatically updated, ensuring that the designs and documentation remain coherent and trustworthy [50].

Some BEM tools include: DesignBuilder, Ecotect eQUEST, EcoDesigner, ESP-r, Green Building Studio, IDA-ICE (IDA Indoor Climate and Energy), VE (Virtual Environment), TRACE 700, TRNSYS and Riuska

Three common tools eQuest, EnergyPlus and Green building studio are discussed in this section.

eQuest is a software that allows users to evaluate the energy consumption of a building in a simple way. This is accomplished through a combination of different tools, including an energy efficiency measure wizard, a graphical display module, and a building creation wizard. The building creation wizard provides users with step-by-step instructions for building modeling, while the DOE engine conducts an hourly building simulation that accounts for various factors such as windows, plug loads, people, glass, ventilation, walls, boilers, pumps, chillers, fans, and energy-consuming appliances. eQuest also includes features such as multiple views, energy cost estimates, lighting and daylighting system control, and automatic energy efficiency measure implementation [51].

The software calculates a building's energy consumption on an hourly basis for an entire year, based on input data like occupant schedules, equipment, lighting, and thermostat settings. It can also simulate the impact of natural light on lighting demands and thermal performance [51].

One of the most commonly used BEM tools is the EnergyPlus simulation engine, developed by the U.S. Department of Energy (DOE).EnergyPlus is a comprehensive program for building energy simulation that can predict a building's energy performance with great accuracy based on comprehensive inputs [29]. EnergyPlus is a newer simulation tool based on DOE and BLAST [21]. The software's goal is to be a simulation engine with no interfacing options, with input and output represented as comma-separated texts.The simulation depends on the user-specified time step, with EnergyPlus determining the loads and transferring them to the building systems' simulation. The building systems' simulation module determines the cooling and heating system parameters and response of the electrical system plant, with time steps as small as seconds.

EnergyPlus offers several advantages, such as [21]:

1.Flexible simulation capabilities

2.Links to other system and plant simulations

3.Multizone airflow, and algorithms from the new ASHRAE loads toolkit.

4.Compared to other energy simulation tools, EnergyPlus has very flexible simulation capabilities and input/output options.

Another common software for BEM is GBS (Green Building Studio) which is a cloud-based service that is adaptable and enables designers to conduct simulations for building performance and enhance energy efficiency at an earlier stage in the design process. This leads to an expansion of the capacity to design high-performing buildings in less time and at lower costs compared to traditional approaches [50].

2.6 Benefits of BIM and BEM

The benefits of BIM with BEM are illustrated in figure 2.7. The use of BIM can streamline data exchange, automate energy modeling, enhance output presentation, organize and store building data, and supplement existing information by incorporating new updates into the standard energy simulation process. [33] These contributions are further elaborated in greater detail.

Automation of energy modelling

One of the primary benefits of integrating BIM into BEM is the automatic modeling process [52]. This feature can help save time, reduce costs, and lower the likelihood of errors that may occur when compared to traditional energy modeling methods involving manual intervention. In conventional energy modeling processes, a graphical model is developed in Building Energy Modeling tools by utilizing data related to geometry, materials, schedules, and equipment [53].

Presentation of output

BIM has another noteworthy advantage, which is its capability to aid in the presentation of results within an energy management system. [54].When utilizing computer tools that do not feature a graphical user interface (GUI), the aforementioned benefit becomes

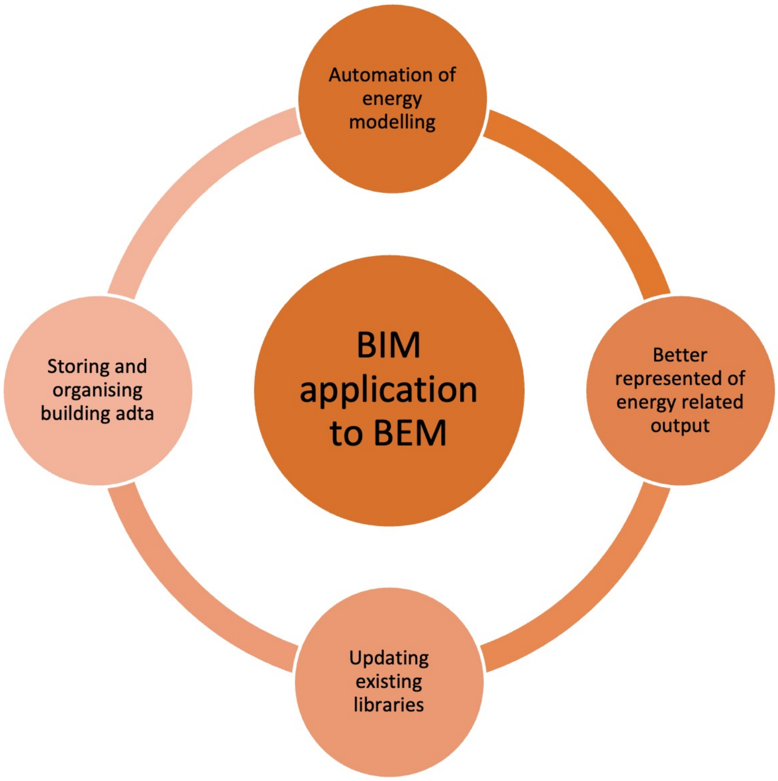

Figure 2.7: Benefits of BIM application to BEM

even more valuable. Vernatha and Jen, for instance, constructed a BIM-EMSS (Energy Management Support System) model utilizing Revit to establish a BIM model that can perform real-time energy simulations using smart measurement tools or sensors. This technique combines the geometric data from the BIM model with energy performance measurements, allowing the user to keep track of real-time energy simulation results in various zones within the structure [55].

Store and organize data

The ability to organize and store energy-related information for buildings is also an important benefit offered by BIM . For instance, real-time energy simulation monitoring systems generate data on the building's energy consumption, occupancy, and temperature, which needs to be saved properly under specific conditions. Alahmad et al. [56] propose using a "BIM" model for real-time monitoring systems, which consists of a hardware component called "RTPM" (Real Time Power Monitoring) and software called "RE-BIM" (Real Time Electrical Building Information Modelling).

Integrating BIM with BEM also helps with real-time monitoring of occupancy changes, facility upgrades, and energy-related strategy changes to store updated and real-time information. Woo et al. [57] that BIM with sensors placed inside a building can be linked with SensorML, a system that facilitates data processing for sensors and actuators.

Update libraries

BIM can also be valuable in enhancing the libraries that contain information about the properties of materials used in energy modeling simulations. While these libraries may offer some thermal-related properties, such as a material's thermal conductivity, certain projects may require additional research and information on the life cycle assessment (LCA) of a building. BIM can act as a bridge between energy simulation and CAD tools, providing further measurements for LCA that may not be available in either tool's libraries. For instance, BIM can help optimize the design of HVAC systems by enabling the early selection of appropriate systems and materials and facilitating the process of providing various design alternatives [58].

Laine et al. [4] the advantages of incorporating BIM in energy analysis, including enhanced data input, the opportunity to reuse existing data, the possibility of using dynamic methods instead of static ones, and the ability to perform comprehensive building simulations. The primary advantage of using BIM throughout the building's life cycle is the continuous monitoring of energy efficiency.

The completed BIM integrated construction project in the Dominican Republic was analyzed by Egwunatum et al. [5]. According to the research, BIM-driven energy analysis played a pivotal part in creating the world's first 103% positive energy building. By incorporating an energy analysis tool with a BIM model, the energy analysis procedure can be expedited, producing more accurate and comprehensive results, which ultimately leads to the construction of energy-efficient buildings. As a result, the scholars recommend that all projects, regardless of their procurement or scale, should incorporate level 2 BIM and integrate BIM in the energy analysis procedure.

2.7 Challenges in implementing BIM and BEM

There has been many challenges in implementation of BIM to BEM due to the challenges it has not been imployed in AECO industry. Some of the challenges are discussed in this section:

2.7.1 Lack of Standardization

Location: The local temperature, solar radiation, wind direction and speed, rainfall intensity, and other parameters are all influenced by the surrounding climate. To conduct an accurate energy analysis, the actual values of these parameters are required, which are typically obtained through the geographical location of a building. While authoring tools can store this information in data schemes, simulation tools are unable to retrieve this kind of information, and coordinates are reset to the software's default location [59].

