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Enhancing facility management for existing facilities with building information modeling

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ENHANCING FACILITY MANAGEMENT FOR EXISTING FACILITIES WITH BUILDING INFORMATION MODELING

By

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Abstract

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Building information modeling (BIM) refers to the process of creating a comprehensive three-dimensional (3D) model that allows for a seamless transition from design and construction to operation & maintenance during a building's lifecycle. While a majority of past research for building information modelling was focused on design and construction, research has shifted to operation, maintenance and renovation. This study investigates the feasibility of integrating BIM (Autodesk Revit) and facility management (BUILDER SMS). BUILDER SMS is currently used at the sponsor's facilities to encourage proactive maintenance and provide updated condition assessments. While both datasets have their own benefits, this study investigates the practicality of Revit and BUILDER SMS integration. To accomplish this, an integration workflow was developed, tested using a case study and the resulting integrated BIM model evaluated by a focus group. Of the integration methods evaluated, using an intermediate database linked by unique component identifiers was found to be the faster option, especially for frequent updates of the BIM model and BUILDER SMS database. The focus group was most interested in the visualization capabilities of data-rich BIM models, such as visual filtered views for condition assessments and the ability to view the BIM model on a tablet/mobile device.

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Introduction

Overview

Building information modeling (BIM) can be a useful tool during all stages of a building's lifecycle. While past research has mostly focused on BIM in the design and construction phase, the goal of this study is to develop and evaluate novel ways to use BIM during the building operation phase, i.e. to support facility management (FM). Autodesk Revit is the primary BIM tool used in this research [1]. In this particular case, BIM models are created from 3D scans of existing buildings. For FM, building components are inventoried separately and entered into BUILDER SMS, a web-based application that assists engineers, technicians and managers with building maintenance to improve its sustainability. The incorporation of BUILDER SMS data into Autodesk Revit associates facility data with a building's geometry, leading to better data visualization opportunities. Successfully exchanging information between BIM and facility management software may support improved analyses for building sustainability, e.g., condition assessment mapping or energy analysis.

Building Information Modeling

Building information modeling refers to the process of creating a comprehensive three-dimensional (3D) model to encourage efficient project planning for multiple disciplines. BIM models are superior to traditional two-dimensional CAD drawings in that they are displayed in 3D, they have additional data parameters associated with their components, and they are designed for interoperability between different disciplines. A key feature of BIM is that it represents the physical and functional characteristics of a

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building. The physical characteristics include the building envelope, mechanical equipment, location/orientation, and dimensions. The functional properties of a building information model include, but are not limited to, structural analysis properties, energy analysis parameters (thermal resistance, electrical load, etc.), maintenance history, fire safety rating, and facilities management data. The use of both physical and functional characteristics in a BIM model makes it applicable to different disciplines and encourages collaboration among stakeholders to develop and utilize data-rich representations of buildings. BIM models with essential information for all phases of a building's life cycle enables a seamless transition from design and construction to the operation phase and provides a reliable source for owners' to retrieve and analyze information.

One method of creating BIM models of existing buildings is the use of a 3D laser scanner that outputs point cloud data of a building. This point cloud data associates each scan with a 360-degree image of the interior or exterior of the building, depending on the location of each scan. This method is particularly useful for structures with complex shapes or for a building that does not have accurate dimensions in its original drawings. The point cloud can be imported into a 3D modeling program and traced to create a 3D building model.

BUILDER SMS for Facility Management

The use of a facility management system is advantageous for the operation phase of the building's lifecycle. BUILDER Sustainable Management System (BUILDER SMS) is a web-based application that provides updated condition assessments of components within a facility and encourages proactive maintenance and repair. In their

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current use, BUILDER SMS databases are created from an onsite inventory and then updated as changes are made to the building components.

BIM and Facility Management

The Sustainable Facilities Center at Rowan University [2] uses point cloud data and Autodesk Revit to create 3D BIM models of existing structures including the building envelope, utilities and furniture. Facility data are also recorded and entered into BUILDER SMS, and reports are generated to assess the condition of each component. The BIM model in Revit and BUILDER SMS files contain unique information for the same components of the facility and are not directly compatible with one another. Integrating the two resources will combine the visual advantages of the BIM model with the valuable maintenance information in BUILDER SMS to develop a more detailed and useful model of the building. To make the two sets of data compatible, it is necessary to extract information from both files and create a link between the data formats.

For Revit and BUILDER SMS to exchange information, the data from each source needs to be converted to a compatible format. The differences in the two datasets was investigated in this study to find a method of connecting them. To analyze the concept of linking the two data formats, a test facility was used to simulate the exchange of information between BIM and facility management software. Once the method was deemed to be successful, a case study of a facility was performed to test the feasibility of integrating Revit with BUILDER SMS. Finally, the integrated BIM model was demonstrated to a focus group to obtain feedback for the presented scenarios and suggest new applications.

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Research Objectives

The overall objectives of this thesis study are:

- Identify parameters needed for BIM and FM integration, through literature review and through facility management personnel (interviews, surveys, etc.);

- Identify best practice for facility data collection during site visits;

- Identify best practice for data entry to BUILDER SMS and Revit BIM to ensure data availability and compatibility;

- Identify best practice for exchanging facility data between BUILDER SMS and BIM Revit files; and

- Evaluate the FM-enabled BIM.

Literature Review

Building Information Modeling

Building information modeling (BIM) is a tool used in the architecture, construction, and engineering (AEC) industries for a seamless transition of building data from the design phase, through construction, and to the maintenance phase of a building's lifecycle [3]. BIM has been defined by the National BIM Standard – United States [4] as a, "*representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward*." Eastman, Teicholz, Sacks and Liston define BIM as an, "*approach to design, construction and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format,*" [5]. BIM does not refer to a specific software, but a process that uses a variety of software and techniques [6]. Traditionally, project documents are handed down from staff members of different disciplines such as structural, architectural, and MEP (mechanical, electrical and plumbing). Because of differences in expertise, there can be conflicts if the building documents are misinterpreted as the life cycle progresses. Building information modeling provides data-enriched 3D models that provide information for all project life cycle phases [7]. Building information modelling can be applied to all phases of a building's life cycle, which are defined as design, construction, operation & maintenance, and retrofit & renovation, shown in Figure 1 [8].

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Figure 1. Building life cycle flowchart.

There are several computer programs that are used to develop BIM models. The major vendors for BIM modeling software include Autodesk Revit and Navisworks, Bentley Architecture, Graphisoft ArchiCAD, Tekla and Nemetschek Allplan [9]. Autodesk Revit, the BIM modeling tool used in this study, is a widely available BIM development tool that has been used in past research involving building information modeling [10]–[13]. Revit BIM models contain elements that are assigned to different categories, families and types [14], as shown in the hierarchy in Figure 2. Categories classify all Revit elements with a predefined, unchangeable list fixed within the software. Families are a part of each category and have two types: system families, whose characteristics cannot be changed by the user; and component families whose characteristics can be created and edited by the user. Types are variations of a Family based on sizes and recognized characteristics. The lowest step on the hierarchy is an instance, which refers to a particular element in a model (Figure 3).

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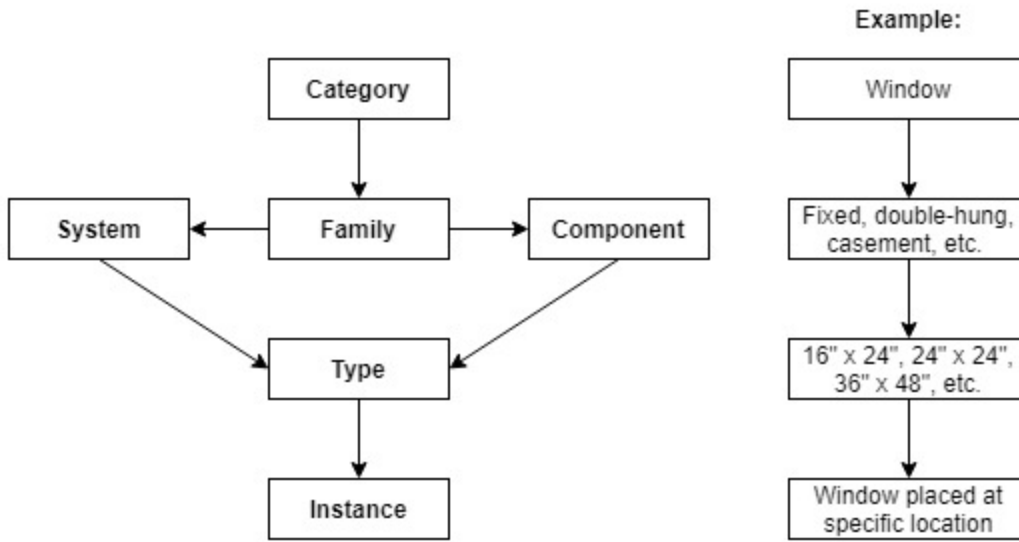
Figure 2. Revit data hierarchy adapted by author from [14].
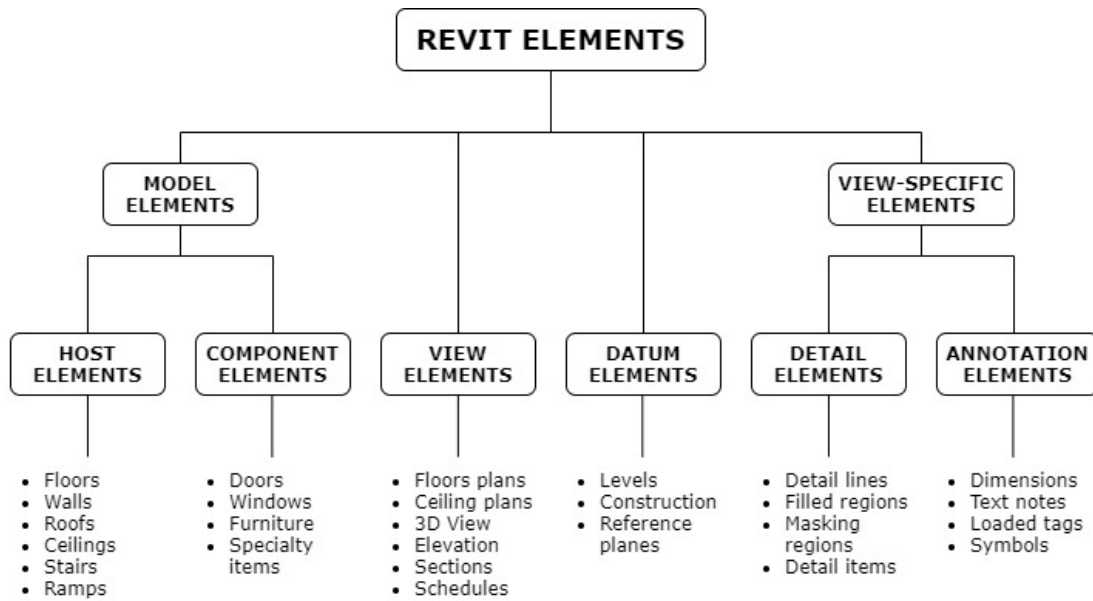
Figure 3. Hierarchy of Revit elements from Autodesk [15].

Facility Management

Facility management (FM) has been defined by Alexander [16] as, "*the process by which an organization delivers and sustains support services in a quality environment to meet strategic needs*." An earlier definition of FM by Nutt [17] is, "*a supporting tool to obtain sustainable and operational strategy for an organization over time through management of infrastructure resources and services*." Facility management plays an integral role for a building in that it constitutes over 80% of the project cost, but its importance is often be overlooked [18]. FM provides an integrated approach to maintaining and improving a building to support efficient and effective maintenance and day-to-day operations [19]. Computer maintenance management systems (CMMS) are used to assist facility managers with keeping updated information of their building [20]. The facility management software used in this study is BUILDER Sustainment Management System (BUILDER SMS). It is a web-based software application that promotes sustainable facilities management and encourages proactive resource allocation [21]. The work presented here was supported by a sponsor that manages numerous facilities but wishes to remain anonymous. BUILDER SMS data are recorded and displayed using the UNIFORMAT II Classification for Building Elements [22]. While the software has potential to be beneficial for successful asset management, there was no relevant literature found where BUILDER SMS was analyzed as a tool for facilities management.

