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USING NAMING CONVENTIONS TO FACILITATE DATA TRANSFER BETWEEN ASSET MANAGEMENT SYSTEMS AND BUILDING INFORMATION MODELS

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USING NAMING CONVENTIONS TO FACILITATE DATA TRANSFER BETWEEN ASSET MANAGEMENT SYSTEMS AND BUILDING INFORMATION MODELS

by
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A Thesis

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Abstract

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2021-2022
Jess W. Everett, Ph.D.
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An improvement to the workflow developed by Loeh et al. (2021) is proposed using a Revit template with BUILDER SMS naming conventions when creating the Sustainable Facility Management-enhanced BIM Model. The method presented by Loeh et al. (2021) is modified by integrating BUILDER SMS parameters and naming conventions into the BIM model during, as opposed to after, the creation of the model.

Four building models created in 2020-21, four from 2021-22, and one building from 2019 were used in this study. Two groups of students were used to evaluate the effect of the building-specific BIM templates. Evaluating the 2020 and 2021 group's progress logs' milestone completion times using the T-test and ANOVA indicated that using the building-specific BIM template did not take significantly more time than allowing model builders complete freedom regarding naming conventions when creating BIM models.

The initial time commitment required to create the building-specific template makes it easier to identify the location of elements in the model. Developing the Revit model with the BUILDER SMS naming convention in mind creates a compatible BIM model for transferring data.

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Chapter 1

Introduction

The operational phase of a building accounts for the majority of the cost of the building's lifecycle. According to estimates, the lifecycle cost is five to seven times that of the initial investment (Lee et al., 2012). Buildings account for over 40% of all energy use in the United States, and 30% of greenhouse gas emissions (UNEP, 2009; Energy.gov, 2015). There is strong demand for efficient and sustainable management of new and existing facilities for both economic and environmental reasons.

Project stakeholders often need to consider the operation and maintenance (O&M) phase during design and construction (Heaton et al., 2019). The operation and maintenance of a building and its equipment and facility management (FM) work in tandem (Kelly et al., 2013). FM maintains a built environment's functionality, comfort, safety, and efficiency (Barrett & Baldry, 2003). Sustainable facility management (SFM) is FM that reduces the negative impact of buildings on their occupants and the environment (Fennimore, 2014).

Building data are an essential resource for effective facility management. During the construction of a facility, several databases may be compiled and provided to the owner for FM. Alternatively, these databases may be assembled after construction, likely at significant expense or expenditure of effort. Asset Management Systems (AMS) are software applications that optimize FM processes. The US military uses the BUILDER Sustainable Management System (BUILDER SMS, https://www.sms.erdc.dren.mil) as a sustainable AMS. BUILDER SMS is the AMS studied in this research.

Building Information Modeling (BIM) is an intelligent model-based approach to data management that offers knowledge and tools for more effective building and infrastructure planning, design, construction, and management (Lavy & Jawadekar, 2014). BIM often includes 3D models of a building's physical aspects. BIM can be used to create, assemble and access building data during a building's life cycle (Lavy & Jawadekar, 2014). Autodesk Revit (www.Autodesk.com) is the BIM software used for this research.