Geometry: When transferring geometrical data between BIM and BEM tools, various discrepancies arise, primarily due to changing thermal zones, room boundaries, and flaws in interpreting non-planar geometry. These discrepancies result in missing or duplicated elements, as well as incorrect determination of space volumes [60].

Mistakes in building geometry can occur due to various reasons, such as incorrect wall center-line calculations or flawed volume determination caused by suspended ceilings and floors. These errors can lead to discrepancies in energy performance simulation between BIM and BEM as detailed in [61] and [62].

Building systems: Energy simulation tools have limited ability to inter-operate with HVAC system elements. This issue has become more significant as the importance of HVAC system elements has increased, and even the latest version of IFC format (IFC4) has not presented a solution to the problem [63]. As a result, users must manually input information, even though there is no option for system description, leading to inaccurate simulation outcomes.

Material Characterstics: According to Jeong et al. [64], IR absorptivity parameters that are essential in energy simulation tools are not available in authoring tools. Gourlis and Kovacic [37] installed material properties manually in EnergyPlus because the gbXML and IFC schemes could not export information for the density, thermal conductivity, and specific heat capacity of construction layers, despite providing options to do so.

2.7.2 Resistance to change

Resistance to change is a common reaction of the people. There is a limit to how much change individuals can absorb, and employees may resist change because they lack awareness of the business requirement for it. To address this, it is helpful to assess the underlying reasons for resistance, including factors such as desire, awareness, knowledge, reinforcement, or ability. To achieve effective resistance management, it is crucial to educate employees and raise their awareness. The best way to evaluate employees' concerns is through direct interaction, and supervisors and front-line stakeholders can play a significant role in this process. These managers can conduct the evaluation to identify potential resistance issues [65].

2.7.3 Lack of Expertise

The term ”Workforce Barriers” refers to the insufficient availability of skilled workers and inadequate skills among the current workforce. Examples of this include the inefficient use of software tools and trainers' lack of knowledge regarding sustainability [65].

BIM models are often created by design partners who lack familiarity with the intricacies required for energy modeling. As a result, these models are inconsistent and prone to errors during creation. Additionally, they are constructed using BIM tools that have objects and parameters that differ significantly from those needed in performance simulation tools [66]. This leads to difficulties when translating these models into energy modeling programs, as they are primarily intended for construction documentation rather than performance simulation. Furthermore, they often contain architectural details that are irrelevant to an energy model, while lacking the necessary details such as clean space boundaries and matching edges.

Chapter 3

Methods

3.1 Research Approach

The research on the adoption of BIM and BEM in the construction industry has been ongoing for over a decade in construction industry but this is new at the Construction Management Department of the University of Washington. I did an in-depth literature analysis on BIM and BEM adoption in the AECO industry. Then, I have conducted Interviews to gather firsthand perspectives from stakeholders on the challenges, benefits and tools used of implementing BIM and BEM in the AECO industry.

3.2 Research questions

Building Information Modeling (BIM) can overcome the drawbacks of traditional building energy modeling, including time-consuming preparation, inconsistent models, and high expenses. Over the past few years, BIM-based building energy modeling has become a crucial and widespread topic in both academia and industry.

The adoption of BIM-based energy modeling has immense potential for enhancing building sustainability and energy performance. Numerous studies have explored the use of BIM for energy simulation, performance analysis, and system optimization. Furthermore, research has focused on the integration of BIM and energy modeling in the design phase, as well as BIM's effectiveness in monitoring and managing building energy usage.

The research questions aimed to understand:

The construction industry is still new to the concept of BIM with BEM which has resulted in confusion in defining it. To address this issue and identify gaps in the industry, a thorough literature review was conducted. The aim was to explain what BIM based BEM means for the AECO industry.

The Literature review revealed that the industry has been slow in adopting BIM based BEM technology due to significant challenges. The research explored the challenges such as data exchange between BIM and BEM, the need for enhanced education and training in these domains, and the impact of integrating BIM and BEM closely on time and resources. However, there is an increasing trend towards its implementation. To explore these challenges, the study investigated how BIM is implemented with BEM in the construction industry.

Additionally, there are no standard tools or software for BIM based BEM implementation. People are using different tools and methods for BIM based BEM. After answering all the above questions, the study also analyzed the benefits and future of using BIM with BEM for the construction industry.

In order to address the research question regarding the concept of BIM and BEM within the construction sector, the difficulties involved in implementing it, and the tools and techniques employed, recognizing the advantages and obstacles of integrating these technologies.

The six themes that are potential areas to explore are:

1.Data exchange format

The primary difficulty with BIM-based BEM is the exchange of data, and this obstacle's impact on industrial professionals is investigated.

2.Accuracy of BIM and BEM

The precision of both the input data and the resulting output is also a matter of concern that is influenced by multiple factors. Industry experts' perspectives are examined to explore these factors.

3.Tools for BIM and BEM

Although there are several tools accessible for BIM and BEM, certain commonly used tools are analyzed to determine why they are preferred.

4.Benefits of BIM and BEM

Although there are difficulties in incorporating BIM with BEM, there are advantages to be gained, which are being investigated. The question remains whether investing time in BIM-based BEM is worthwhile.

5.Challenges in implementing BIM and BEM

Industry professionals' and researchers viewpoints are used to examine the challenges of implementing these technologies.

6.Expertise of BIM and BEM

Implementing BIM with BEM is a complex process that entails numerous challenges, necessitating expertise in these technologies.

By exploring each of these themes and analysing data as per these themes in the context of the research question, it may be possible to gain a deeper understanding of BIM and BEM in the construction industry, including their strengths and limitations, and how they can be effectively implemented to improve project outcomes.

3.3 Research method

Interviews

Interviews are used as a methodology to obtain direct insights and accounts from individuals or groups on the implementation of BIM and BEM in the AECO industry. These interviews were semi-structured and carried out through Zoom.

Sampling: Interviewees were selected from academics as well as professional background in field of BIM and BEM. They have relevant knowledge and experience related to the BIM and BEM.The main focus it to get the insights from the practitioners in the industry.

Recruitment: The interviewees were contacted through email and LinkedIn, some interviewees were contacts of Professor Carrie Sturts Dossick, and the interviews were conducted on Zoom.The background of each selected interviewee is described in the following section.

Before conducting interviews, I received approval from the University of Washington Human Subject Division for the study, which was determined to be exempt.

Data collection: During the interview, I employed effective methods such as active listening, asking follow-up questions, and probing for further information. Additionally, I obtained the interviewees' permission to record the interview and made detailed notes for reference.

Data analysis: After conducting the interviews, the data was analyzed meticulously and sorted into six distinct themes.

Ethics: I adhered to ethical principles and guidelines throughout the research process, which includes safeguarding the confidentiality and privacy of the participants involved and taking consents from participants.

Semi-structured interviews offer a level of adaptability and room for unrestricted questioning, while still adhering to a general framework to direct the dialogue.

The interview template comprises three segments:

1.Building information modelling (BIM)

The section explored about the difficulties encountered when applying BIM, the tools and techniques utilized, and the benefits involved.

2. Building Energy Modelling

The section focus on the obstacles faced when implementing BEM, the tools and techniques employed, and the advantages obtained.

3.BIM and energy modelling

The concept of BIM with BEM is investigated, along with the challenges of implementing BIM and BEM, the tools and techniques employed, and the benefits obtained.

3.4 Interviewee Background

In my interviews with five individuals who possess academic and professional experience in BIM and BEM, I discovered that while most of them have a research background, they have also collaborated with consultants for assistance in areas such as energy modeling or BIM.

Interviewee 1

The interviewee 1 is a PHD candidate at Technische Universität Berlin. She has been in industry for for around an decade. She used BIM for collaboration and communication as well as visualizing projects in preconstruction. She uses BEM tools For investigating the energy performance of the buildings in as-built situation and for renovation scenarios.

She says *"BIM is a beneficial project management technique that facilitates collaboration and communication between engineers and practitioners, streamlining the exchange of information related to the building. Renovation projects can benefit from BIM, but its application is limited since many existing buildings lack BIM"*.

Interviewee 2

The interviewee 2 is a Professional Engineer at Solarc Energy Group in Washington. He has been in industry for for around an decade. He didn't use BIM for visualizing projects. He works only on Project in Washington.