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BIM for Existing Buildings

Building information modelling was originally developed as a tool to improve the design and construction phases [9], for which its worth is well demonstrated [10]. While the use of BIM during the design phase has many advantages, implementing BIM for existing buildings can also be beneficial [23]. A review by Volk et al. of research on BIM in existing buildings found that BIM implementation has been limited [9]. One crucial finding in the review is that there is limited use of BIM in existing buildings and when it is applied, it is usually to <u>recently</u> completed buildings. This leaves a research gap for older buildings with outdated construction documentation, which can prove to be more of a challenge for planning BIM implementation. A more recent study focused on the automated creation of BIM for existing buildings and concluded that the adoption of BIM for the operation phase is still significantly less frequent than in the design and construction phases [24]. Barriers to the adoption of BIM for FM include identifying the amount/types of information required, developing and maintaining the BIM, and the information exchange between the BIM model and facility management system. Another study confirmed these obstacles and added that uncertainty in building data can make the information exchange even more of a challenge [25]. This uncertainty can be caused by lack of available information or differences between the available building documents and what is observed at the physical site. Overcoming these challenges is essential to successful implantation of BIM for existing buildings.

Despite relative underuse, building information modeling for existing buildings can be beneficial to facility owners. One benefit appealing to facility owners is BIM's effect on sustainability. Chong et al. looked at all phases of the building's lifecycle and

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cite the importance of BIM in eliminating inefficient systems, reducing the cost of maintenance, and decreasing energy consumption through proper renovation [26].

Antwi-Afari et al. look at the critical success factors for implementing building information modeling [27]. Out of the 34 listed factors, the relevant factors that involve existing buildings include improved operations and maintenance, accuracy and reliability of data and ensuring effective communication. Through analyzing the critical success factors, some of the benefits of BIM for existing buildings are identified as quality control, assessment of energy and space management, and retrofit planning. Therefore, while BIM for design and construction is more widely implemented, there are clear benefits of BIM for FM that can be optimized with additional research focused on existing buildings.

There are several research gaps that need to be addressed for BIM to be more widely implemented in existing buildings. Volk et al. conclude their literature review with several issues and future needs for BIM with existing buildings [9]. One recommended focus for research is the initial data capture coupled with the information maintenance in BIM. For BIM of existing buildings to be effective, data must be accurate and up to date. Another major obstacle with BIM and FM is informational issues where interoperability is difficult. Volk et al. state that universal data structures are continuously created to increase interoperability, but the developments continue to focus on new buildings, not existing ones [9]. They also suggest that research is moving toward reducing the effort required to create BIM models, citing that laser scanning is a common form of automation, but can be expanded on with material-based recognition or learning algorithms.

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Pishdad-Bozorgi et al. present a case study of integrating BIM with FM and proposes a research framework for future work in this field [20]. The main objectives for future studies should include: 1) Defining BIM data needed for FM tasks; 2) Developing a FM-enabled BIM workflow process; 3) Proposing a new BIM-enabled FM procedure; 4) Determining the business value of implementing FM-enabled BIM. The study calls for more exploratory studies following its research framework to add to the knowledge of utilizing BIM for existing buildings. This thesis study constitutes such an exploratory study.

Integration of FM and BIM

While BIM is a valuable asset for all phases of a building's lifecycle, it can be especially helpful for the operations and maintenance (O&M) phase of a facility. The overall life cycle cost of a building is largely influenced by the O&M phase [28]. Furthermore, lack of interoperability among different software applications can be costly, with two-thirds of interoperability costs being associated with the O&M phase [29]. Building information modeling is normally implemented with this issue in mind to ensure a more logical transition from design and construction to the building's owner for facility management. Ideally, a BIM model should hold essential information for different stakeholders, enable a seamless transfer through different phases, and provide a reliable database for facility managers to retrieve and analyze information [20]. However, there are cases where, if BIM was not used from the design phase, there are issues creating a BIM model during the operations phase.

From previous studies and industry implementation, it can be concluded that there are many benefits to integrating BIM with facility management. A BIM model with

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adequate information for FM can be useful for: commissioning and closeout; quality control and assurance; energy management, maintenance and repair; and space management [23]. The versatility of BIM has led to an increasing interest in using BIM models for FM, even though they have mostly been used for design and construction. BIM models also improve the sustainability of a facility if utilized through the operation phase. In a review of BIM for sustainability, Chong, Lee, and Wang found that BIM can help to eliminate inefficiencies in existing buildings with real time FM-enabled BIM systems to conserve energy [26]. Also, since BIM is known to expedite the retrofitting process, facility owners that want to push for greater energy efficiency can use BIM for sustainable design principles when retrofitting a building [30]. Another strength of facility management integrated with BIM is the visualization capabilities of a BIM model that includes facility data. In a study focused on the application areas of BIM-enabled facilities management, 86% of BIM users who responded to the survey submitted "Visualization and marketing" as a potential application area [23]. Visualization gives FM personnel the ability to perform conceptual analyses and makes it easy to prepare presentations of the building. It also can save time for corrective maintenance because the faulty components can be located easily [31]. Finally, the other application areas for FM-enabled BIM determined by the survey from Bercerik-Gerber et al. include locating building components, facilitating real-time data access, checking maintainability, updating digital assets, space management and controlling energy usage [23]. These benefits all show a demand for successful implementation of BIM for facility management and how this can be beneficial for facility owners.

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While a majority of past research for building information modelling was focused on the design phase, more recent research includes facility management (FM), i.e., maintenance and refurbishment during the operation phase [32]. As research shifts towards implementing BIM in the operations phase, several studies have looked at ways that FM-enabled BIM can be used for specific scenarios. A study done by Lu et al. compared the processes of traditional O&M with a BIM-assisted process for three scenarios: daily O&M, emergency O&M, and statutory inspection [28]. One major limitation of the traditional process, as opposed to the BIM-assisted process, was found to be scattered information. In the traditional process, some tasks were repeated by the staff, which is a significant inefficiency and made some of the information acquisitions more time-consuming than those of the BIM-assisted process. Another issue with the traditional process was the difficulty in searching and verifying the correct facility information among scattered files. This was due to facility data being located in spreadsheets and hardcopy formats, while floor plans were stored as their original hardcopies or partial CAD drawings.

Another case study for implementing BIM for FM looked at developing FM-enabled BIM during the design and construction phase [20]. Since the BIM model for the case study, developed using Autodesk Revit, was created during the design stage of the building, the transition between life cycle phases could be analyzed to see if the information could successfully transfer to the facility management staff. While this pilot study was successful in implementing FM-enabled BIM from the design phase, there were some challenges and limitations. The O&M documentation was not fully integrated as it had to be manually entered directly into the facility management software database.

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It was then suggested that to integrate BIM and these documents in the future, the documents could be linked to BIM objects with a URL code. This case study also had issues with its data validation due to incompatibility between the handover documentation from the construction phase and the facility management software.

Other studies also suggest that there can be complications with integrating BIM with FM. Some of the main issues with integrating BIM and FM are summarized in Table 1:

Table 1

Concerns with integrating BIM and FM systems from past research

Concern	Sources
Data incompatibility between BIM and FM software	[9], [13], [19], [23], [25], [27], [33]–[35]
Lack of appropriate FM information / maintaining quality of information	[11], [20], [25], [29], [33]–[36]
Sufficient BIM/FM knowledge of stakeholders	[9], [31], [33], [37]–[39]
Cyber security / data ownership	[9], [23], [32]

These drawbacks were observed from several sources, and each of them were either worked around in their pilot studies or discussed as concerns for the future. This study will look at a particular case of integrating BIM with FM for existing facilities and take into consideration data compatibility, quality of information, sufficient BIM/FM knowledge, and data ownership to fit into the ongoing research for successful BIM and FM implementation.

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Chapter 3

Research Approach

This chapter describes the research approach for this thesis. First, the context of the project and corresponding case study is described, as well as the current workflow for building information modeling and facility management. Then, a summary of the research approach is given.

Application of BIM and BUILDER SMS

This research focuses on developing a BIM model for an existing building and integrating it with a facility management database. For authoring of the BIM model, a scan-to-BIM workflow is utilized, where the envelope of the building is traced from a 3D point cloud. Currently, the sponsor's facilities are modeled by scanning the interior and exterior of the building and using Autodesk ReCap to assemble a point cloud file for the building [40]. Then, point cloud files are loaded into Autodesk Revit 2018 to develop the envelope of the building based on the visible surfaces of the point cloud [1]. BIM models of the facilities include the envelope of the superstructure, the interior layout, and exposed mechanical, electrical and plumbing (MEP) systems. One important limitation of using this workflow is the amount of information available for creating this model is limited to what can be seen in the point cloud. Since the point cloud file only contains surfaces that can be seen with the human eye, some of the systems and material compositions must be assumed or are not included. While this is a limiting factor when compared to BIM generated from the design phase, the resulting BIM model is a significant upgrade to the current documentation consisting of hand-drawn plans on paper, 2D CAD plans printed on paper, and electronic 2D CAD files, which often date to the building's design phase and may not reflect building modifications after construction.

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In addition to BIM models, asset management databases are created for the sponsor's facilities. On-site inspections are used to complete a BUILDER SMS database. BUILDER SMS is a web-based application that stores and tracks building components and updates with each new inspection. The initial inspections, which usually occur in conjunction with BIM scans, are performed according to the Army BUILDER SMS Inventory and Assessment Guide [41]. Data are entered into a Builder Remote Entry Database (BRED, or BuilderRED). Once the offline BRED database is complete, it is imported into the online BUILDER SMS database. The data are then viewable and updateable with consistent access to the information for all building components. In addition to common facility management information such as year of installation, equipment manufacturer, serial number and last inspection date, BUILDER SMS offers calculations to assist with life-cycle analyses. BUILDER SMS can promote proactive facility management practices by calculating the remaining service life and the replacement cost of components in the building. BUILDER SMS also tracks a Condition Index (CI) for building components, which is a scalar quantity ranging from 0 to 100 that rates the component and gives an indication of its priority for being rehabilitated or replaced. While BUILDER SMS is effective asset management tool, it has potential to be more useful for facilities if integrated with Revit via data sharing, creating an FM-enabled BIM model [10], [23], [31].

The purpose of this study is to develop, demonstrate, and assess the potential and feasibility of integrating the facility information stored in BUILDER SMS with the building information model in Revit. BIM and facility information integration is best initiated during the design phase of a project. However, this was not done for the vast

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majority of buildings existing as of 2020. In the scenario explored here, an existing

building is evaluated using facility information and scans obtained from site visits.

BUILDER SMS information and 3D scans for BIM are accumulated separately with no

connection. While they each serve their own individual purposes, their effectiveness can

be improved if their datasets are integrated.

Current workflow. The workflow currently used to develop BIM models and

complete the BUILDER SMS database is summarized in Figure 4.
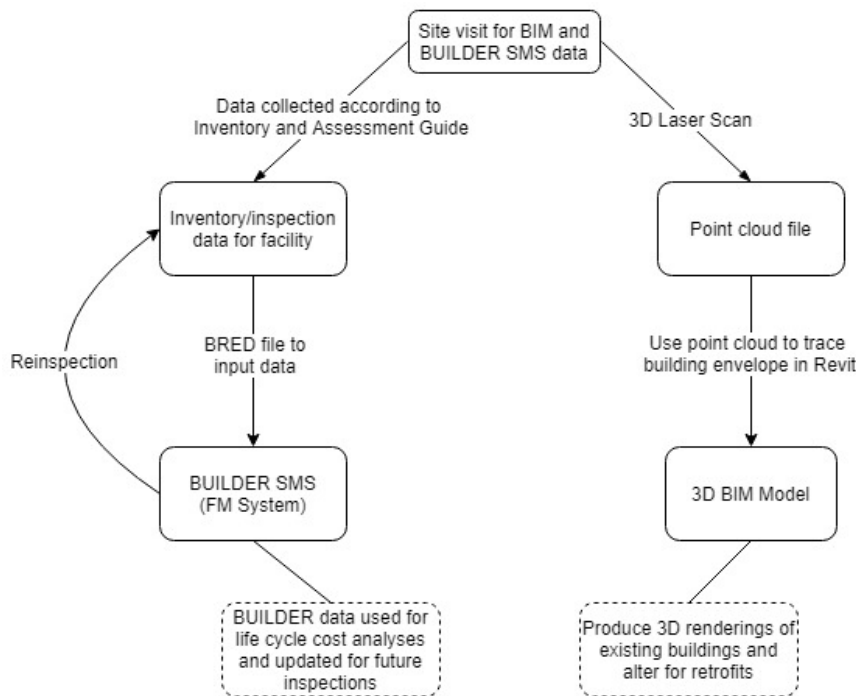
Figure 4. Existing workflow of BIM and BUILDER SMS data collection.