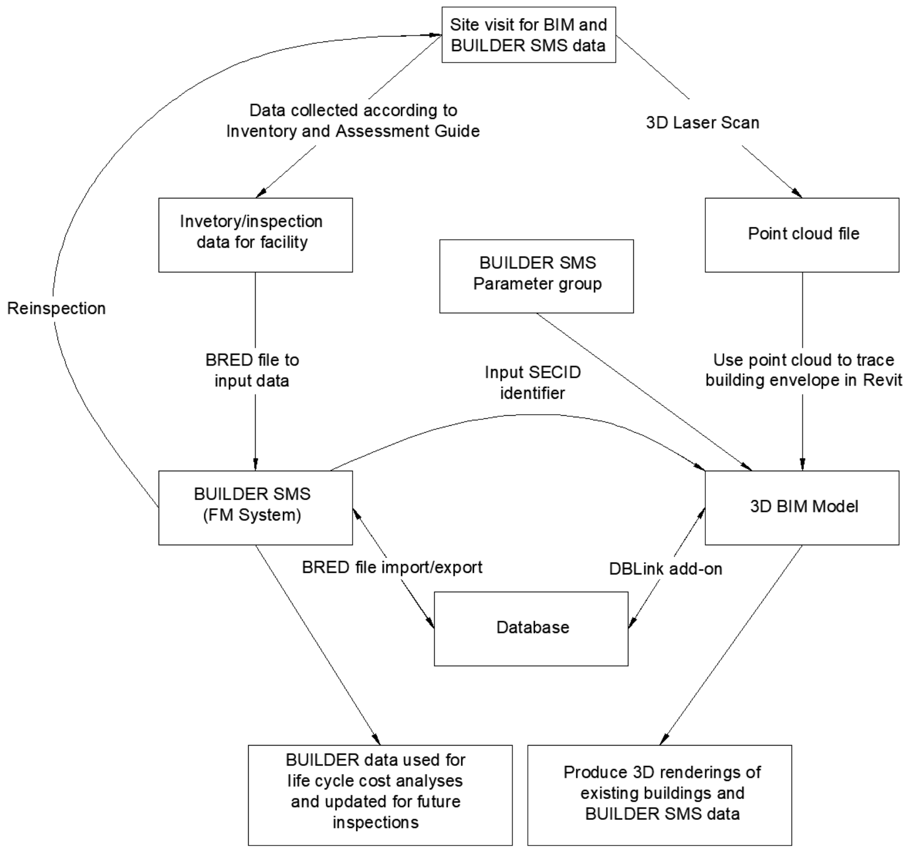
BIM stores data associated with the elements that make up the building. This provides an interactive way to visualize and/or access the data in a 3D model. The associated data are stored within additional parameters of BIM elements and can be accessed in the software or exported to an external database.

For new construction, BIM models are usually created during the design phase. However, BIM models can also be created after the design and construction of a building. A 3D laser scanner can be used to create a collection of points in space called a point cloud. This point cloud can be imported into BIM software and traced to develop the exterior and interior geometry of the building. Data are then associated with various elements in the model. This is the BIM process employed in this research.

Loeh et al. (2021) presented a method for incorporating SFM data from BUILDER SMS into a REVIT-based BIM model. The workflow developed by Loeh et al. (2021) for creating such an SFM-enhanced BIM model is shown in Figure 1. The workflow integrates BUILDER SMS and Revit datasets by adding the SEC_ID created in BUILDER SMS into each corresponding Revit entity.

Figure 1

Integration Workflow for Revit and BUILDER SMS (Loeh et al. 2021)



The research question of this thesis is: Can the workflow developed by Loeh et al. (2021) be improved by using a Revit template with BUILDER SMS naming conventions when creating the SFM-enhanced BIM model?

The scope of this research is limited to creating BIM models of existing buildings for New Jersey Department of Military and Veterans Affairs (NJDMAVA). The BIM models are created by students as part of a Civil Engineering project-based college course. Autodesk Recap and Revit are the software used for creation of the point cloud and 3D BIM model. BUILDER SMS is the sustainable management software used by the NJDMVA. BUILDER SMS data are used to create the SFM-enhanced BIM models.

A literature review of the use of BIM for SFM is included in the Background chapter of this paper. The Buildings and Methods chapter is used to describe the buildings and methods used in this research as well as how the transfer method is evaluated. The Results chapter is used to examine the effectiveness of the building template and data transfer. Conclusions and, suggestions for future work are described in the Conclusions chapter.

Chapter 2

Background

The purpose of this chapter is to provide research information about SFM and BIM. Journal articles and conference papers indexed in Science Direct, Engineering Village and Google Scholar were identified using the search terms: BIM, BIM Facility Management, BIM interoperability and Sustainable Facility Management. References in found articles, as well as tables of contents from key journals also provided additional sources.