He says "We don't have that much experience with Revit. It doesn't make sense, it hasn't made sense yet. We don't do our design work in Revit either, it doesn't make sense for us to try to invest time.

Interviewee 3

The interviewee 3 is a Professor at K. N. Toosi University of Technology in Iran. He uses BIM for Collaboration and Communication and for Model-Based Cost Estimation. He uses BEM for energy efficient buildings. He thinks BIM and BEM helps to increase our efficiency.

Interviewee 4

The interviewee 4 is a Professor at Technical University of Berlin. He do a lot of research in the areas of multi physics simulation,including energy simulation of buildings. He do a lot of modeling,large scale design, space simulation, optimization and so forth. And, another thing that he do is data analytic.

He says *"In our experience, geometry or accurate geometry is not like so crucial for a good energy simulation of the building. Other aspects like the term of properties of materials and so forth, are much more important to get good simulations of it."*

Interviewer 5

The interviewee 5 is a Senior Director for Architecture projects at The Royal Commission for Riyadh City in Saudi Arabia. He do a lot of research in the areas of Circular Carbon Economy and Sustainability Strategies, Net Zero Energy buildings, Climate Change and Resiliency and Digital Twin .

He uses BIM building information modeling to build the model for the construction which is very helpful tools and to support a decision maker or the design team work in one cooperative environment and energy simulation for energy efficient buildings.

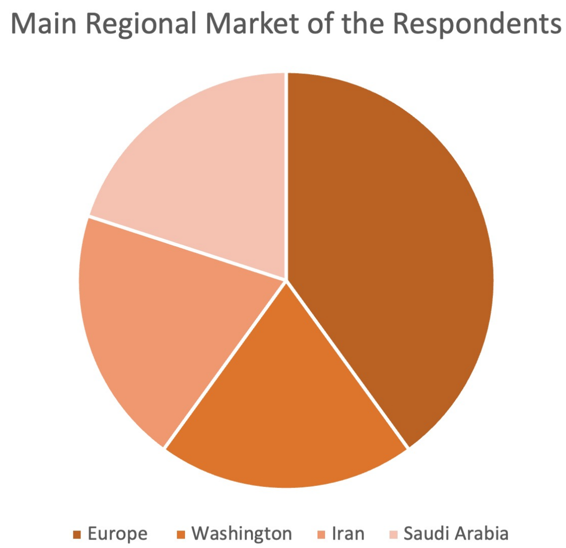

Figure 3.1: The regions respondent's belong

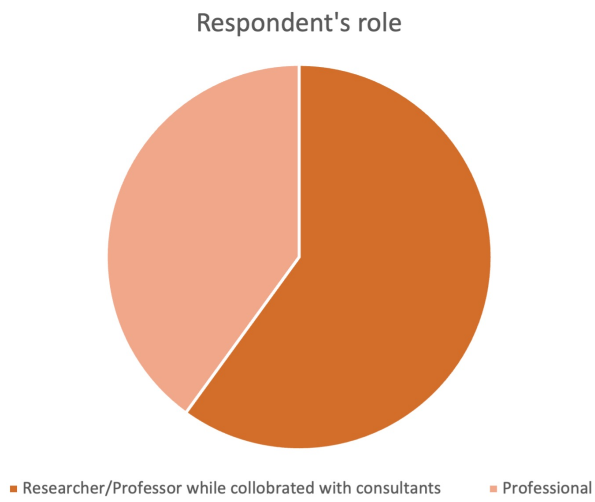

Figure 3.2: The Respondents role

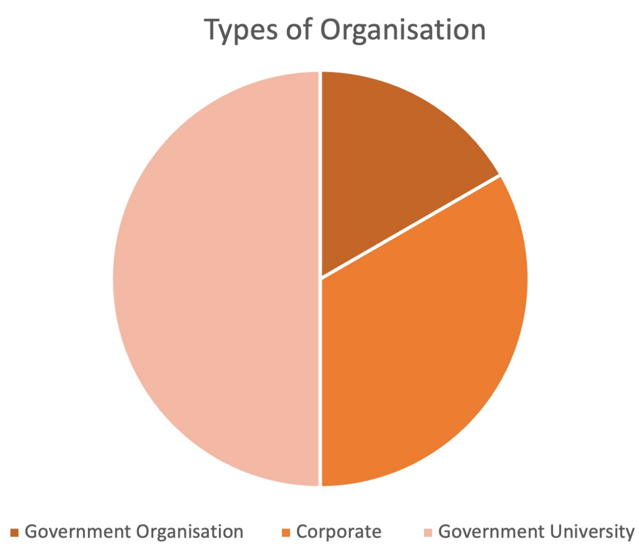

Figure 3.3: Types of Organisation

Chapter 4

Interview Results

4.1 Definitions of BIM and BEM

There a many definition of BIM and BEM exist. I asked my participants to define BIM and BEM in their own terms per their experience.

BIM and BEM are indispensable tools in the field of architecture, engineering, and construction. BIM enables the creation of a digital model that accurately reflects a building's physical and functional characteristics, while BEM utilizes computer-based simulations to analyze and optimize a building's energy performance. The combination of these tools can facilitate the development of eco-friendly and energy-efficient buildings.

4.2 Data exchange between BIM and BEM

Data exchange between BIM and energy modelling is a challenging process. Typically, this involves exchanging information about a building's geometry, materials, systems, and usage patterns to create an all-inclusive model of the building's energy consumption. Specialized software tools, such as those that can read and write data in industry-standard formats like IFC for BIM and EnergyPlus for BEM, are frequently used to execute this transfer.

IFC and gbXML are file formats that enable the transfer of various data types from BIM to BEM. These may include geometric details and material properties, as well as non-geometric information such as HVAC and lighting systems. There are only a limited number of applications that are capable of handling heating, ventilation, and

Interviewee	**Definitions**
Interviewee 1	*BIM is an object-oriented representation of a building, while a general 3D CAD model is generated from a set of pure 3D elements and Energy simulation is a process to estimate the energy behavior of a building according to a set of information of the building such as geometry, thermal characteristics, materials and so on.*
Interviewee 2	*Building Information Modeling (BIM) is a software-based method for creating building models that architects, engineers, and contractors can use to work together in the design, construction, and operation of a building and energy simulation is a computer-based evaluation tool that helps to analyze a building's energy performance and make it more energy-efficient by making design modifications before construction*
Interviewee 3	*BIM is a set of software tools that provide us with the ability to imagine the design we want in more realistic dimensions and by examining different angles and different views of that plan and idea. Energy simulation helps us identify the areas which consume more energy, so we can improve those areas.*
Interviewee 4	*BIM starts with constructing a 3D model, which facilitates document management and coordination of simulation during construction and Building simulation is developing a virtual model of a building and running simulations to evaluate its energy efficiency and operational lifespan under realistic weather conditions over the course of a year.*

Table 4.1: Definitions of BIM and BEM as per Participants.

air conditioning (HVAC) data produced by gbXML while IFC have limitations when it comes to specifying all the required elements for expressing heating, ventilation, and air conditioning systems. Building Materials data can be transferred from BIM to BEM but there are some limitations when transferring materials properties.

Thermal zone spatial definitions in BIM models can be transferred correctly to BEM software, but additional parameters such as ventilation rates, occupancy load, equipment load need to be entered manually in the BEM software or included in the IFC/gbXML file. So, IFC and gbXML data formats are not compatible with all the software's.