This workflow has two teams assembling separate sets of data from the same

facility simultaneously. The BUILDER team inventories all building components and

makes condition assessments, which are entered into BUILDER via a BRED file. The

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BIM team obtains a 3D laser scan that are used to produce a point cloud of the facility and, ultimately, a BIM model. After site visits and data analysis, this workflow results in a database of the facility stored in BUILDER SMS and a BIM model in Revit. Both of these serve their own purposes, but the data are not linked between the two sources in this workflow.

Research Approach

The effectiveness of BUILDER SMS and BIM data integration for existing buildings can be evaluated for its practicality and to identify potential improvements. The results of testing this method are composed of qualitative and quantitative data that can determine the strengths and weaknesses of the workflow. The two main approaches to validating the method are a controlled test of the integration for an existing facility as well as a focus group with sponsor staff.

Transfer methods between Revit and Builder SMS. There are several methods available to integrate Revit and BUILDER SMS via data sharing. The first method considered is manual data entry. For the initial transfer of BUILDER SMS data into the BIM model, the data values for all BUILDER SMS parameters are entered for all components of the building. This method involves having both the BUILDER SMS database and Revit file open to transfer each data point individually. While this method is easy to understand, it is also the most tedious and labor-intensive method.

A second way to transfer the data involves exporting data from each source in a compatible software environment. The BRED export from BUILDER SMS is a Microsoft Access Database [42]. To export Revit data to the same format, the DB Link feature can be used to store Revit data in the Access format. DB Link was used in a

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previous study to connect a BIM model with a Computerized Maintenance Management Systems (CMMS), which involved data transfer with Access [39]. Relationships in Access allow for data from multiple sources to be connected, which require the use of an intermediate database to connect the BRED and DB Link exports.

Another option for transferring BIM and BUILDER SMS data is through an Open Database Connectivity (OBDC) connection with the data. The ODBC connection can be used when data are stored in several different programs and a common environment to manipulate and store data effectively is needed, similar to previous studies where BIM data were integrated with FM systems [43], [44]. The data from both the BIM model and BUILDER SMS can have their relationships established in SQL Server, which was accomplished in a previous study connecting BIM and O&M information [45].

There are also third-party applications that can be used to transfer the data. Dynamo Studio is an open—source visual programming extension for Revit [46]. Dynamo was used in a previous study to extract BIM information for the automatic scheduling of work orders using a facility management system [36]. BIMLink is another option to transfer Revit BIM data to and from an Excel file [47]. This was used for a study integrating BIM with a CMMS program by exporting BIM data into a prepared Excel file to be transferred into the facility management system [20]. These applications can be applied to this case study, but their functionality must be evaluated to ensure the data transfer is accurate and efficient.

Simulate data transfer for hypothetical building. To test the feasibility of transferring Revit BIM and BUILDER SMS data, a simulation was performed for a hypothetical building. This building only included the exterior and interior envelope and

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intended to simulate the BIM developed for existing buildings. The transfer of individual data values was tested to see if changes in Revit were reflected in BUILDER SMS and vice versa. Two transfer methods were tested on this small scale model, which were then selected to be further evaluated for the case study of a real facility:

- Method 1: Manual data entry

- Method 2: Intermediate Access database with DB Link and BRED export to extract data

Test data transfer for Building A. The next part of the evaluation of Revit and BUILDER SMS integration involved a case study of data input and transfer as the BIM operator would perform for a real-world project. To perform the test, Building A was used because it represents a typical building structure for the sponsor's facilities and had completed BUILDER SMS and Revit files. Similar buildings are found across the United States. The building's identity is not revealed here, as per the sponsor's order.
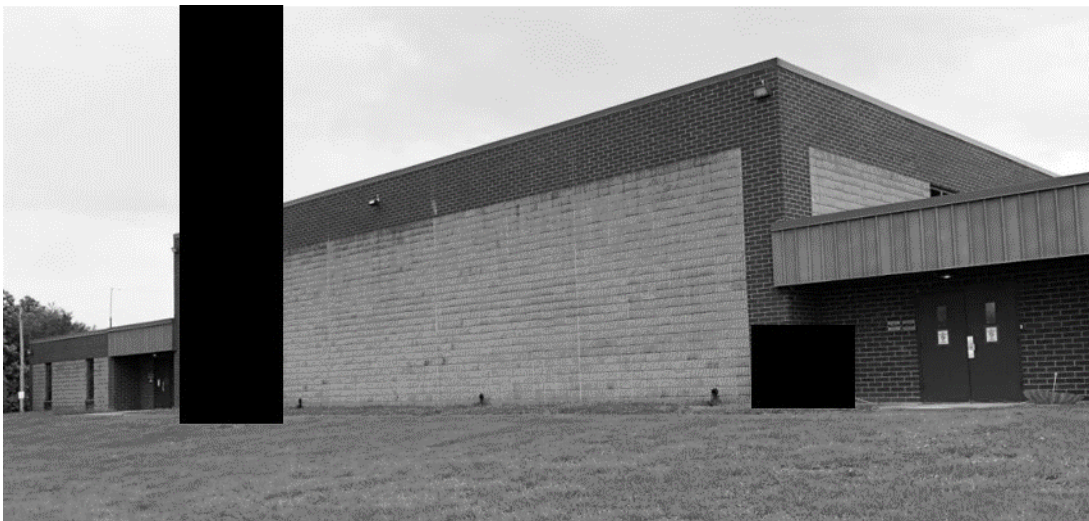
Figure 5. Building A photograph (Portions of Figure obscured as per sponsor order).

The building is a 10,000 to 20,000 square foot facility constructed in the 1980's with between 20 and 30 rooms (Figure 5). The BIM model (Figure 6) was completed in 2016 using the scan-to-BIM workflow described previously. The BUILDER SMS database was completed for this building in 2018 following the BUILDER SMS Inventory and Assessment Guide [41].
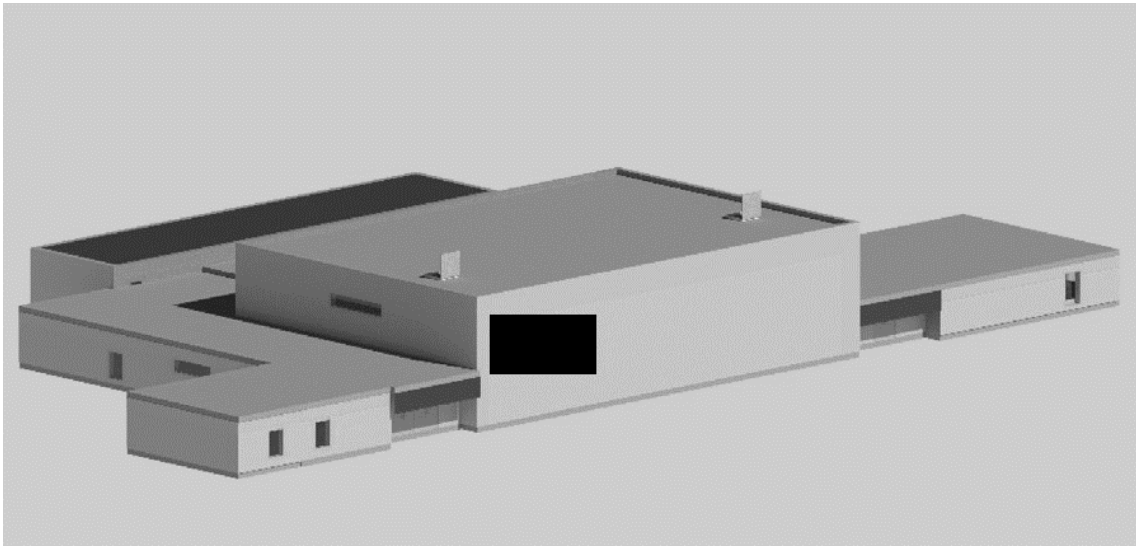
Figure 6. 3D Rendering of the Building A shown in Revit BIM model. Portion of Figure obscured as per sponsor order.

For the integration, the early steps to prepare the model were completed and observations and data incompatibilities recorded. The integration involved sharing data between the Building A BIM model and the existing BUILDER SMS database. For these tests, observations were recorded as well as the time each process took to complete. Throughout the process, any conflicts or errors encountered were to improve the methods and to find their advantages and disadvantages. This serves as both quantitative and qualitative results for testing the feasibility of integrating BIM and BUILDER SMS data.

Identify and evaluate uses for FM-enabled BIM. The following scenarios were identified from literature review and experience using Revit and BUILDER SMS.

- With each component of the BIM model having an assigned Condition Index (CI) from BUILDER, views can be filtered by the CI to display problem in a 3D view. This can be done with other numerical values, such as RSL (remaining service life), RDL (remaining design life), or year installed.

- Future BUILDER SMS inspections of the facility can be done with a BIM model viewed on a tablet. This can give a realistic layout of the facility as well as facility information attached to each component, which is accessible by selecting the component.

- FacilityDude, a work order system, can be used to track maintenance requests for certain areas or components in a facility. The BIM model could reflect this by showing either a filtered view of the facility or a tabular view of components to show which parts of the facility are producing the most work order requests.

- A work order is submitted and delegated to an outside contractor. With a BIM model, they can be given a 3D visualization of the component and its location, as well as BUILDER SMS information such as inspection history, model information, etc.

- With data exchange being possible between BUILDER SMS and the BIM model, data can be altered from two access points and the changes can be reflected in both sources. If retrofitting of a building occurs, the physical model and the SMS data can both be updated in the BIM model, which can be used to update BUILDER SMS.

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To gain insight into the use of Revit and BUILDER SMS integration for the sponsor's facilities, a focus group of relevant sponsor facilities staff was established. The goal of creating this focus group was to find the best way to display facility information in BIM and to assess the value of integrating the two data sources. For the focus group, the idea was to demonstrate some practical scenarios where having a more data-rich BIM model can be beneficial. Through a live demonstration of some of these concepts in both Autodesk Revit and Viewer [48], the officials could see the potential of using BIM with their asset management data. Figure 7 shows a first-person view with visual filter applied based on the Condition Index (CI) of the component. The focus group included open discussion about the possibilities and what they find most valuable from what they have seen. Their suggestions and comments were recorded to find any trends or present any original thoughts that they may have from their perspectives.

Figure 7. 3D Perspective view of Building A Boiler Room with Condition Index (CI) visual filter.

The focus group discussion was recorded and a questionnaire was given to the participants, resulting in qualitative data. The questionnaire for each focus group member asked for their title, duties/responsibilities and their own familiarity with BIM and BUILDER SMS. After viewing the demonstration of some BIM-BUILDER SMS capabilities, short-answer questions gauged their interest in using BIM for their asset management. The value of some of the potential scenarios described was assessed using five-point Likert scale prompts, similar to previous assessments [13], [33], [49]. The results of both the questionnaire and key discussion points from the focus group transcript were analyzed to assess the value of displaying BUILDER SMS information in BIM and determine the best ways to do so.

Chapter 4

Results and Discussion

The purpose of this chapter is to present results from:

- Developing a Revit and BUILDER SMS data transfer workflow;

- Evaluating the data transfer workflow at a sponsor's facility;

- Demonstrating FM-enabled BIM using Revit and BUILDER SMS to a focus

  group of relevant sponsor staff.

Regarding the focus group, the chapter is used to describe the demonstration of the

Revit and BUILDER SMS integration, the results of questionnaires and key discussion

points from the focus group members.

BIM and FM Data Transfer Workflow

After gaining familiarity with Revit and BUILDER SMS, as well as data transfer

methods, a workflow for transferring datasets was established. Note: For the remainder of

this chapter, Revit instances and BUILDER SMS components will be terms used

interchangeably as they both refer to specific objects in the facility, each with its own

unique characteristics, except for the second case in Table 2.