Sustainability

In the United States, buildings consume approximately 40% of all energy and release 30% of greenhouse gases into the atmosphere yearly (UNEP, 2009; Energy.gov, 2015). One of the most effective ways to reduce carbon emissions is by renovating existing buildings to reduce energy consumption (Chong et al., 2017). BIM can aid in the retrofitting and renovating of an existing building by providing up-to-date as-built plans (Volk et al., 2014). Chong et al. (2017) stated that using real-time FM-enabled BIM systems for energy management could improve existing building sustainability by eliminating inefficiencies.

Facility Management

Project stakeholders often neglect a project's future operation and maintenance (O&M) costs during the design and construction phases (Heaton et al., 2019). Since O&M can account for up to half of a structure's total lifecycle expense (Heaton et al., 2019) this oversight can lead to inefficiency. The operation and maintenance of a building and its equipment work together with facility management (FM). FM maintains a built environment's functionality, comfort, safety, and efficiency. Maintaining reliable records is one of the most challenging aspects of facility management.

The FM process can be divided into maintenance and refurbishment (NSF, 2003). Building maintenance is seen as an operation in the broader sense of FM (Barrett & Baldry, 2003; Motawa & Almarshad, 2013). Building maintenance includes FM staff's tasks to ensure that buildings continue to fulfill their intended purposes. This is the longest period in the lifecycle of a building and where the majority of expenditures accumulate (Lee & Akin, 2011). Refurbishment is the process of making changes or improvements to a building (NSF, 2003).

SFM is FM that reduces the negative impact of buildings on their occupants and the environment (Fennimore, 2014). Asset Management Systems (AMS) are software applications that optimize FM processes. BUILDER SMS is a sustainable AMS used by the US military. BUILDER SMS is a web-based application that stores and tracks condition assessments of building components. Based upon results of a literature search as of 2022, BUILDER SMS has not been the focus of any academic research besides the work of Loeh et al., (2021).

Building Information Modeling

BIM is a design and construction 3D representation of a building as an interconnected database of organized, internally consistent, and computable information (Sabol, 2008). This integrated database can contain a large amount of project data, such as material quantities, installation dates, subcontractor obligations, the type of material used in a facility, cost, and schedule. A BIM model can simplify a project's data collection and storage processes because it can be used as a single source for all project data (GSA, 2009). The objective of using BIM for facility management is to facilitate the use of data over the facility life cycle to provide safe, healthy, effective, and productive working environments (Jordani, 2010). During design and construction, a large amount of data are generated. Maintaining this data can result in efficiencies, such as providing current condition building information to reduce the cost and time needed for renovations, increasing customer satisfaction, and optimizing the operation and maintenance of the building systems to reduce energy use.

Developing and incorporating BIM in FM facilitates the management of life cycle data. BIM can be used to perform FM activities such as commissioning and closeout, retro-commissioning, warranty, and service information maintenance, quality control, energy and space management, planning and performing maintenance, emergency management, retrofit planning, and deconstruction (Akcamete et al., 2019; Chen et al., 2012; Becerik-Gerber et al., 2012; Costin et al., 2013; Volk et al., 2014). BIM is designed to possibly transfer needed building data to FM information systems while also improving FM processes through advanced visualization and analysis capabilities (Becerik-Gerber et al., 2012).

Autodesk Revit (https://www.autodesk.com) is a popular BIM authoring software, and has been a subject of BIM-related research (Yin et al. 2020; Ede, Olofinnade, and Sodipo 2017; Orr et al. 2014; Lin and Su 2013 and Loeh et al. 2021). Autodesk Revit allows architects and building professionals to design and document a building by creating a parametric three-dimensional model that includes geometry and non-geometric design and construction information (Eastman et al., 2018). The term parametric model reflects that changes made to the parameters of a repeated component within the model would be reflected throughout the whole model and associated documentation, not just the individual component.