When discussing about the data exchange challenge in both domains. Interviewee 5 added that *"There is a lot of the challenge right now facing as you cannot exchange data between two domain i.e design domain and data information and simulation domain. The challenge is to bridge the gap between these two software."*

Talking about the BIM and BEM challenge interviewee 4 said *" Why would you include*

Figure 4.1: BIM to BEM data transfer

this all in BIM when you can model all these aspects directly in the energy simulation? The second aspect is often times people hope that they can get the, the geometry out of BIM into their energy simulation, which is also not so easy because the geometry needs to be prepared in a specific way. But then also it's not like in our experience, geometry or accurate geometry is not like so crucial for a good energy simulation of the building, Other aspects like the term of properties of materials and so forth, are much more important to get good simulations of it"

When we are discussing the challenge of BIM and BEM Interviewee 1 said *"One of the challenges is the difficulty happening in defining the geometry in the BEM when different versions of simulation tool is available. I think the topic of data standard in BIM and BEM is an important issue. IFC as the most famous include a lot of detail and one of the ongoing research topics in this field is how to develop standards which more practical for specific applications. For BEM, there is IDF which is used in EnergyPlus, but there is also gbXML, which is easier to work with. To develop such standards based on the use case, and having standardized procedure of construction activities helps in better collaboration of project partners and increase the efficiency of the project."*

Interviewee 2 said *"Although there are industry standards such as IFC and gbXML that have been created to make data exchange between BIM and BEM tools easier, some software applications do not fully comply with these standards. This can result in discrepancies and mistakes during the data exchange procedure."*

So, Data transfer between BIM and BEM can be challenging due to several factors,

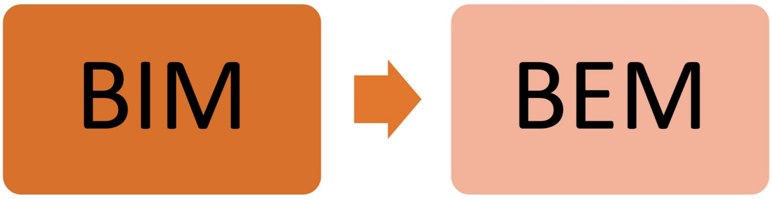

Figure 4.2: Data transfer from BIM to BEM is one directional

including:

Data Format: Different software systems used for BIM and BEM may have different data formats, making it difficult to transfer information seamlessly.For instance, BIM software such as Revit and ArchiCAD typically use proprietary file formats, while BEM software such as EnergyPlus and OpenStudio use open formats. This can lead to data loss or inaccuracies during data exchange.

Data Accuracy: The precision of the data transferred between BIM and BEM is critical for precise energy analysis and performance simulation. Any inaccuracies in the data can have an impact on the simulation's outcomes.

Data Consistency: Ensuring that the data transferred between BIM and BEM is consistent and up-to-date is a major challenge, as changes made in one system may not be reflected in the other.

Data Integration: Integrating the data from BIM and BEM can be challenging, as it may involve reconciling differences in the data structure, nomenclature, and units.

During the discussion of the data exchange challenge between BIM and BEM, interviewees have highlighted various issues. These include bridging the gap between design and simulation domains, incorporating all aspects into BIM, and the notion that precise geometry is not always necessary for an effective energy simulation. They also noted the challenge of defining geometry in BEM and emphasized the need for practical data standards. Additionally, they raised concerns about software applications that do not fully comply with industry standards, which can lead to errors in data exchange.

4.3 Accuracy of data from BIM to BEM

The accuracy of data is crucial as it directly impacts the simulation results. Any inconsistencies in the input data can result in inaccurate outcomes. This section discusses the importance of accuracy in input data and how it affects the final results.

Interviewee 4 said *"The energy performance gap is about 30 percent. When we do the energy simulation for new buildings, we are very far away often. Problem is then how do we measure this?So is it like in a design, when you're in the design and you're comparing different alternatives for building. It's still might give you good indication of which option you have is better . But then even in reality, it might be 30 percent. But the option you chose through the simulation, 30 percent off is still better than the other options."*

The accuracy of Building Information Modeling (BIM) and Building Energy Modeling (BEM) results depends on several factors:

The quality of the input data

The accuracy of BIM and BEM models is heavily reliant on the precision of the input data since the models are only as reliable as the data that is utilized to generate them. If the data is deficient or imprecise, the resultant models will also be erroneous or incomplete. For instance, if the dimensions of a building are incorrectly fed into a BIM model, then the whole model will be unreliable. Similarly, if the material properties of the building components are not precise, the consequent energy simulation will be inaccurate. Hence, it is imperative to ensure that the input data used in constructing the models is accurate and comprehensive to attain dependable results.

Interviewee 1 explains the importance of the accuracy of input data by saying " *This depends on the level of detail of the data which is available. If enough data about the building, occupants, outdoor weather condition and so on is available it can be used, otherwise assumptions can be used. Based on that, the accuracy of the energy model can be defined. For instance, in the project that I was working in, the occupants' schedule is not the real data rather it is an assumption. Or the weather data is a standard format to represent the long-term condition of the outdoor situation. Although it may not represent the real future condition, a prediction of what will happen in future regarding the weather situation is used."*

Interviewee 2 explains the important of input data and assumptions on the simulations. He said *"Usually the big assumptions are surrounding the occupancy and how the building will be used by the occupants. The HVAC will largely be driven by the external* *weather conditions or outdoor weather conditions, but it's the energy used from lighting schedules and occupancy schedule is really the biggest assumption that we make. The effect of input data will be on the predicted energy use or energy consumption. So I think it impacts the time and the money."*

The level of detail in the models

The accuracy of BIM and BEM models is influenced by the level of detail.The accuracy of BIM and BEM models is affected by the level of detail, and it is crucial to achieve a balance between the level of detail and practicality to ensure accurate results.

Interviewee 1 said *"Energy modeling like any other modeling process is dependent upon the complexity in the modeling process and the accuracy of input. I am not sure if it is relevant to the type of construction project rather on the accuracy of the available data for the project"*

Interviewee 1 emphasized the significance of maintaining an appropriate level of detail in BIM and BEM models to obtain accurate simulation results. If the model is overly simplified, then the simulation results will be inaccurate. Alternatively, if the model is detailed much more, it may become difficult to manage.

During the discussion of simulation outcomes for a renovation project, she suggested that *"comparing the simulation results with the building's energy bill and making adjustments based on this comparison is one way to enhance the accuracy of the simulation. However, she also noted that while this approach is useful, it is one of the limited methods available for generating reliable estimations."*

Interviewee 2 highlighted the importance of the input data as per the type of construction. He said *" In the case of commercial buildings, the energy model must be detailed enough to cover aspects such as mechanical systems, lighting, and plug loads. In contrast, in the case of residential buildings, the energy model must include information about insulation, windows, and appliances."*

The expertise of the individuals using the tools

The accuracy of BIM and BEM is also reliant on the expertise and experience of the modeller. Highlighting this fact Interviewee 2 said *"The accuracy of the model depends on the experience of the energy modeler. We've done enough reviews of energy models for third parties where I know that there's a wide, wide margin. it's like a, a big group of people and the experience level is very distributed"*.

Interviewee 3 said *" The several assumptions made in simulation such as Climate, thermal properties of some materials, outdoor air per person, HVAC system, operating*

Figure 4.3: Accuracy of data

schedule effects the simulation result. I use experts' opinions, research articles for regarding these assumptions."

While discussing the reasons for data accuracy from BIM to BEM Interviewee 5 said *" It depends person to person"*

He explained by giving a real example *"I did this as a test with a number of the students, like three students in one classroom. I give them the same, M file and they request from them to export it into an energy model and perform the simulation for energy consumption. Unfortunately, I receive different results because everyone has his way to export the file."*

Overall, There is usually a 30 percent energy performance gap in new buildings and measuring it can be a challenge. The accuracy of energy modeling depends on the complexity of the modeling process and the accuracy of the input data, rather than the type of construction project. Comparing simulation results with the building's energy bill and making adjustments based on this comparison is a way to enhance accuracy, but it is a limited method. Additionally, the accuracy of the model depends on the experience of the energy modeler and there is a wide margin of error. Similarly, the accuracy can vary widely depending on the individual exporting the file.

4.4 Potential Benefits of BIM and BEM

If the interoperability improves between the BIM and BEM software it offers several benefits some of these are discussed below.

Is the time spend on the BIM and BEM integration is worth it ?

Interviewee 1 said *" If the BIM is available through, it can save time through BIM-to-BEM conversion."*

She also highlighted the benefit of using BIM with BEM . She said *"Through the integration of BEM and BIM, designers can pinpoint the most energy-efficient design alternatives for a building. With BIM's precise 3D building model, designers can generate a precise BEM simulation, which allows them to assess and contrast various energy-saving methods."*

Different stack-holders get different benefit from the technology and tools. While highlighting this fact Interviewee 2 said *" I would say that, it takes a lot of time. 80 % of the projects I work on, I think that the owner gets the financial or external benefit from doing energy modeling that they wouldn't otherwise receive on 20% of projects. They didn't need to do it, but I'd say on the majority of them, they will get a return on investment."*

When discussing about who gets the most benefit of the energy simulation owner or designers?