Step 1: Make alterations to BIM model to increase compatibility with FM

database. Comparing the data structures of the Revit BIM model and the BUILDER

SMS database reveals potential conflicts that could interfere with data transfer. The

issues and their workarounds are shown in Table 2. Alterations are made to the Revit

BIM model so it is compatible and ready to be populated with BUILDER SMS values.

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Table 2

Potential conflicts between Revit BIM and BUILDER SMS datasets

Issue	BIM (Revit)	BUILDER SMS	Workaround
Building directional referencing	Adjusted in project settings by setting Project North and True North directions	During data entry, certain components are associated with relative position in the facility ("East Wall Windows")	Cardinal directions must be accurate to the actual facility in both models to ensure compatibility and user comprehension
Objects with quantities	Each individual object is modelled as an instance, each with its own unique properties and identities	Windows, doors, fixtures, etc. are modelled as groups with a quantity. Their data applies to all of the components in that group	Each instance in Revit can have the same parameter values as the group in BUILDER SMS, so each individual object in Revit will have the same properties as others in the grouping
Surface finishes	Most models were previously made with walls/roofs/floors modelled as a single instance with multiple layers	Floor construction and floor covering are two separate entities, each with their own identifying data	Add very thin wall/roof/floor coverings to each surface
Window groupings	Window models loaded in as single instance with multiple panels	Window sections with multiple panels in BUILDER are counted as quantities with the number of panels	Window instance in Revit is given the data for the component in BUILDER, with the number of panels given by the window type
Wall/partitions	Most models were previously made with walls modelled as a single instance with multiple layers	Walls have data records for the exterior wall, interior partition, and surface finish	Future BIM models would need separate exterior and interior layers to allow for walls to be referenced

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Step 2: Add FM parameters to BIM Model. To populate a Revit model with

BUILDER SMS data, the first step is to add custom groups of BUILDER SMS

parameters. New parameters are added to the Revit file so they can be populated with

BUILDER SMS information. For the case study used here, two parameter groups were

added. The "Component_Section" group was applied to all model instances in Revit so

each building component contains data from the corresponding table in the BRED

database (Figure 8). The "Component_Section" table in the BRED database contains the

majority of relevant information, including each component's unique identifier, or

"SEC_ID," which is an alphanumerical value generated by BUILDER SMS. There was

also a "SectionDetails" parameter group created in Revit for MEP equipment, which

corresponded with the "SectionDetails" table in the BRED file. A complete list of

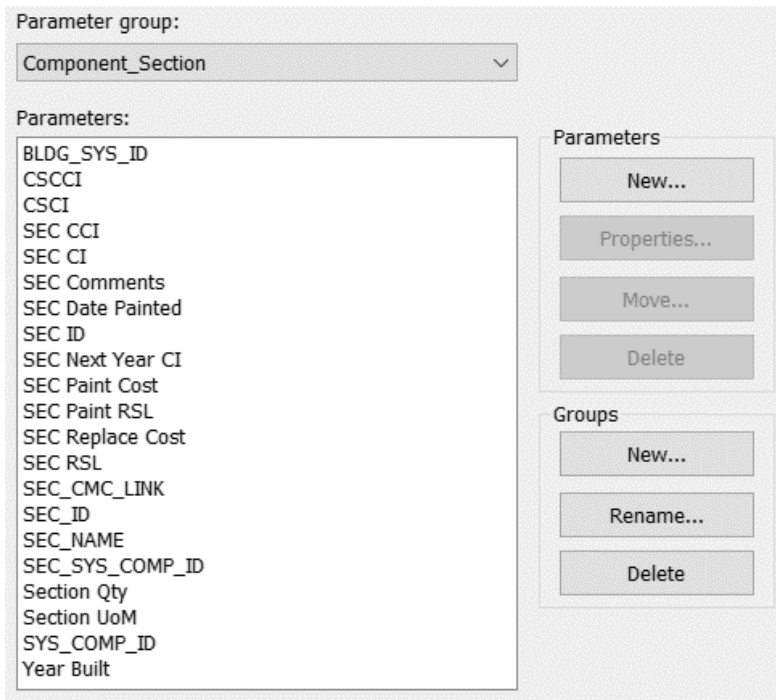"Component_Section" and "SectionDetails" parameters are given in Appendix A.

Figure 8. "Component_Section" parameter group in the BIM model.

Step 3: Retrieve data from FM database. The BUILDER SMS database is exported to a BRED file compatible with Microsoft Access Database. Figure 9 shows an example of a BRED file in the MS Access environment. While the online BUILDER SMS database contains formulas for calculated quantities, such as replacement cost and remaining service life, the BRED file only stores values for the building data.

BRED_Status	SEC_ID	SEC_SYS_COMP_ID	SEC_CMC_LINK	SEC_QTY	SEC_YEAR_BUILT	SEC_DATE_PAINTED
	{00433463-155F-47E0-9CBB-60CA6F903E89}	{1389BC87-94DF-4DB6-8F7B-8689C6A97876}	21453	48.3097679848977	1984	2017
	{00D312F6-8CA6-4214-BA27-C6CA39FDD396}	{2AE042D6-BB5F-4345-BF0F-4E18E90BE4E0}	21401	1	1984	
	{017E56E4-9154-4FF7-A810-7F3067DC5A3E}	{F78442E6-44DE-4FA5-94F0-98007CF5F74A}	21624	51.0968699840264	1984	
	{01B65EE0-BBE8-4459-AE25-EF0B8501E2AC}	{F2BC0B02-C898-4151-90BA-9EE72BCA06CC}	42116	26.7561791916356	1984	
	{02215B15-D9A0-4AF8-900E-2BF63AB81A49}	{F78442E6-44DE-4FA5-94F0-98007CF5F74A}	30198	3.71613599883828	1984	2017
	{02431E22-701C-4C65-893E-EAA4BD15462E}	{F2BC0B02-C898-4151-90BA-9EE72BCA06CC}	21447	501.678359843168	1984	
	{073898B2-33A2-4E46-A473-C6A17635AEF5}	{4E406B59-89F3-4B42-B64F-A258541D5D93}	41011	1471.96146913984	1984	
	{0979D04C-C5D7-489E-BF4E-F727214C1BB1}	{10A6F605-DEB1-40E7-9381-70BE4DE5FE32}	20409	1	1984	
	{0B1A4D02-B442-43C0-B78D-2D77BE6598BF}	{62F4C86A-96F5-436B-B6D6-F8B93BD303BB}	21422	26.7561791916356	1984	2017
	{0B4AE521-0EBA-47FA-AAB4-DF6B66791A5F}	{62F4C86A-96F5-436B-B6D6-F8B93BD303BB}	30159	11.1484079965149	1984	2017
	{0BA4485C-8CE9-48FE-91C9-E0ABE37E2211}	{5072CB83-FD96-4B06-919D-203A46BE62F8}	21374	500.656422443488	1984	
	{0BDE86F5-0C2B-420D-9B9C-DC8448C69E71}	{F2BC0B02-C898-4151-90BA-9EE72BCA06CC}	21439	7.43227199767657	1984	
	{0DE8E12D-D677-48F1-9420-61C1C0D51AC2}	{4B19EC3F-DA78-4530-9E87-AA14A520B301}	41213	4056	1984	
	{0DEA468E-8BEF-4A39-A45F-F85B627660D2}	{F51F0FDE-1523-45DF-ADF7-DE751960B6BE}	21603	1	1984	
	{0ECEAF16-C38D-49D1-83A0-BCA306968AB2}	{78693830-4389-43BB-9C16-2A39F8965ED6}	40213	1	1984	
	{0EEBBF0C-10D6-4E12-AC31-09A66BF46CE7}	{BD864B65-9DE7-41EB-A4B6-9C29F77C12A4}	21478	2	1984	
	{0F4C6476-A500-41AE-A5A6-BB5918E7463A}	{BD864B65-9DE7-41EB-A4B6-9C29F77C12A4}	21479	4	1984	
	{105BFBC1-2187-46AF-A169-E40A18C0A77C}	{62F4C86A-96F5-436B-B6D6-F8B93BD303BB}	21422	501.678359843168	1984	2018
	{107E2339-008B-421B-9195-D0E7377CD20D}	{F78442E6-44DE-4FA5-94F0-98007CF5F74A}	30198	13.9355099956436	1984	2017
	{11C6BA40-424E-4FD0-A277-BF64E9F0C26F}	{C6CA73F2-6AA9-434C-B286-F06C4504CCE6}	21396	1	1984	
	{1280D08A-0950-419C-885E-29FEB4707265}	{17AD5D0A-C9EF-4614-93A3-57C47BEAAA86}	21610	1	1984	
	{12A3886C-52E1-4A52-9745-FD97A897BCF4}	{4B19EC3F-DA78-4530-9E87-AA14A520B301}	44162	2	1984	
	{12BA8296-3B9A-491A-AB07-AB105145835A}	{F51F0FDE-1523-45DF-ADF7-DE751960B6BE}	21602	1	1984	
	{13BA9E0C-AB1B-424B-9D58-610CC2EDAE66}	{1389BC87-94DF-4DB6-8F7B-8689C6A97876}	21456	2.6012951991868	1984	
	{14FDC85C-5BF9-4DA9-A3D4-7F8CB3761A5C}	{5072CB83-FD96-4B06-919D-203A46BE62F8}	21374	557.420399825743	1984	
	{151A4AC0-5D31-417D-B0A2-002F5E1E7043}	{1389BC87-94DF-4DB6-8F7B-8689C6A97876}	21456	26.012951991868	1984	
	{15533630-B725-4B6F-9E20-0AE91B252B5B}	{78693830-4389-43BB-9C16-2A39F8965ED6}	21629	1	2004	
	{15AE2048-D14A-4467-963F-A44724F6E0C5}	{F51F0FDE-1523-45DF-ADF7-DE751960B6BE}	44045	2	2016	
	{179782EE-66EB-4E4E-A5BE-07C2A2EE962C}	{F78442E6-44DE-4FA5-94F0-98007CF5F74A}	30198	13.006475995934	1984	2017
	{18CA5019-23E5-4DFE-A39C-F261629ED2EF}	{62F4C86A-96F5-436B-B6D6-F8B93BD303BB}	21422	13.006475995934	1984	2017

Figure 9. "Component_Section" table in BRED database.

The database can be populated and altered with BuilderRED, a software used for offline entry of inspection data that alters the database file with an easy-to-use interface. The updated database can then be imported back into BUILDER SMS and used to update calculated values. With the BUILDER SMS dataset linked to an Access database, the FM data can be more easily shared with the BIM model.

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Step 4: Transfer data between BIM and FM. Several techniques can be used for the actual transfer of data between Revit and BUILDER SMS. For this study, two methods were developed and evaluated for their effectiveness.

Method 1 involves the manual input of all BUILDER SMS data in the BIM model. This involves entering BUILDER SMS data for each component in the BUILDER SMS database into the corresponding Revit instance. This is labor intensive, but serves as a worst-case scenario for integrating Revit and BUILDER SMS data.

Method 2 involves entering only the unique identifier (SEC_ID) of each BUILDER SMS component into each corresponding Revit instance and transferring the rest of the facility data using the intermediate database. Once the components and instances are linked in the intermediate database, the data interpretation within the integrated tables becomes much simpler. In the intermediate database, selection queries are used to connect data from the exported database tables from both Revit and BUILDER SMS. The data can then be easily updated in the form of a single table for each Revit category (i.e. "Walls", "Doors", "Floors", etc.) of the building.

The data transfer was evaluated using a simple hypothetical model in Revit to ensure that data could be exported and imported back into Revit. The simple model only included features for the building envelope. The initial transfer method involved a basic import/export of the Revit data in an Excel format. Data values were altered in the spreadsheet file and imported back into Revit to confirm that the data could be edited outside of the BIM authoring software.

For testing DB Link and its capabilities to transfer data between the BIM model and BUILDER SMS, parameter values were altered to determine if the changes would be

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reflected in both sources. The DB Link addon in Revit was fairly seamless in its data transfer and each import of new data provided a log containing any errors encountered. BUILDER SMS was less consistent; changes to the BRED file were not always observed in the online BUILDER SMS database, hereafter referred to as the "online database". For the transfer, the raw data was changed in Microsoft Access and confirmed in the BuilderRED interface before being imported to the online database. However, after changing the data value in the BRED database file, which specifically involved changing the "Year Installed" parameter, the change was not reflected when uploaded to the online database. In another attempt, the "Painted?" and "Paint Year" parameters were changed in the BRED database in Access and the change was reflected in the BuilderRED program. Then, when uploaded to the online database, all ("Year Installed", "Painted?" and "Paint Year") changes were reflected. This demonstrated that changes in the Access file would be confirmed in the BRED program, but there was a possibility for the changes to be ignored during the import into BUILDER SMS. The root of the problem was not determined but could cause further errors in the future if frequent updates to the database are made.