The project's data or information is an essential resource in adequately managing a facility. With accurate current condition data, facility managers can function effectively (Kirkwood, 1995). Data exchange and interoperability between a BIM model and AMS is a significant challenge. In a case study by Loeh et al. 2021, these challenges were addressed by developing a workflow to integrate BIM and FM databases (Figure 1). The workflow integrates BUILDER SMS and Revit datasets by adding the SEC_ID created in BUILDER SMS into each corresponding Revit entity. BUILDER SMS and Revit do not have a built-in option to transfer data between them.

BUILDER SMS and Revit use different terms to classify building components. Building information data stored in BUILDER SMS are grouped into categories. An example of a category is the exterior enclosure. A category is further subdivided into components. Components of the exterior enclosure category include exterior walls, windows, and doors. A particular component is identified as a section. BUILDER SMS can export the database as a Builder Remote Entry Database (BRED), which are compatible with Microsoft Access.

Revit models are composed of objects called families. These families are grouped into three categories: system families, loadable families, and in-place families. System families are objects predefined in Revit, such as walls, roofs, floors, ducts, and pipes. Loadable families are elements that can be loaded into Revit and edited by the user, for example, windows, doors, fixtures, and furniture. In-place families are unique elements created by the user within a specific Revit project (Autodesk.com, 2021). A particular family entity is identified as an element. BUILDER SMS components and sections are equivalent to Revit families and elements. Autodesk Revit uses third-party plugins to export database files into various file formats.

BUILDER SMS generates a unique alphanumeric SEC ID for each building element. Loeh et al. (2021) used the Builder SMS parameter "SEC ID" for each component to link the BRED database and the Revit model elements. These unique identifiers were added as an additional parameter to each Revit element after the 3D models are created.

There has been little research on the data transfer between SFM software and BIM models. This study modifies the method presented by Loeh et al. (2021) by integrating BUILDER SMS parameters and naming conventions into the BIM model during, as opposed to after, the creation of the model. The intent of this effort is to present a more efficient means to accomplish the data transfer methodology proposed by Loeh et al. (2021).

Chapter 3

Buildings and Methods

The buildings used in this research are existing buildings operated by NJDMAVA, the sponsor for this research. Undergraduate students working within the Sustainable Facility Center (SFC) at Rowan University create BIM models for four NJDMAVA buildings per academic year; this research uses four building models created in 2020-21, four in 2021-22, and one in 2019. The creation of the BIM model for an existing building starts with 3D scans. Building scans are imported into Autodesk Recap and stitched together to create a 3D point cloud. This 3D point cloud is imported into a building-specific BIM template for Autodesk Revit and traced to create a 3D building model, the building envelope first, then the interior. The final 3D model includes the building envelope, the interior walls, and the visible mechanical, electrical and plumbing systems.

These buildings were selected to be modeled based on a master schedule provided by NJDMAVA. Building identities are not revealed here, as per the sponsor's security requirements (NJDMAVA 2006).

Buildings

BIM models for four New Jersey National Guard Readiness Centers (RC) were created during the 2020 Fall and 2021 Spring semesters. Each RC consisted of a drill floor, offices, kitchen and cafeteria, storage rooms, bathrooms and mechanical room. The year-built dates for these building varied from 1940 to 1977 and the square footage varied from approximately 18,000 sq. ft. to 35,000 sq. ft. as seen in Table 1.

Table 1

Building Summary

Designation	**Floorspace (1000 ft^2)**	**Scans**	**UNIFORMAT II Categories included in model**
20A	18	64	5
20B	30	79	5
20C	33	110	5
20D	35	86	5
21A	12	19	5
21B	18	58	5
21C	35	157	5
21D	95	195	5
16	16	40	9
19	15	36	9

Four more BIM models were created during the 2021 Fall and 2022 Spring semesters. Each of the RCs consisted of a drill floor, offices, kitchen and cafeteria, storage rooms, bathrooms and mechanical room. Facility 21D also has an approximately 45,000 sq. ft. indoor turf field. Facility 21A consisted only of general storage space. The year-built dates for these building varied from 1939 to 1987 and the square footage varied from approximately 12,000 sq. ft. to 95,000 sq. ft.