He says *"I would say it goes owner then designers. It kind of depends on the project.I'd say on average probably 80 to 120 hours worth of our time."*

While discussing his thoughts on integrating BIM with BEM he said *If I was better at Revit, maybe, but I don't think that's a straightforward yes, and that's why we haven't tried to invest the time to get better."*

Interviewee 3 said *"It can help reduce the operation costs and environmental impacts and it does saves times but have high initial investment cost."*

BIM with BEM can be used to evaluate the building's energy performance throughout its lifetime, allowing for continuous improvement in energy efficiency and reducing operational costs. Discussing this Interviewee 4 said *"I believe that you can save a lot of money afterwards during the operation of the building. The problem with energy simulation and BIM, it's actually not very costly, but you don't have enough experts that know how to do it that may exit so expensive. Creating a building energy simulation for a single family house, including all the surveying that would be require maybe for*

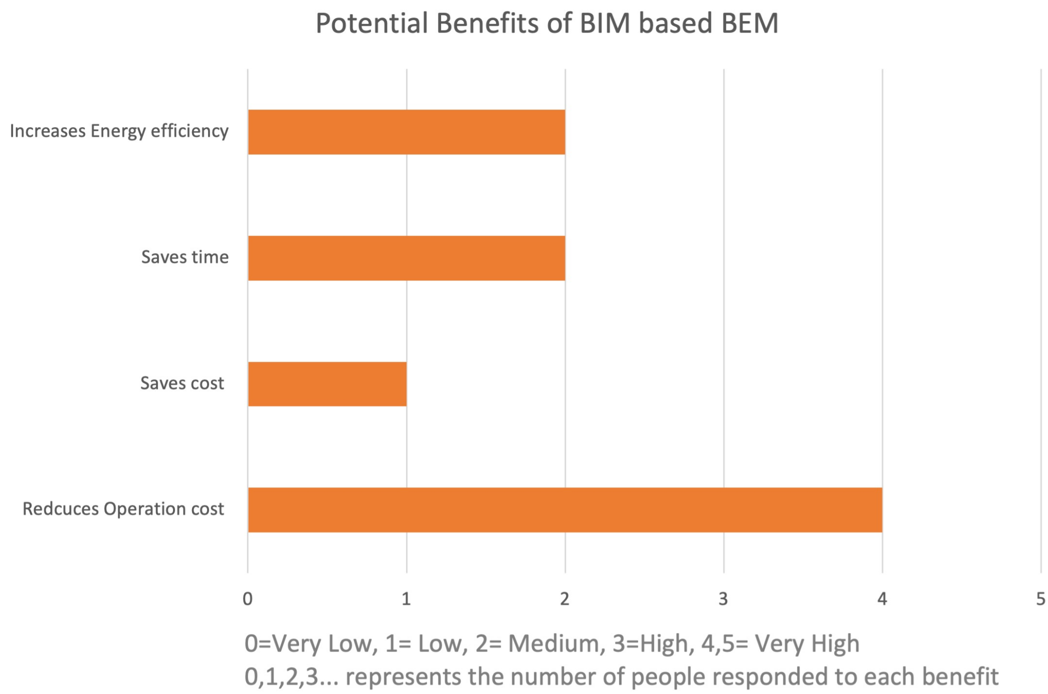

Figure 4.4: Potential Benefits of BIM and BEM

$4,000, $5,000."

He thinks that while it can results in saving in operational cost but I don't think BIM with BEM is a great idea. He highlighted this by saying that *"I propose to all people and all my students that wanna do an energy simulation, not to use BIM as people use BIM for defining geometry, but you can also just define the geometry directly in the energy simulation software. So,* but then why people are using BIM with energy simulation? *They're hoping that they can speed up the simulation, but I don't think they will succeed. I don't think BIM and BEM integration save times. I believe that it costs more time and in the end costs more."*

"As I said, the information that you need in BIM is made mainly for architectural design of the building. So an architect can create a set of drawings fairly nicely in Revit. Most of the information you need for an energy simulation is not there, and then energy modelers doesn't want to necessarily create it in Revit. so it doesn't make sense to integrate these two tightly."

Interviewee 5 said *"There are lots of benefits. A lot of decision you can change your architecture decision based on that model. The integration of BIM and BEM offers designers and building owners a more extensive set of information regarding the building's energy performance. This comprehensive data enables them to make knowledgeable decisions concerning building materials and design options."*

While discussing about the cost and time he said *"Definitely I agree it saves time and cost. Spending time on that and defaulting the tools and make it easy for the user, I think this will be very helpful."*

Overall, the integration of BIM and BEM can lead to time savings and the provision of detailed information for energy-efficient design options. Interviewees have varying perspectives on the advantages and drawbacks of this integration. Some says that it can save time and money while helping one to make decisions which helps in energy savings, while others believe that it takes more time and may not be required . Nevertheless, there is consensus on the need to invest in user-friendly tools to enhance the integration's efficacy in the long term.

4.5 Tools for BIM and BEM

Different software options are accessible for BIM and BEM, and organizations can opt for various tools that meet their specific demands and project requirements. Autodesk Revit, Bentley Microstation, and ArchiCAD are among the commonly used BIM software, whereas EnergyPlus, IESVE, and eQuest are well-known BEM software. The decision to select software depends on a few factors, including financial resources, complexity level, and compatibility with other software used by the organization.

These software aids assist designers and building owners in developing intricate 3D models, conducting energy simulations, and assessing various energy-efficient approaches. The selection of the appropriate tools is contingent on the specific project specifications, the degree of accuracy required, and the user's proficiency with the program.

Interviewee 5 said *" I use Energy plus, Simergy and Modelica. Modelica is a very advanced one. These are the famous softwares I used during my study regrading the energy efficient buildings."*

Interviewee 1 said *"I have worked with EnergyPlus energy simulation tool directly and embedded in OpenStudio and Sketchup software. I did not try the BIM to BEM conversion process which can be challenging in term of geometrical transformation. I used EnergyPlus directly and in scripting by R and Python to investigate the energy performance of the buildings in as-built situation and for renovation scenarios". Energy Plus does not have a graphical interface for visualizing and understanding building design. Third-party software such as Design Builder must be used instead. "*

Interviewee 2 said *"We almost do everything primarily in eQuest. The reason why we use eQuest is that it's been around since the eighties and we trust the results that come*

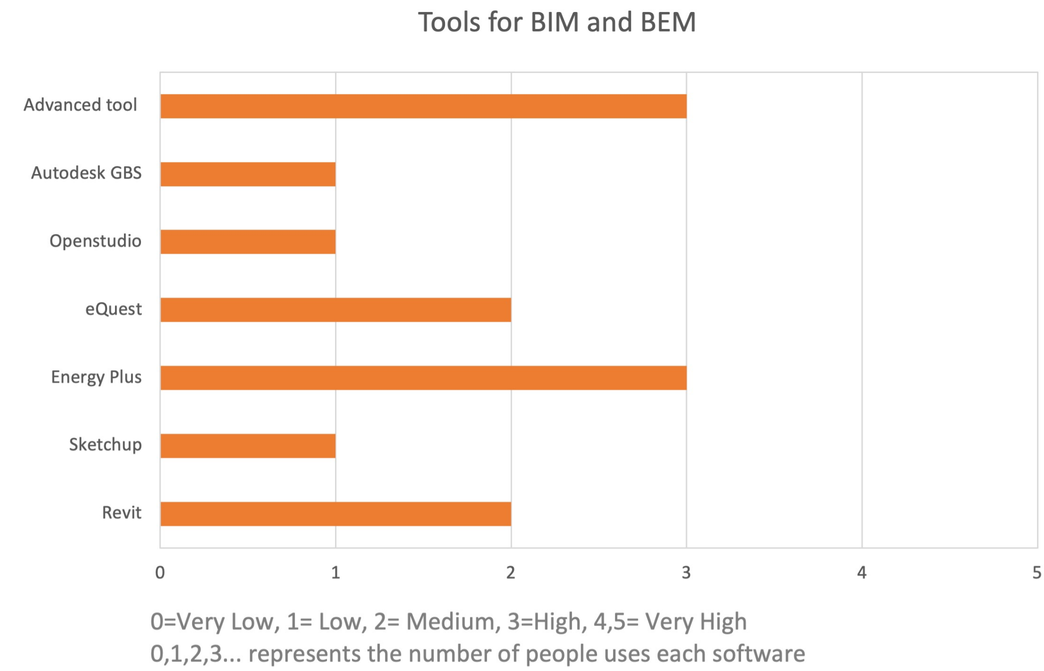

Figure 4.5: Tools for BIM and BEM

from it. Additionally I would say that the graphical user interface is intuitive in eQuest, than other programs out there.Some engineers use train trace and carrier half, which are paid programs from the manufacturers. So they usually do those because they con conduct their sizing runs to figure out how big the equip the HVAC equipment needs to be and so then they're able to run simulations in those programs. I was just gonna say, as it's paid,it's limits the ability for everyone to have access to it."