Another significant observation from this test was changing a value used to compute calculated values in BUILDER SMS will only trigger a change in the value in the online database. For example, changing the "Year Installed" value, which is one of the variables for calculating the Condition Index, would not alter the calculated values in the BRED export database. The change was only reflected when imported into the BUILDER SMS online database. The formulas for these calculations are stored in the

online database and calculated values will not change automatically if any data alterations are only made locally to the BRED database.

Once the ability to transfer data was proven on a simplified scale, it was then implemented for the test facility of Building A. The BRED file for this facility was exported and the BIM file was then prepared to have its data exported into the database format.

Case Study Evaluation

The data transfer workflow was evaluated by applying it to Building A. Steps 1-3 were performed first. Step 1 was completed so that all components in the BIM model were compatible with their corresponding BUILDER SMS component. In step 2, parameter groups were added to the Revit model. Step 3 involved the export of the BRED file for the facility. Step 4 was then performed to evaluate the methods of data transfer:

- Method 1: Manual input using traditional data entry

- Method 2: Data transfer using Access queries in intermediate database

Method 1 is the manual input of BUILDER SMS data directly into the BIM model. Each instance in the BIM model was identified and the available information for each custom BUILDER SMS parameter was populated. Each instance in Revit had to be selected individually and populated with the data one at a time, except for groupings where multiple instances in the Revit model were associated with the same BUILDER information. Figure 10 shows a breakdown of time expenditure to input data for each Level 2 UNIFORMAT II category [22].

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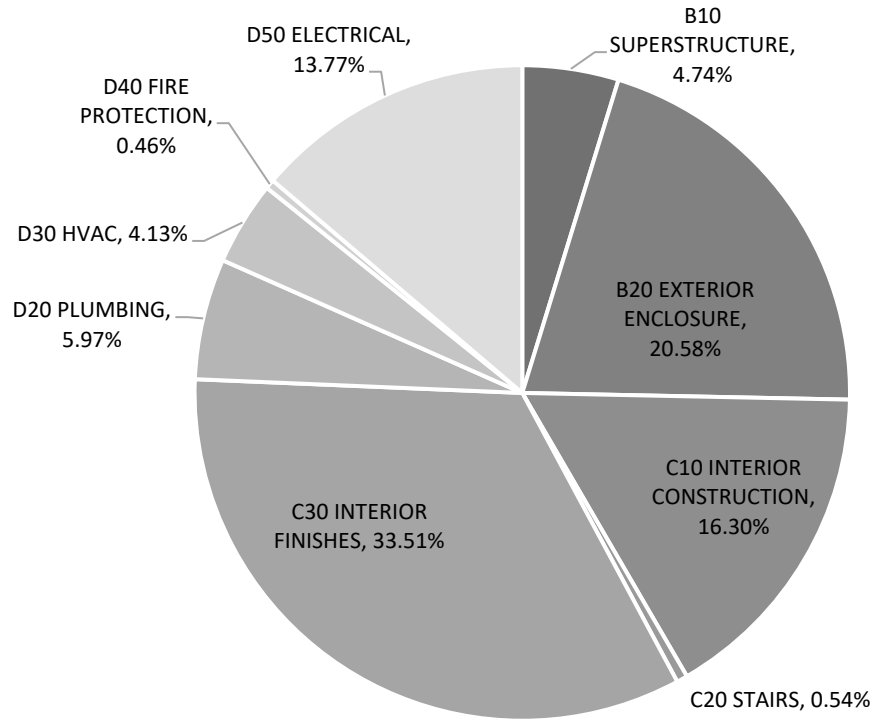
Figure 10. Data entry by asset management group, all manual entry, % time.

For Method 1, the total time to complete the transfer was 218 minutes. Based on the characteristics of the building, each building component was populated with BUILDER SMS data in an average of 1.21 minutes. As expected, this method felt very tedious and could have taken even more time if a larger and more complex facility were tested. There was a great amount of information that had to be entered into the Revit model, which slowed this process down.

A positive aspect of the method is its simplicity. Populating each component in Revit with the BUILDER SMS facility data gives the user more direct control of the exchange since every data value is transferred manually. While this can provide an accurate transfer of data between the BUILDER database and Revit, there are several drawbacks to Method 1. First, the time spent on data entry and the tedious nature of it

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makes this method less favorable. It can be a major hinderance on overall productivity if this method is used for multiple facilities as well as repeated multiple times if data are changed in BUILDER SMS or Revit. In addition, manually entering each data value has a high chance for errors to be made during the data input. Also, as mentioned previously, this method depends on an extensive knowledge of the BIM model and BUILDER database if it is to be done in a timely manner. Finding the right components in the model and trying to reference them in the BUILDER SMS database simultaneously is difficult if the user is completely unfamiliar with the building.

Method 2 involved a less labor-intensive process of data transfer where the Revit and BUILDER SMS data were exchanged in a single intermediate database environment. For Method 2, the SEC_ID identifier value is entered into the BIM model to connect the Revit and BUILDER SMS datasets together with a common data value. To create a connection between Revit and BUILDER SMS, it was necessary to understand their data structures. The BRED file that is exported from BUILDER SMS has relationships that help link the data hierarchy together (Figure 11) as well as create several selection queries to support the functionality of the database.

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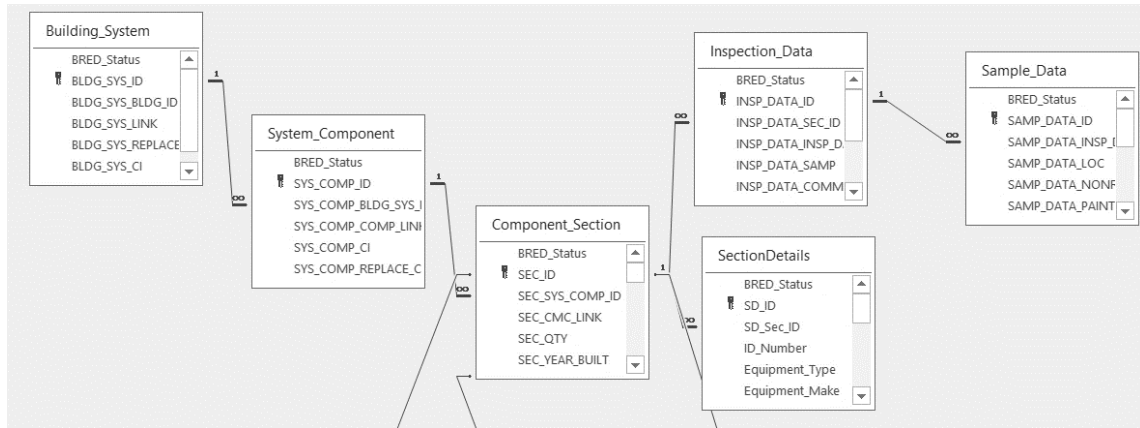
Figure 11. Table relationships inherent in the BRED database.

The relationships are created by linking similar parameters from different tables together, which can be done from the two separate databases if they both include the same parameters. In this case, with the BUILDER SMS parameters added to the Revit database, these tables can be linked, and their data can be updated. The relationships rely on a primary key to match datasets together, so the surrounding data parameters are arranged correctly. To allow for these relationships to be created, a unique identifier was implemented in the Revit data to link to the BUILDER SMS identifiers. There are identifiers in BUILDER SMS that establish a data hierarchy for the database (Site, Complex, Facility, Building-System, System-Component, and Component-Section). For linking Revit and BUILDER SMS components to each other the SEC_ID value was used since it is the lowest step in the hierarchy and provides the most specific reference to a component in the building. Once the instances are associated with one another, the other data parameters can be linked between BIM and BUILDER SMS.

This part of the test was completed in 117 minutes, which included locating the component, finding its referenced component in the BUILDER database, and inputting the identifier into Revit. This value can vary based on the user's experience and

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familiarity with both the BUILDER database and the BIM model. While this stage was fairly straightforward, it was tedious and difficult to expedite in any way. Also, the time to input the BUILDER identifiers into the model can vary based on the size of the building as well as more complex or detailed building models. The time to complete this data input did not include working out some of the discrepancies and adjustments made to the BIM model in order for it to be compatible. The test had to be paused on several occasions to make sure all components were accounted for. The test was done with the QC-5 Section Details export (Appendix B) from BUILDER SMS displayed simultaneously with the BIM model. However, the process of manually inputting the SEC_ID value in the BIM model could have been shortened with better knowledge of both datasets and consistent data representation from both sources. So, the test completion time might be effectively longer if a model is not already completely prepared for the transfer of BUILDER SMS data.

The next part of Method 2 was to set up the intermediate Access database to organize the data from both sources and prepare it for effective data transfer. The Select queries were set up so that all of the BUILDER SMS parameters in the BRED export and corresponding parameters from the Revit DB Link export were visible in the same view. This method takes advantage of having the tables linked by the SEC_ID of each component, which joins the two tables together. As seen in Figure 12, the Revit table for a particular category is joined to the "Component_Section" table from the BRED export.
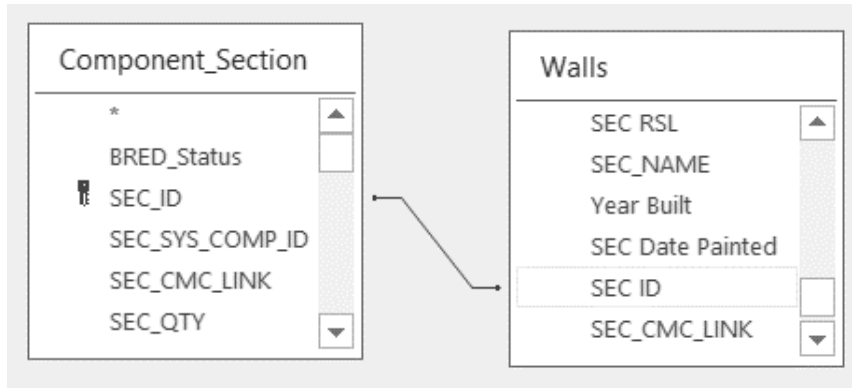
Figure 12. Query design showing the joined tables in Access intermediate database.

By joining these tables by their matching parameter, the resulting Select query will display any data points that share the same SEC_ID, which in Figure 12 would be all of the Walls with their BUILDER identifiers. Once one of these Select queries was created, their SQL statements were copied to create a Select Query for each Revit category, where the Table name for the Revit category was replaced each time. The process of creating the Select queries was found to take 20 minutes for this facility. In addition to linking to the "Component_Section" data, some of the Revit categories included Section Details that were also linked using a similar procedure. It took an additional 11 minutes to link those tables with appropriate Revit tables. With the Select queries now created, the BUILDER SMS data now appeared side-by-side with the corresponding Revit parameters. Now, the data can be transferred easily while it appears in the spreadsheet-like format. For this test, the time to transfer the BUILDER data into the Revit parameters in addition to importing the data back into Revit was 12 minutes. Since the intermediate database is linked to the Revit DBLink export, the data can immediately be imported back into Revit once the transfer in Access was completed. The

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log for this addon also showed no errors (Appendix C) in the data transfer as all fields from BUILDER SMS were now populated with facility data in Revit.