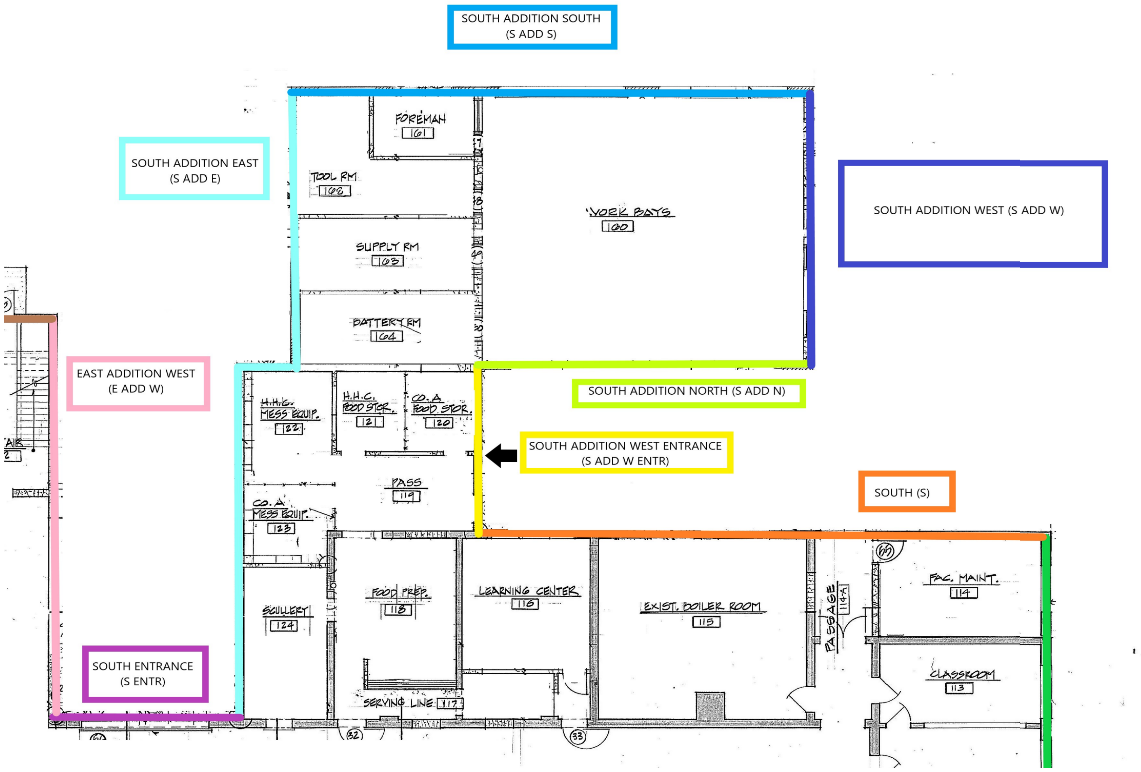
The BIM model for Building 16 was created during the 2016 Fall and 2017 Spring semesters (the building used by the Loeh et al., 2021). The BIM model for Building 19 was created during the 2019 Fall and 2020 Spring semesters. Building 19 was chosen because it is similar to the Loeh et al. 2021 building in floor area, types of rooms, and number of UNIFORMAT II categories included in its Revit model.

BIM Template

This research focuses on developing an improved process for creating SFM-enhanced BIM models for existing buildings. The building-specific BIM template file contains elements created using the UNIFORMAT II naming convention used in BUILDER SMS. This facilitates data transfer between BUILDER SMS and Autodesk Revit. The master BIM template uses the UNIFORMAT II naming convention already used in Builder SMS. Custom parameters within Autodesk Revit allow for the classification of specific elements within the model. The master BIM template is duplicated and modified to contain the specific building components for each building to be modeled. Standard operating procedures (SOP) for creating master BIM and building-specific templates are described in Appendix A. An example of the UNIFORMAT II naming convention for the exterior walls is shown in Figure 2. The colors designate the UNIFORMAT II names and locations of exterior walls. The two parameter groups added to the Revit template model are Component Section and Section Details.