Interviewee 4 said*" There are a lot of different approaches we used for energy simulation. We use Energy Plus and one really good company is ESP-r (Energy Simulation Software tool).They probably have the most advancement and tooling available. It is a mathematical software tool designed for project managers. It integrates various applications and tools such as data coordination, simulation, CAD, performance evaluation etc. The software uses complex equations to handle multiple aspects of the project simultaneously, including geometry, construction, operation, distribution, heat dissipation, etc."*

"People get confuse between energy modeling and energy simulation.Everything is not real simulation. There's are simulation package, but the rest is not a simulation, it's just calculation.They give some rough values. We also use TRNSYS which is a transient system simulation software tool designed to model complex energy systems. It has a modular structure that allows the problem to be divided into smaller components, making it easier to develop. It also enables users to incorporate components created using

other software tools such as Matlab, Excel, VBA, etc.”

Interviewee 3 said *” We use Autodesk green building studio for energy simulation and we commonly use energy simulation for energy efficient buildings”. It is a cloud-based software tool that provides advanced building simulation and analysis capabilities to support the design and optimization of high-performance buildings. The tool integrates with other Autodesk building design software, allowing users to import 3D models and simulate energy consumption, thermal comfort, indoor air quality, and other critical performance parameters.”*

Overall, Some people used EnergyPlus and third-party software for energy simulation. While others use eQuest for its intuitive graphical user interface, Autodesk green building studio for energy simulation, ESP-r for its advanced tooling and mathematical software design, TRNSYS, Simergy, and Modelica for advanced calculations.

4.6 Expertise of BIM and BEM

Expertise in BIM and BEM is necessary as without expertise in BIM and BEM, organizations may struggle to effectively utilize these tools and miss out on the benefits they offer.

Lack of expertise in Building Information Modeling (BIM) and Building Energy Modeling (BEM) can be a significant challenge for organizations looking to adopt these technologies. BIM and BEM require specialized skills and knowledge, including proficiency in software tools, data management, and project management.

To reap the full benefits of BIM and BEM, a team with the necessary skills and expertise is required. Training programs, new employee recruitment, and collaboration with outside consultants or contractors are means to get the expertise on the BIM and BEM.

In my interviews with five individuals who possess academic and professional experience in BIM and BEM, I discovered that while most of them have a research background, they have also collaborated with consultants for assistance in areas such as energy modeling or BIM.

Discussing about the lack of expertise in BIM and BEM Interviewee 4 said *” A lot of architects have in house expertise for BIM and BEM. Because not much people have expertise in energy simulation. People are using it but not much that’s a big problem. ”*

He explains the reasons behind the lack of expertise *“Several factors contribute to the scarcity of BIM and BEM expertise. As these technologies are still relatively new, many*

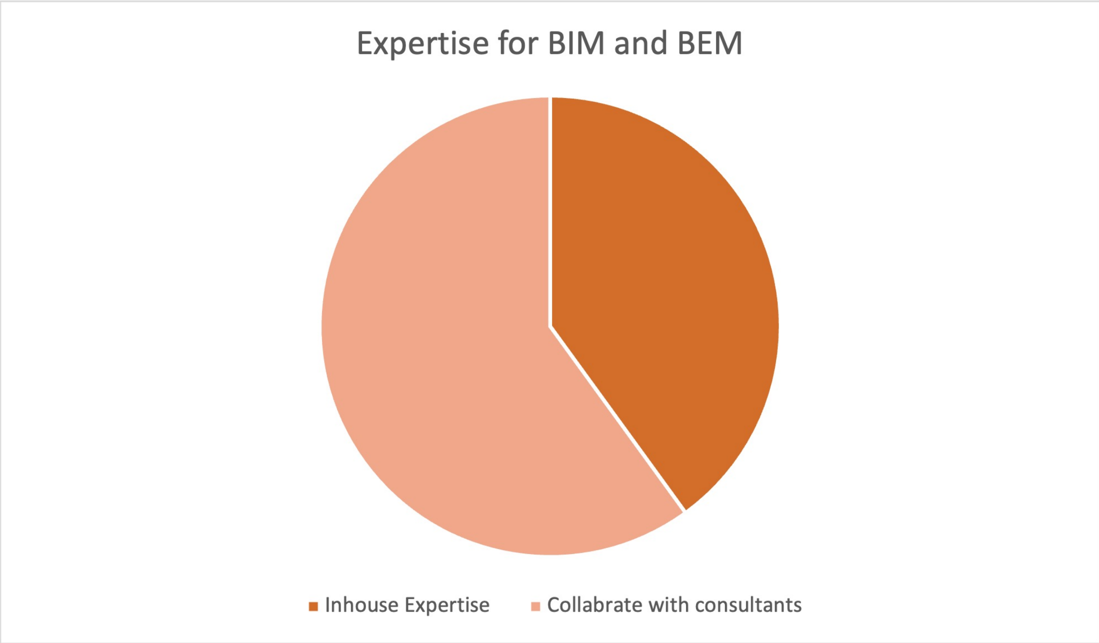

Figure 4.6: Expertise of BIM and BEM

professionals lack experience or training in their use. Second, working with BIM and BEM requires specialized knowledge and skills that can be difficult to obtain. Third, the complexity of the software and the requirement for interdisciplinary collaboration make developing expertise difficult. Finally, smaller businesses may find the cost of implementing BIM and BEM prohibitively expensive, preventing them from investing in the required software and training."

When I asked about working with consulants he said *"We have very advance international Companies. So we work together with large energy consultants such as Arup, Arcadia or Buro Happold . They are very, all of them are very sophisticated in using simulations."*

Interviewee 1 said *" Energy experts and civil engineers who are working in with BIM and BEM usually have this expertise. Development of the software is required to be done by software developers but the domain expertise to develop such tools come from us as civil engineers I would say".*

She says "As I am PHD candidate working on BIM and BEM research projects. I have gained knowledge on these tools and I practise it by myself."

While discussing about the choice between in-house expertise or consultants for BIM and BEM implementation with Interviewee 5 said *"It depends on the project's complexity, timeline, budget, and resource availability"*. He added *"As I incorporate BIM and energy simulation for research purposes it is done by industry consultant"*

Interviewee 2 said *"As we are experts in energy simulation, and I am a Professional Engineer at Solarc Energy Group, we do in house modelling"*.

He explains the benefits of in house expertise by highlighting *"provides greater control and adaptability in the design and simulation process, enabling organizations to personalize their approach and tools as per their specific needs. This leads to smoother and more efficient workflows, removing the need to outsource the work to external consultants or contractors. It also results in cost savings over the long run as external services are avoided. Ultimately, internal expertise can lead to a better understanding of the simulation results."*

Overall, Some organizations choose to develop in-house expertise on BIM and BEM by providing training and development programs for their employees. Others prefer to hire external consultants or contractors with expertise in these areas to assist with the implementation and execution of BIM and BEM projects. The choice between in-house expertise and external consultants often depends on the organization's budget, timeline, and available resources.

Interviewee	**Expertise**
Interviewee 1	As I am PHD candidate working on BIM and BEM research projects. I have gained knowledge on these tools and I practise it by myself or collaborate with consultants
Interviewee 2	As we are experts in energy simulation, and I am a Professional Engineer at Solarc Energy Group, we do in house modelling
Interviewee 3	I Integrate Autodesk Revit with Autodesk Green building studio for my research projects.
Interviewee 4	We worked with large international companies for energy simulations
Interviewee 5	I use a combination of Autodesk Revit and EnergyPlus for conducting simulations myself and do collaborate with consultants for energy modelling.

Table 4.2: Expertise of Participants on BIM and BEM .