For Method 2, there are several advantages when compared to the initial manual test. An apparent difference is the amount of time spent actually inputting and transferring data from one format to another. The time for completion of this method was 161 minutes, with the breakdown shown in Figure 13.
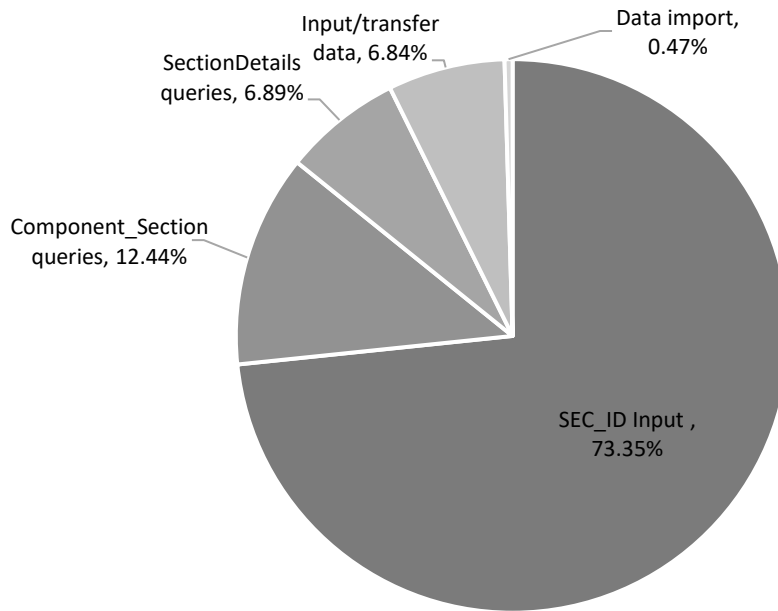
Figure 13. Percentage distribution of time to complete each stage for Method 2 evaluation.

Based on this breakdown, Method 2 would prove to more efficient for regularly updating datasets. For a comparison to Method 1, Method 2 was completed at a rate of 0.89 minutes per component. The majority of the time to complete this method is spent inputting the BUILDER identifiers, but only needs to be done when setting up the relationship. For future updates, the process only consists of the "Input/transfer data" and

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"Import data" phases, or 7% of the time expenditure (about 12 minutes, or 0.07 minutes per component). Another advantage is that once this process is set up, it is fairly easy for different users to complete the data transfer since the knowledge of the building is mostly required for the initial setup. Interpreting the data in a spreadsheet view is fairly comprehensive and easy to repeat as additional data updates are needed. A drawback with this method is the time and effort it takes to setup the intermediate database and how it may need troubleshooting if there are errors in the structure of the database. Since there is less direct control of each data value than a strictly manual data transfer method, this leaves the possibility for an ineffective setup of the intermediate database, creating the need for manual fixes to any incorrect data. It is important to compare the facility data in both the BIM model and BUILDER SMS database to ensure the data values for the same components correlate with each other.

Data transfer method comparison. The two methods for transferring data between BIM models and a BUILDER SMS database can be compared for their strengths and weaknesses based on test results and practicality for implementation. A summary of the comparison is shown in Table 3.

Table 3

Summary of comparison for data transfer methods

Strengths	Weaknesses
Method 1 (manual)	
• Most intuitive method since it resembles simple data entry • Little initial setup required; data transfer is the majority of time spent	• Longer completion time for single data transfer • Slowest method for frequent updates of databases • Prone to human error due to large amounts of individual data points being inputted manually
Method 2 (intermediate database)	
• Easier to interpret data in spreadsheet-like view • Transfer/import process is faster than previous method • Ideal for frequent updates	• Setup process is slowed down by manually inputting BUILDER SMS identifiers setting up Access queries for multiple facilities • Requires both Revit and BRED database exports to be accurate and updated frequently

Improvements to be made. Based on the observations made while transferring data, the quality control and the efficiency of future data transfers can be improved.

1. *Interaction between BIM model author and BUILDER SMS inventory staff*: The current scan-to-BIM workflow as well as building inventory development for BUILDER SMS is flawed in that data for the same components have no connection with one another. For the tests performed in this study, it was difficult to connect the information between the two sources without a basic knowledge of both datasets prior to simulating the data transfer. The current process uses a BIM scanning team and BUILDER SMS inventory team for site visits. If there was more interaction between different team members (i.e., swapping roles temporarily, BIM team helping with data collection during scans, etc.), the BIM

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models would be created with BUILDER SMS integration in mind to minimize alterations to the model when making the initial data transfer. These changes to how the staff collects the information need to be tested for creating a BIM model and developing its FM database from scratch.

2. *Accuracy/compatibility of information between platforms*: When inputting the BUILDER identifiers into the previously created BIM model, there were some discrepancies that caused extra time either editing the BIM model or trying to interpret the BUILDER SMS data, e.g., cardinal directional referencing being inconsistent, the number of doors/windows in the BIM model not matching those recorded in BUILDER, and components not being modelled to match how they are accounted for in BUILDER SMS. Some of the alterations listed in Table 2 can be used to fix these issues, but a more proactive approach for these issues is to model the building with these workarounds in mind from the start of the inventory and building modelling process. If the BIM modeler has a greater understanding of the building's layout, there will be less discrepancies between the BIM model and FM database, and the time to complete data transfers can be reduced. Similar to the first improvement, this improvement needs to be applied to the creation of a BIM model instead of applying the workarounds to an existing model.

3. *Input BUILDER SMS component identifiers simultaneously with model creation*: The case study was performed with a previously completed Revit model that did not include BUILDER SMS identifiers. For future models, the BIM author can enter BUILDER SMS identifiers as the Revit model is created. They will need access to the BUILDER SMS database, which will allow for the BIM model

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developer to have a greater knowledge of the building, improve quality control by verifying compatibility with BUILDER SMS, and should be more efficient than adding the identifiers later.

4. *Development of fully integrated BIM-BUILDER SMS workflow for data transfer/updates*: There is a need to automate the data transfer between both the BIM model and BUILDER SMS. While the two methods evaluated here provide a workaround for inputting BUILDER SMS data into the BIM model for a more data-rich representation of the building, they are labor-intensive and time-consuming, especially if applied to multiple buildings with constantly changing data. For more frequent database updates with less time taken in the transfer process, a new data transfer method using a computer program to automate the data exchange should be developed.

A previous study proposed a research framework for future studies of integrating BIM and FM, which includes a step for developing a FM-enabled BIM workflow process [20]. Figure 14 shows a revised workflow for collecting and developing the data for the existing buildings using both Revit BIM and BUILDER SMS.
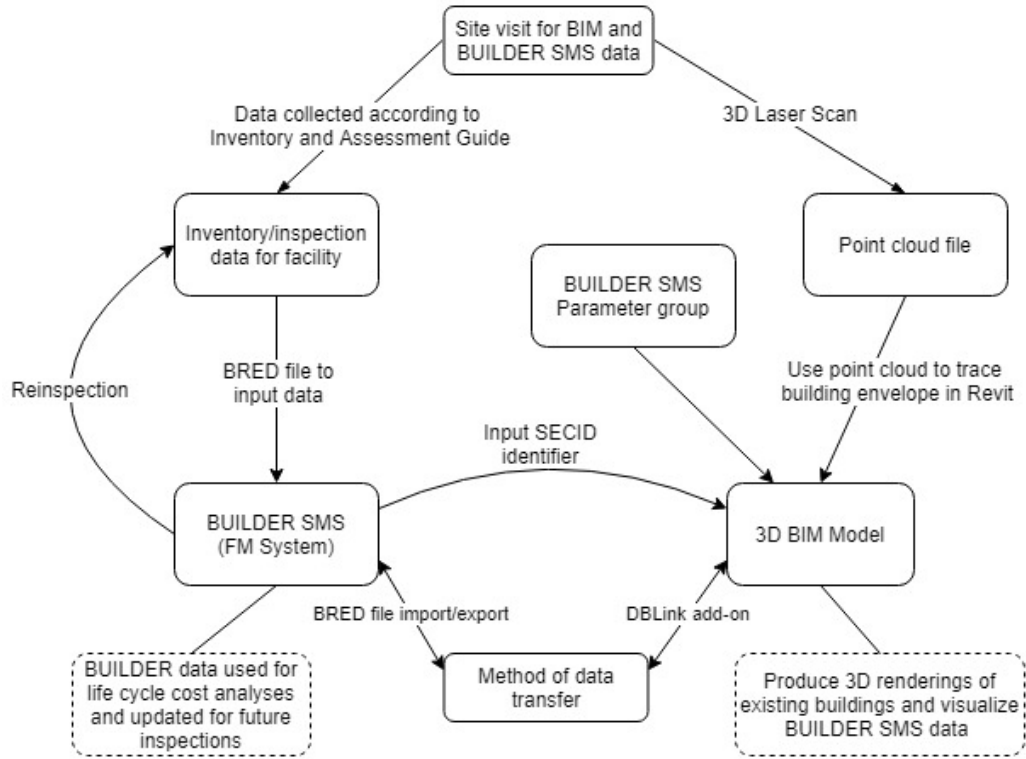
Figure 14. Proposed workflow of BIM and BUILDER SMS data collection.

The new workflow illustrates the relationship between Revit and BUILDER SMS

and how their datasets are connected. BUILDER SMS data are imported and exported

with its BRED file, which is in the file format of a Microsoft Access Database. Autodesk

Revit uses DB Link to import and export its data in the form of an Access database. With

the two datasets in a compatible file format and software environment, they are linked in

an intermediate database that manages the BUILDER and BIM data.

Focus Group Results

The second method of research for this study was a focus group used to gain

feedback on displaying facility information in BIM. The last part of the research

framework proposed by Pishdad-Bozorgi et al. was to determine the value of

implementing the integration of BIM and BUILDER SMS, which was accomplished by the focus group [20].

Focus group members. The focus group was comprised of five sponsor Staff with differing experience but who are all similarly tied to the potential use of BIM and BUILDER SMS. Each focus group member completed an initial questionnaire. Table 4 summarizes each focus group member's title, typical responsibilities and perceived familiarity with BIM and BUILDER SMS based on a Likert scale (1: not at all familiar, 2: slightly familiar, 3: moderately familiar, 4: very familiar, 5: extremely familiar).

Table 4

Focus group members by title and responsibilities

Title	Responsibilities	BIM Familiarity	BUILDER SMS Familiarity
Facilities Manager	• Enter/process work orders • Ensure buildings/facilities are maintained and fully functional	Slightly	Slightly
Status Program Manager	• Create installation status reports	Somewhat	Very
Facility Management Chief	• Oversee all facility maintenance for sponsor	Somewhat	Slightly
Building Management Specialist	• Responsible for facilitating the repair of all buildings • Process/add/track work orders put into Facility Dude (software)	Not familiar	Not familiar
Energy Manager	• Coordination of Building Energy Audits • Facility electrical/gas/oil water bulling review and reporting • Energy efficient project procurement	Slightly	Slightly

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As seen from these answers, this focus group had an overall low familiarity with both building information modelling (BIM) and the asset management tool of BUILDER SMS. However, there was high potential to use BIM and BUILDER SMS. The focus group served as a way to educate them on each individually and obtain feedback on the potential use of BIM/BUILDER SMS integration.

Demonstration of facility data shown in BIM. The discussion began with a brief overview of Revit and BUILDER SMS because of the varying levels of expertise among the group. They were able to see the data shown in the online database for BUILDER SMS as well as how it is currently entered using BuilderRED. It was explained that while the information in the database is important, it is not organized in a visually appealing way, especially for those who are less experienced. This transitioned into showing this data displayed in a BIM model. The first demonstration involved showing Building A in Autodesk Viewer, a web-based 3D viewer compatible with Revit BIM models (viewer.autodesk.com). Autodesk Viewer is an online file viewer compatible with several design and construction file formats that allow for viewing and sharing of documents. It was used to show a 3D rendering of the building and to display its accessibility and ease of use. This demonstration showed how a BIM model can be easily accessible to a variety of staff members and the usefulness of its first-person capabilities, as shown in Figure 15.

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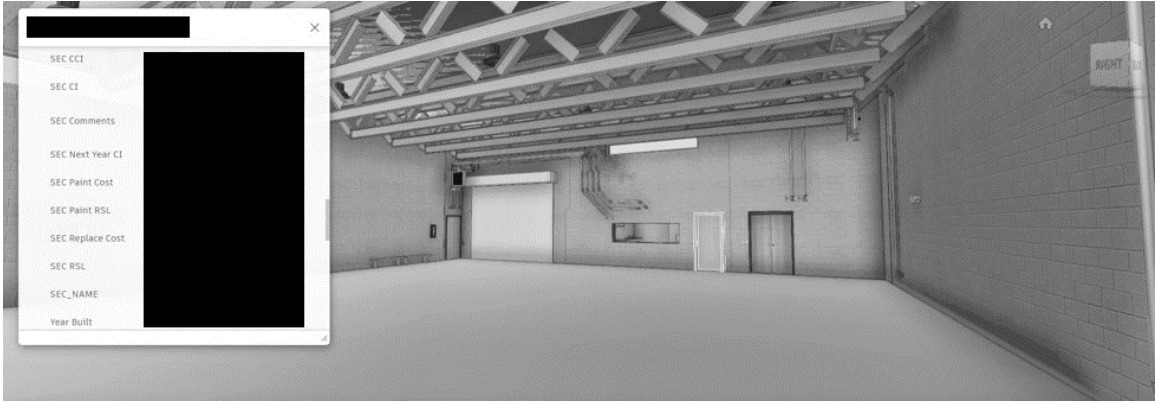
Figure 15. First-person view of Building A as shown in the focus group demo (Portions of Figure obscured as per sponsor order).

Some of the features demonstrated included walking through a building and selecting instances in the view to see properties and associated BUILDER SMS data, which is demonstrated in Figure 15 by selecting a single-flush door. It was suggested that this could be helpful in planning future site visits so individuals familiarize themselves with the building layout, view the layout and contents of particular rooms, or access BUILDER SMS data on a tablet while on site. One of the members suggested providing Viewer access to buildings to vendors before they arrive on site.

The next part of the demonstration involved showing other data visualization methods in Revit. One of the concepts demonstrated is the use of visual filters based on BUILDER parameters. Since the color scale of BUILDER SMS Condition Index is based on green, amber or red, a visual filter based on the CI value was applied to the model to demonstrate a way to summarize the condition of the building. A 3D view with this filter applied for next year's CI is shown in Figure 16.

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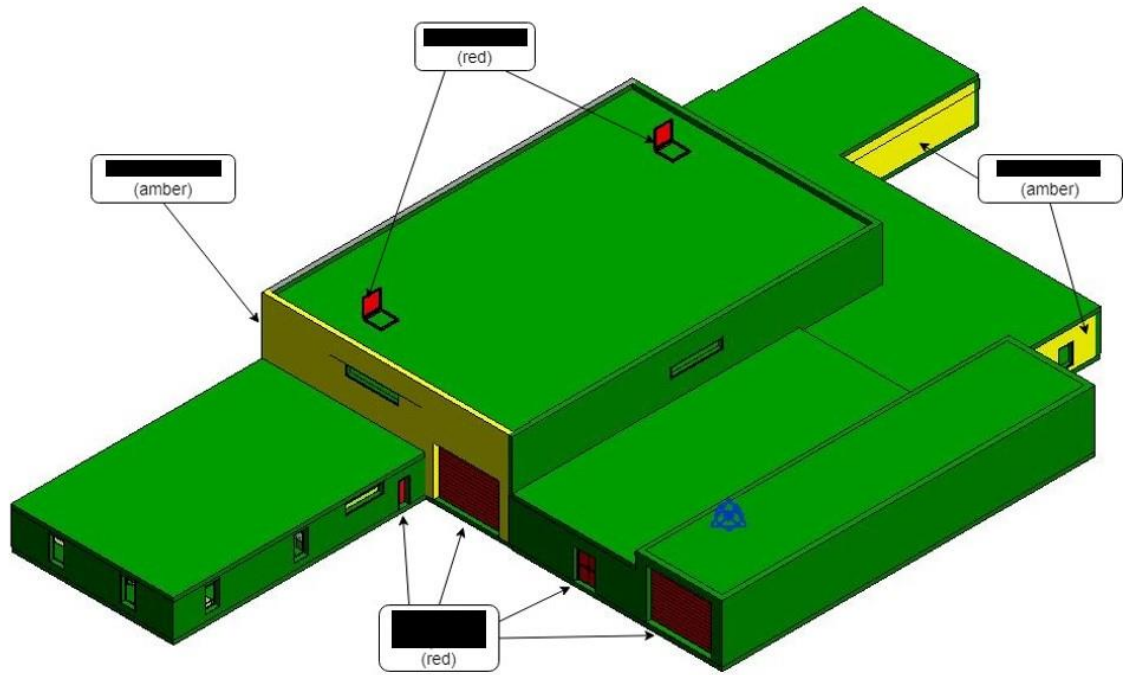
Figure 16. Demonstration of visual filter for Condition Index (CI) value of Building A (Portions of Figure obscured as per sponsor order).

In addition to 3D model views, the BIM model can also provide data-rich floor plan views. It was demonstrated that a side-by-side 2D view of Building A could be used to compare the current CI value with next year's projected CI according to BUILDER SMS, which visually shows expected degradations (Figure 17).

Floorplans obscured as per client order. The original figure showed two floorplans of Building A. The top floorplan showed current condition indexes, all green and amber. The bottom floorplan showed next year's condition indexes as calculated in BUILDER SMS. Several building components degraded to amber or red.

Figure 17. Current CI vs next year CI floor plan comparison.

One of the members noticed a difference in color between the two views of the model and it demonstrated that a visual representation of the depreciation of building components can be useful for facility staff. Another member suggested that using these visuals and the data attached with them can assist in planning ahead if they were to, for example, have to replace a certain amount of lighting fixtures.

The last part of this Revit demonstration was a prerecorded walkthrough of the building, with and without the visual filter applied. The idea was to show that a basic overview of the building's health can be shown if the walkthrough covers all rooms, or it can be used to give more specific information for a particular location in the building. Once some of these features were demonstrated, the discussion became more open-ended with comments and suggestions, concluding with the attendees completing the provided questionnaire.

Questionnaire results after demonstration. The second part of the questionnaire was completed by all five staff members to gain insight on their reaction to the demonstration as well as any feedback or suggestions they have for utilizing BUILDER SMS data displayed in BIM. There were short answer questions that allowed the group to share their thoughts on how integrating BIM and BUILDER SMS data could be valuable in different aspects of their work.

One of the questions prompted them to consider how BIM could be used to improve preventative maintenance at their facilities. Their responses were unanimous in that they saw the use of BIM for displaying their BUILDER SMS data as an improvement. One response stated that, "being able to quickly identify pieces of equipment's' lifecycle or direct input assessment for current and future years gives a quick identification of what may fail." The visual aspect of BIM was seen as useful for, "fast, visual review of components," After being shown the facility data in both the database format as well as in a BIM model, four out of five of the respondents expressed that they preferred the visual format of viewing data in BIM. The other respondent stated that they had no preference. They explained that the visual representation can allow them

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to, "identify issues more quickly and with greater detail," and "more easily get a high-level overview of a facility." Finally, when asked if BIM should have a more significant role in assisting with their facility management, the group was unanimous in thinking that it should be used. One focus group member, a building management specialist, described that using BIM and BUILDER SMS would allow for better cost-saving efforts and improved building assessments. These short answer questions resulted in positive feedback for BIM and BUILDER SMS overall and a significant interest in utilizing these tools for their facility management practices going forward.

The last part of the questionnaire involved rating the perceived usefulness of BIM in assisting with the given scenario, followed by suggestions for other uses for using BUILDER SMS data in BIM models. The rating was based on a Likert scale ranging from not all useful (1) to extremely useful (5). Table 5 has the average ratings for each scenarios sorted from highest to lowest based on the questionnaire.

Table 5

Summary of results for BIM-BUILDER SMS scenario ratings

BIM-BUILDER SMS Scenario	Rating
1. Using BUILDER SMS parameters for visual filters to track patterns and problem areas in facilities.	4.6
2. BIM models can be viewed on a tablet/mobile device during future inspections or other site visits.	4.6
3. An outside vendor is given the BIM visualization of the facility to assist them with planning and giving them information on the component(s).	4.4
4. BIM model is connected to work order system to track FM data in the facility and relate it to rooms and spaces in the building.	4.4
5 . Any retrofit projects of the building can be updated in both data locations if changed in either BIM or BUILDER SMS.	4.2

All of the scenarios were seen as very useful by the focus group members. The two highest rated scenarios were visual applications of the BIM model, which aligns with a previous study in which 86% of survey respondents saw "visualization and marketing" as a potential application area [23]. Scenario 3 and 4 also align with the literature in that they can help save time when completing any maintenance tasks by expediting the process of locating faulty components [31]. While Scenario 5 was still rated as a very useful application, it may have been rated lower because it was not something that would apply to the focus group members directly, rather the BIM and BUILDER SMS database developers. However, the ability to update digital assets [23] and assist with retrofit projects [9] is still beneficial to the sponsor.

The meeting was also used to identify additional scenarios where BIM and BUILDER SMS can be used. The focus group identified the following:

- Condition of building components based on amount of funding

- Phone application to show 3D BIM model including details of components

- Incorporation GIS (ex: Add weblink to the online browser viewer within the ArcGIS viewer currently used to have access to both floor plan view and 3D view

- Repairer ability to input real time data, similar to FacilityDude (www.dudesolutions.com), which can be combined with BIM

- Attach photos/documents to equipment for inspector/technicians to have available while on site

Discussion points. The transcript of the focus group meeting was also analyzed for qualitative data and to find trends in the attendees' perspectives of the BUILDER SMS data shown in BIM. There were several questions asked by the staff that prompted discussion on expanding BUILDER SMS and BIM into their day-to-day operations. An idea prompted by the Facility Management Bureau Chief involved using the data collected from both BIM and BUILDER SMS to keep better inventory of their fire suppression systems. He elaborated on the fact that storing this information would assist in future interactions with vendors by easing the process of writing contracts. The issue brings up a need for the data to be accessible and accurate, particularly for buildings' fire suppression systems [23]. The increased accuracy of information would prevent certain components being, "left off to the wayside," while writing up the contract. Another example that was brought up was the potential use for future installation of carbon

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monoxide detectors. Based on the demonstration that they were shown, they saw a case where they could use BIM to meet standards for installing these devices, specifically where, "it has to be on every room that is touching the boiler room." This shows a significant example of how connecting the physical dimensions of a BIM model to facility data can be helpful for relevant staff members. Another example of how this can advantageous was the use of BIM to track the locations of light fixtures that need to be replaced. This specific scenario involving light fixtures has been tested in a previous study, where the estimated annual energy savings in kWh for upgrading to LEDs was calculated in the BIM model [25]. Not only would this assist in anticipating the need for replacement based on the design life and energy demand, the facility management team would be able to use the location of these fixtures to schedule their replacements more efficiently.

There was a request from the group for the ability to attach documentation to a building component in the BIM model, in this case, "the manual, warranty information, etc."). This was then compared to the capability of BUILDER SMS to attach images to components from inspections. This points to a future addition to the integration in which images from BUILDER SMS--as well as other electronic documents could be attached to BIM model components. There was also a long discussion of the potential for using BIM with the sponsor's work order system, FacilityDude [50]. It was suggested that being able to select specific components for work orders with a location attached would make the process more efficient. Also, being able to track the amount of work orders from a building component can help make decisions for preventative maintenance in the future. Since this has been done for previous research using other work order systems, there is

potential to use BIM with FacilityDude in the future. Finally, it was suggested to have the

BIM models work hand-in-hand with their existing GIS system. The energy manager

described an ideal case where, "you could have a link to (the Autodesk Viewer model) in

the building. So, you could view it in the map like you're using GIS and then instead of

having to go find it somewhere else, it's in that property bubble," and the BIM model can

be viewed. While this use for the BIM models deviates slightly from facility

management, it could assist in having more centralized data structure if all tools used by

the sponsor are connected. Overall, the focus group members had mostly positive

feedback for the demonstration they were shown, with a particular interest in the visual

capabilities and have the data for their facilities be less fragmented among different

databases.

Chapter 5

Conclusions

The integration of BIM for FM was analyzed for their use during the operations &

maintenance phase of a building's lifecycle. A workflow for Revit-BUILDER SMS

integration was developed. A hypothetical BIM model was created in Revit to test basic

data transfer between the two sources. Once the process was established, it was tested

using on a typical sponsor building, Building A. Observations and time expenditure were

recorded during the simulation to compare two data transfer methods. Method 1 involves

manual data entry and Method 2 used an intermediate Access database and a unique

identifier to connect each component in BUILDER SMS to each Revit instance in the

BIM model. The strengths and weaknesses of these two transfer methods were compared

and improvements to the workflow suggested. A workflow schematic was developed that

can be used to guide BIM-FM integration (Figure 14). Once the data transfer was

completed, the resulting BIM model with FM information was presented to a focus group

to demonstrate its capabilities. Feedback for the demonstration was recorded via a

questionnaire as well as the transcript of discussion. Examples of scenarios for utilizing

BIM and BUILDER SMS integration were presented and suggestions for other

applications were documented.