4.7 Challenges in implementing BIM and BEM

The challenges of BIM and BEM adoption must be considered because they can have an impact on the successful implementation and use of these technologies in the AEC industry. Understanding and addressing these issues can assist organizations in overcoming obstacles and realizing the full potential of BIM and BEM. Lack of expertise, resistance to change, interoperability issues, data management, and cost are some of the barriers to BIM and BEM adoption.

There are several challenges in adoption of BIM and BEM. These are following :

Lack of standardization

One of the barriers to BIM and BEM adoption is a lack of standards, which makes ensuring consistency and interoperability across different projects and software platforms difficult. BIM and BEM generate large amounts of data, which can be difficult to manage effectively.

Interviewee 1 said *" I think the topic of data standard in BIM and BEM is an important issue. IFC as the most famous include a lot of detail and one of the ongoing research topics in this field is how to develop standards which more practical for specific applications. For BEM, there is idf which is used in EnergyPlus, but there is also gbXML, which is easier to work with. To develop such standards based on the use case, and having standardized procedure of construction activities helps in better collaboration of project partners and increase the efficiency of the project."*

Interviewee 3 said " As there are many tools available in the market so, the Lack of suitable information about how to integrate these two is the main challenge. "

When I asked about the main challenge in implementing BIM into BEM Interviewee 4 straight way said *"The main challenge is to transfer the data from BIM to simulation software.As I said before, I don't think BIM has the information or the important information for energy simulation point.So it does not help much to automatic transfer. We cannot define the geometry in the BEM software but you can define the geometry in the BIM software and the existing automated approaches to export the geometry don't work so well. So we need to do a lot of extra work. And then on the other hand, it's not so important for the energy simulation, so you can fairly quickly recreate a geometry in your energy simulation software."*

Explaining the challenge of data exchange interviewee 5 said *"The reason is a lot of the challenge right now facing is we cannot exchange between two domain because you are dealing with two domain i.e design domain and data information and simulation domain. Bridging the gap between these two software is the solution"*

Lack of expertise

BIM and BEM require specialized knowledge and expertise, which may not be readily available within an organization. This can lead to additional training costs or the need to hire external consultants or contractors.

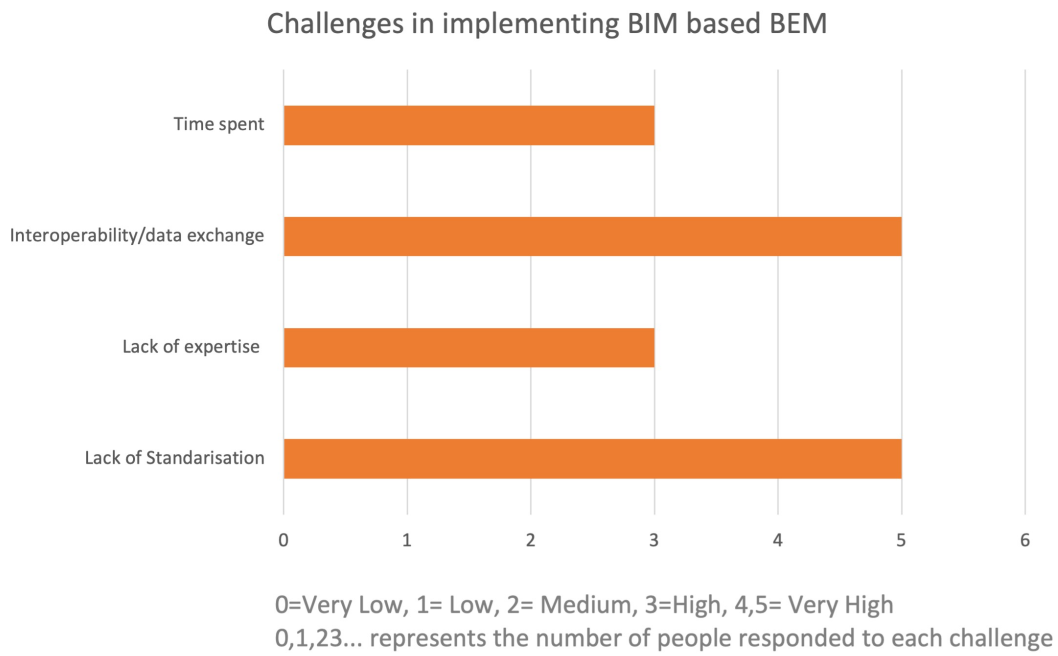

Figure 4.7: Main Challenges in adoption of BIM and BEM

Interviewee 4 the lack of expertise as a challenge. He said *" Not much people have expertise in energy simulation and that's a big problem."*

Lack of expertise is also an important factor which impacts the results of the simulation. Interviewee 5 highlighted this by saying *" If we ask different practitioners to export model energy simulation software. I received different results because everyone has his way to export the file. So there is a lack of standardization on exchanging data. So how can we rely on this thing if they are not great? We need to let the industrial focus first of all having one common standard to exchange file from domain to domain and then perform the performance."*

Time required

Transferring building information from BIM to BEM poses a substantial challenge, as it depends on several factors, such as the size and complexity of the building, the level of detail in the BIM model, and the level of accuracy necessary in the BEM simulation.

Interviewee 5 highlights this challenge by saying *" Sometimes it takes days to run a CFD simulation model. If you need a simulation,especially CFD model, it takes a lot of time. if you're doing, for instance, a smoke fluid.This is this is a crazy one. You need days to run the model. There is a challenge and that need to be considered."*

Interviewee 4 said *"I mean, for a relatively complex building, it might take you two, three hours to, to model the geometry and it's not so important or accurate that there's* *much more accurate to other material values. It takes a lot of time to model and as the data exchange between the BIM and BEM is one directional, if the data exchange is not complete then we have to spend more fixing that"*

Interviewee 4 explains why it doesn't make sense to integrate both tools. He highlighted this by saying that *"I propose to all people and all my students that wanna do an energy simulation, not to use BIM as people use BIM for defining geometry, but you can also just define the geometry directly in the energy simulation software. So, but then why people are using BIM with energy simulation? They're hoping that they can speed up the simulation, but I don't think they will succeed. I don't think BIM and BEM integration save times.I believe that it costs more time and in the end costs more"*

Overall, adoption of BIM and BEM is hampered by a lack of standardization, a lack of expertise, and the time required to transfer building information from BIM to BEM. The lack of standards makes ensuring consistency and interoperability difficult. BIM and BEM necessitate specialized knowledge and expertise, which may be lacking within an organization. The amount of time required to transfer building information is determined by several factors, including the building's size and complexity.

4.8 Future of BIM and BEM

The future of the construction industry looks promising, with the integration and streamlining of both BIM and BEM expected to become even more advanced in the coming years.

While discussing about the future of BIM and BEM in construction industry Interviewee 1 said *"Yes it will be beneficial because it allows engineers and practitioners to collaborated and communicate the information about the building much easier. One of the places it can be used more in in renovation projects which is applied less currently, because not too many of the existing buildings have BIM."*

She added *"One of the important aspects which maybe makes different software various from each other is the BIM to BEM conversion, to include the required information and to tackle the challenges in the geometry transformation. The other aspect is the data standard available for BEM. For instance, IDF is used in EnergyPlus and it is a popular standard, but there is some software which also promote applying gbXML which is another format and easier to edit and work with."*

Discussing about how BIM and BEM is changing construction industry Interviewee 2 said *"I think that it's just helping to push higher efficiency, HVAC designs further* *forward because a lot of times what ends up happening is you trade off inefficiencies in the building envelope with efficiencies with the HVAC system."*

When taking about the BIM and BEM future in Washington he said *" I would just say that at least in Washington, the prevalence of energy modeling is only going to increase. As the energy code continues to become more and more difficult and so that's just something to think about for construction and ownership teams is that consultants that provide energy modeling or even just energy code consulting are becoming more and more normal as the architects and mechanical engineers are trying to keep up with the building code for the architects and mechanical/plumbing code for the mechanical engineers those are becoming more complex, so then you're just adding an extra layer of difficulty in understanding the energy code pulley. So energy code or energy analysis consultants are going to be more and more prevalent."*

While discussing about the BIM and BEM impact on construction industry in coming years Interviewee 5 said *" I'm an architect, working in the field of designing. We are using BIM to build the model for the construction. So using BIM this is will definitely support the coordination and support engaging. However doing a simulation based on the BIM there is a lot of the challenge right now . You cannot easily exchange the information between two domain i.e design domain and data information and simulation domain. We need to bridge the gap between these two software."*

He also said *"BIM and BEM are quickly becoming essential tools in the construction industry, and their use is only expected to increase in the years to come. They will help facilitate collaboration, generate data, increase automation, and promote sustainability, making construction processes more efficient and effective."*

Interviewee 4 said *" I can't say much, but all I can say is if you wanna really have a future and if we really wanna reach our energy saving goals (energy neutrality by 2050), then we need to significantly reduce the energy use of the existing building stock. And as I said in the beginning for renovation projects, I don't see any way how to really do an energy efficient renovation without a good energy simulation."*

"He said that once we overcome the main challenge to transfer the data from BIM to simulation software we can expect the future. As the existing automated approaches to export the data between the two software don't work so well. So we need to do a lot of extra work."