Conclusions

Based on the simulation of data transfer as well as results from the focus group

demonstration, the following conclusions are drawn from this study.

1. There were several alterations made to the BIM model to make it compatible with the FM database before data transfer was evaluated, but time can be saved if the model was created to be compatible.

2. BIM and BUILDER SMS integration was achieved using the following process:

   a. Step 1: *Make alterations to BIM model for increased compatibility with FM database*

   b. Step 2: *Add FM parameters to BIM Model*

   c. Step 3: *Retrieve data from FM database*

   d. Step 4: *Transfer data between BIM and FM*

3. Two methods of data transfer were successful in populating the BIM model with facility information. Method 1 (manual) took a total of 218 minutes to complete while Method 2 (intermediate database) took 161 minutes. A majority of the time taken for Method 2 was spent manually entering the BUILDER SMS identifiers into Revit instances. Subsequent transfers would only take approximately 12 minutes.

4. Both methods require some manual data entry, which can cause slowdowns when setting up the workflow for multiple facilities. However, manual data entry is only required during the first transfer for Method 2.

5. Unanimous responses to the questionnaire showed that BIM was seen as an improvement to preventative maintenance for the sponsor and that BIM should have a more significant role in facility management.

6. The focus group was most interested in the visual capabilities of BIM and BUILDER SMS integration. Based on the Likert scale ratings of "usefulness", the use of visual filters based on BUILDER SMS parameter values as well as the possibility of viewing

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the model on a tablet/mobile device during site visits were the most enticing applications to them.

7. There are specific applications for BIM and BUILDER SMS of interest to the sponsor including tracking of fire suppression systems, planning replacements of lighting fixtures and connecting BIM to their GIS records.

Future Work

This study serves as an examination of an improved workflow using BIM and BUILDER SMS integration. Additional research in this area needs to be completed for a better understanding of the applications areas and to improve efficiency in the information exchange process. The following are possible future areas of research..

1. Additional testing of two-way transfer between Revit BIM and BUILDER SMS with the established methods can further demonstrate the feasibility of the workflow developed here since this study mostly focused on the transfer from BUILDER SMS to Revit.

2. A BIM and BUILDER SMS integrated workflow was developed but not fully tested from start-to-finish. Rather than using and altering existing datasets, additional testing for developing a Revit model and BUILDER SMS database from scratch with the improved workflow can be done to reinforce its potential value.

3. While considering the possible data transfer methods, one that was observed, but not tested in this study, involved the use of an ODBC connection and SQL Server to manage the flow of information between Revit and BUILDER SMS. A

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proposed workflow was developed if this transfer method were to be implemented

in a future study (Figure 18).

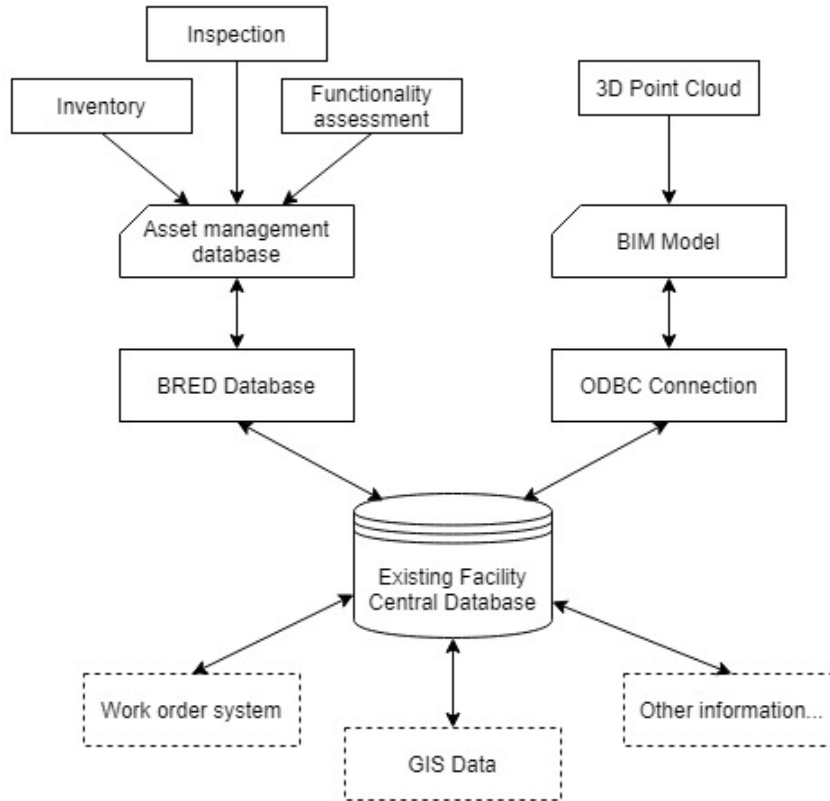*Figure 18.* Proposed integrated information workflow for existing buildings using BIM

and BUILDER SMS.

4. The focus group resulted in a discussion of using their work order system,

    FacilityDude, together with BIM to improve their handling of maintenance

    requests. This specific software has the potential to be applied to the proposed

    workflow to increase the functionality of the BIM model.

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Appendix A

Component_Section and SectionDetails Parameters

Table A1

BUILDER SMS parameters from BRED file

Component_Section Parameters:	SectionDetails Parameters
• SEC_ID*	• SD_ID
• SEC_SYS_COMP_ID	• SD_Sec_ID*
• SEC_CMC_LINK	• ID_Number*
• SEC_QTY	• Equipment_Type*
• SEC_YEAR_BUILT*	• Equipment_Make*
• SEC_DATE_PAINTED*	• Model
• SEC_NAME*	• Serial_Number
• SEC_BDGT_LINK	• Capacity*
• SEC_PAINT	• Manufacturer
• SEC_COMMENTS*	• Date_Manufactured*
• SEC_PAINT_LINK	• Date_Installed*
• SEC_REMAIN_LIFE*	• Control_Type_Make*
• SEC_PAINT_RSL*	• Warranty_Date*
• SEC_CI*	• Warranty_Company*
• SEC_CCI*	• Location*
• SEC_REPLACE_COST*	• Comment*
• SEC_PAINT_COST*	• Warranty_Date2
• SEC_QTY_SOURCE	• Warranty_Company2
• SEC_DATE_SOURCE	
• SEC_TYPE_SOURCE	
• SEC_STANDARD	
• SEC_PROJECTED_CI	
• SEC_PROJECTED_CCI	
• SEC_NEXT_YEAR_CI*	
• SEC_NEXT_YEAR_CCI	
• SEC_A	
• SEC_Alpha	
• SEC_Beta	
• SEC_PaintA	
• SEC_PaintAlpha	
• SEC_PaintBeta	
• SEC_FunctionalArea_ID	
• SEC_Status_ID	

*Indicates parameters that were added to the Revit model and used in transfer evaluation

Appendix B

QC-5 Section Details

QC-5 Section Details obscured as per client order.

Appendix C

DB Link Edit & Import

Edit Database before Import

Custom Parameters

Select Table:

StructuralFabricReinforcementTypes
StructuralFoundations
StructuralFoundationTypes
StructuralFraming
StructuralFramingTypes
StructuralRebar
StructuralRebarBarTypes
StructuralRebarHookTypes
StructuralRebarShapes
StructuralStiffeners
StructuralStiffenerTypes
StructuralTrusses
StructuralTrussTypes
SwitchSystem
TelephoneDevices
TelephoneDeviceTypes
Topography
TopographyTypes
Views
Voltages
VoltageTypes
Walls
WallSweeps
WallSweepTypes
WallTypes
WallUsageEnums
Windows
WindowTypes
WindowWall
WireInsulations
WireInsulationTypes
WireMaterials
WireMaterialTypes
Wires
WireTemperatureRatings
WireTemperatureRatingTypes
WireTypes
WiringTypeEnums

⊁ Cut 📋 Copy 📋 Paste ✳ NewRecord ✖ Delete

SEC Cl	SEC Comments	SEC Next Year Cl	SEC Paint Cost	SEC Replace Cost	SEC RSL	SEC_NAME	Year Built	SEC Date Painted	SEC ID
95		89	50.6708691...	1385.38362...	11.8897760...	HALLWAY	1984	2017	{CDB512A8-...
95		89	50.6708691...	1385.38362...	11.8897760...	HALLWAY	1984	2017	{CDB512A8-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		93	64.5115232...	9946.24658...	48.4340257...	RM 113 KIT...	1984		{017E56E4-...
95		89	633.385864...	17317.2953...	11.8897760...	DRILL HALL	1984	2018	{2A0B3D14-...
95		89	633.385864...	17317.2953...	11.8897760...	DRILL HALL	1984	2018	{2A0B3D14-...
95		89	59.1160140...	1616.28089...	11.8897760...	RM 112 BOI...	1984	2017	{98C77B70-...
95		89	59.1160140...	1616.28089...	11.8897760...	RM 112 BOI...	1984	2017	{98C77B70-...
95		89	59.1160140...	1616.28089...	11.8897760...	RM 112 BOI...	1984	2017	{98C77B70-...
95		89	59.1160140...	1616.28089...	11.8897760...	RM 112 BOI...	1984	2017	{98C77B70-...
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95		89	22.5203863...	615.726055...	11.9445330...	RM 111	1984	2007	{E1AE401B-...
95		89	22.5203863...	615.726055...	11.9445330...	RM 111	1984	2007	{E1AE401B-...
95		89	22.5203863...	615.726055...	11.9445330...	RM 111	1984	2007	{E1AE401B-...
95		89	633.385864...	17317.2953...	11.8897760...	DRILL HALL	1984	2018	{2A0B3D14-...
95		89	633.385864...	17317.2953...	11.8897760...	DRILL HALL	1984	2018	{2A0B3D14-...
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95		89	14.0752414...	384.828784...	11.8897760...	CORRIDOR	1984	2017	{55EBC924-...
95		89	14.0752414...	384.828784...	11.8897760...	CORRIDOR	1984	2017	{55EBC924-...
95		89	14.0752414...	384.828784...	11.8897760...	CORRIDOR	1984	2017	{55EBC924-...
95		89	215.820368...	5900.70803...	11.8897760...	RANGE	1984	2017	{94CB5A7B-...

OK   Cancel

Appendix D

Focus Group Questionnaire

Name: _____

Position/Title: _____

Describe your typical duties/responsibilities:

_____

_____

_____

What would you say is your current familiarity with Building Information Modelling (BIM) (Circle answer)?

Not familiar   Slightly familiar   Somewhat familiar   Very familiar   Extremely familiar

What would you say is your current familiarity with BUILDER SMS (Circle answer)?

Not familiar   Slightly familiar   Somewhat familiar   Very familiar   Extremely familiar

FILL OUT THE REST OF FORM AFTER DEMO

Do you see BIM as a potential improvement for preventative maintenance in NJ DMAVA facilities? If so, how?

_____

_____

Do you prefer to see data visually in the context of a BIM model rather than the more traditional database view of facility data? Explain.

_____

_____

Should BIM have a more significant role in assisting with facility management?

_____

_____

65

For the following scenarios, rate your perceived usefulness of applying BIM to assist in completing the task:

Not at all useful	Slightly useful	Moderately useful	Very useful	Extremely useful
1	2	3	4	5

Scenario	Rating
1. With each component of the BIM model having analytical values from BUILDER associated with them (such as Condition Index, remaining service life, replacement cost, etc.), visual filters can be used to locate problem areas in the facility.	
2. Future inspections of the facility can be done with a BIM model being viewed on a tablet. This can give a realistic layout of the facility as well as facility information attached to each component	
3. A work order is submitted and delegated to an outside contractor. With BIM-FM, they can be given a 3D visualization of the component and its location, as well as its inspection history, model information, etc.	
4. FacilityDude, as a work order system, can track maintenance requests for certain areas or components in a facility. The BIM model could reflect this by showing, which parts of the facility are producing the most work order requests.	
5. If retrofitting of a building occurs, the physical model and the SMS data can both be updated in the BIM model, which can then be updated in BUILDER SMS.	

Suggestions for other potential scenarios:

_____

_____

_____

_____

_____

_____