He also recommended *" Not to use BIM for energy simulations, as defining geometry directly in energy simulation software is more effective. People use BIM for energy simulations in hopes of speeding up the process, but this integration ultimately costs* *more time and money. BIM is mainly intended for use in architectural design, and commonly lacks the necessary information for conducting energy simulations. As a result, it does not make sense to tightly integrate BIM and energy simulation software."*

In general, the use of BIM and BEM is becoming increasingly important in the construction industry. However, there are difficulties in exchanging information between the design and simulation domains that must be addressed to achieve energy-saving targets and ensure the continued relevance of these tools in the future.

Chapter 5

Conclusions

5.1 Conclusions

During my research, I came to know many aspects of BIM and BEM technology. Both BIM and BEM are important tools for the construction and building industry. Collaboration and decision-making can be improved by creating digital models through BIM, which ultimately lead to better projects. As greenhouse gas emissions and climate change progress, building energy modeling can also reduce a building's carbon footprint.

BIM and BEM are technologies that have transformed the construction industry by creating digital energy efficient models of buildings and infrastructure projects. Although BIM and BEM are distinct ideas, they are frequently employed in combination to enhance building efficiency.

BIM can provide the accurate information required to create a dependable BEM model, and BEM can identify opportunities to improve a building's design and operations. They have numerous applications and are increasingly important in creating sustainable and energy-efficient buildings. BIM and BEM will continue to play an important role as the construction industry evolves to combat climate change.

Data exchange is always the challenge in these two platforms. BIM focuses on the physical and functional characteristics of a building, while BEM focuses on its energy performance. While both disciplines have their own unique sets of data, there is a need to exchange data between BIM and BEM to ensure the building's energy performance is optimized.

Per our research data exchange between BIM and BEM poses some challenges. They are Data Compatibility, Data Integrity and Lack of Standardization. In order to have a future, we needs to bridge the gap between these two software's.

For precise data transfer between BIM and BEM, it is essential to understand data models and interoperability requirements. Furthermore, applying compatible software, standardized data formats can help reduce errors and more accurate results. Efforts to standardize data exchange are ongoing, but progress is slow and the challenge remains a significant obstacle to BIM and BEM adoption in the building industry.

The accuracy of transfer between BIM and BEM depends on the way the model is transferred, experience of the energy modeler, complexity of model process. Transforming data from one format to another is necessary when transferring it. It is also critical that the data is complete and accurate in order for the transfer to be successful. Incomplete or inaccurate data also yields incorrect results regarding the energy performance of the building.

One challenge in implementing BIM and BEM is the requirement for specialized knowledge and expertise, which may not be readily available within an organization. This may necessitate additional training costs or the hiring of external consultants or contractors. Additionally, BIM and BEM integration into current process and systems can be challenging and time-taking. Employees who are accustomed to traditional design and construction processes may also be resistant to change. Finally, ensuring data accuracy and consistency across multiple platforms and software systems can also be a challenge.

According to the research, it seems that a significant number of individuals and organizations seek the services of consultants for energy simulation, since there is a lack of expertise in this field. Moreover, it appears that only a few individuals connect BIM and BEM platforms, which is crucial for optimizing building energy efficiency. This highlights the need for enhanced education and training in these domains and greater recognition of the advantages of integrating BIM and BEM systems. By boosting expertise in energy simulation and encouraging the adoption of integrated BIM and BEM systems, it may be possible to enhance building energy performance and promote sustainable development.

BIM and BEM pose challenges in terms of their complexity and associated costs. Transferring data between BIM and BEM data models can be challenging due to the complexity of the models and their inter-dependencies. In addition, the expense of implementing data exchange can be excessively high, including costs such as software licenses, hardware, and training. This can make it challenging for small and medium-sized businesses to adopt data exchange. Moreover, the cost may further increase due to the lack of experts who are well-versed in energy simulation.

On the other hand some people think integrating BIM and BEM does not save time, but instead requires more time and resources, resulting in increased costs. BIM primarily focuses on the architectural design of the building, so although architects can produce high-quality drawings in Revit, most of the data required for an energy simulation is not available. Energy modelers may not wish to produce this data in Revit either. Thus, it is not logical to integrate BIM and BEM closely.

There are various software tools available for BIM and BEM. The tools can help stakeholders collaborate more effectively, make better decisions, and deliver better projects. The common BIM tool used is Autodesk Revit to define geometry. Some people use Sketchup to define geometry. *So, Is sketchup a BIM tool?*. The common energy simulation tool is Energy plus. Many people also use eQuest, Autodesk green building studio and other advanced tool such as ESP-r (Energy Simulation Software tool), Synergy and Modelica.

Despite the challenges, Building Energy Modeling (BEM) and Building Information Modeling (BIM) have numerous advantages in the construction and building industries. BIM and BEM benefit the owner up to the 80 percent. Building operations can benefit financially from incorporating BEM and performing energy simulations. Energy simulations can be used to identify and implement energy-efficient design strategies and systems, resulting in lower energy consumption and operating costs. While conducting energy simulations may require an upfront investment, the costs are generally low when compared to the long-term savings that can be achieved through improved energy efficiency.

BIM and BEM are predicted to have a bright future, as they keep bringing changes to the construction and building industry. They are expected to expand and continue to transform the industry by integrating with IoT and AI to create intelligent buildings and infrastructure, urban planning, improved compatibility between various software platforms, and emphasizing on sustainability and energy efficiency to enhance their adoption. One emerging trend is the merging of these technologies with other advancements such as IoT and AI to produce smart buildings and infrastructure. As a result, the buildings will operate more efficiently, reduce energy consumption, and lower costs.

Furthermore, the advancements in BIM and BEM technology are projected to increase interoperability between various software platforms and data formats, thereby simplifying and refining data exchange.

In conclusion, the increasing focus on sustainability and energy efficiency is anticipated to boost the implementation of BIM and BEM in the construction and building industries. To decrease carbon footprint and tackle climate change by 2050, BIM and BEM can serve as crucial tools by constructing sustainable and energy-efficient buildings and infrastructure. Nevertheless, achieving these goals can be challenging, especially when renovating existing buildings that may not possess a pre-existing BIM model.

5.2 Future Prospects of Our Work

The integration of BIM and BEM is crucial in optimizing building energy performance, but it poses certain challenges that must be addressed to ensure accurate data exchange. The accuracy and consistency of data exchange between these systems are vital in order to optimize building energy performance. It is important to conduct further research to establish a standard format for data exchange between BIM and BEM systems, which is a key element in achieving this. ISO 16739:2013 and the IFC data exchange format by BuildingSMART are two examples of standards for BIM and BEM data exchange. Further efforts are necessary to ensure that the standards for BIM and BEM data exchange are adopted and effective, which involves cooperation among multiple stakeholders, including software developers, building owners, architects, engineers, and policymakers.

In the future, it is important to consider whether BIM based BEM are simplifying our work or making it more complicated. Shouldn't these systems be designed to make our jobs easier? We need to reflect on these questions and evaluate the impact of BIM and BEM on our work processes.

The study may not represent the views and experiences of larger population or other people in the AECO industry as the study size is limited. To get a broader and accurate understanding of the study, the data should be collected from larger population. Additionally, the participants of the study are researchers and professors, the experience of the professionals will give a better and different understanding of the topic. So, it is important to consider the current study limitations such as sample size and selection criteria.

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