Figure 2

UNIFORMAT II Naming Convention



Data Transfer

Data transfer is accomplished by opening a Builder SMS BRED file in Microsoft Access. The Builder SMS BRED file is an offline database that is exported by Builder SMS for offline data entry. The Microsoft Access select query for Component Section and Section Details are exported to a Microsoft Excel spreadsheet. The SOP for data transfer is in Appendix A. A example of results from a Component Section query is shown in Figure 3.

Figure 3

Component Section Query

Component_Section

SEC_NAME	SEC_ID	SEC_SYS_CON	SEC_CMC_LINK	SEC_QTY	SEC_YEAR_BU	S
E ADD W	3F04823AD911}	.5A452D10AAE}	30038	83.6130599738614	1988	
S ADD W ENTR	32B7CBD22FB7}	.5A452D10AAE}	30038	27.3135995914614	1988	
S	DA9DC992FEB1}	.5A452D10AAE}	30038	18.2090663943076	1958	
S ENTR	4C7542CE6AE1}	.5A452D10AAE}	30038	30.286508390532	1958	
S ADD N	FC185BD0E308}	.5A452D10AAE}	30038	150.968024952805	1988	
N	A76C11E556B8}	.5A452D10AAE}	30038	144.743497154751	1958	
E ADD S UPPER	-864EEF4708F8}	.5A452D10AAE}	30038	44.5007285860884	1988	
N UPPER	32AD1BCB670A}	.5A452D10AAE}	30038	49.4246087845492	1958	
E ADD S	DECBEE33A5B3}	.5A452D10AAE}	30038	47.3807339851881	1988	
S UPPER	464BFB1D4A89}	.5A452D10AAE}	30038	50.1678359843168	1988	
E ADD N	'D6DD0A59E35}	.5A452D10AAE}	30038	123.933135561257	1988	
E ADD E UPPER	7419F206F67A}	.5A452D10AAE}	30038	66.9833513790601	1988	
S ADD E	5D40F82544F4}	.5A452D10AAE}	30038	103.86600116753	1988	
S ADD S	90C61F5D5B1E}	.5A452D10AAE}	30038	45.8942795856528	1988	
S ADD W	102B51A32948}	.5A452D10AAE}	30038	83.6130599738614	1988	
W	9DE3F14FC740}	.5A452D10AAE}	30038	153.848030351905	1988	
W UPPER	31A45CB22B7A}	.5A452D10AAE}	30038	43.6645979863498	1988	

Diroots SheetLink (https://diroots.com/revit-plugins/revit-to-excel-sheetlink/) is used to export data from Revit to an Excel spreadsheet. Diroots SheetLink is a Revit plugin that allows the transfer of model data back and forth between Revit and spreadsheets. The two excel files, one from BUILDER SMS and one from Revit, are merged into a third Excel spreadsheet using the Excel Power Query command. Power Query is used to combine different spreadsheets based on matching column data. The data in the resulting spreadsheet are then imported back into Revit using Diroots SheetLink.

A test of the data transfer method was performed to ensure the feasibility of the process. A simple building model with only the envelope was created. After the successful data transfer of the test building building-specific BIM templates are created using the master BIM template.

As already described, two groups of students were used to evaluate the effect of the use of the building-specific BIM templates on the time to create a BIM model from a registered point cloud model. The 2020-21 students did not use the building-specific BIM templates when creating their BIM models while the 2021-22 students did. Both groups created four BIM models (one per student) from existing buildings using the Scan to BIM method. Each student kept a daily log that contains information on the progress of their models (Appendix C). These progress logs were used to evaluate the progress of each group.

Comparison of Approaches

A comparison of the Loeh method (Loeh et al. 2021) and the method presented in this research is evaluated based on the following:

a) Ensuring data transfer compatibility: Time to create Building-specific template with the SEC_NAMES before model creation versus inputting SEC_ID after model creation.
b) Creating the BIM models: Completion time in weeks of the interior and exterior of the 3D BIM models are the two milestones achievements that were used to compare progress between 2020 Group and 2021 Group. The T-Test and ANOVA will be used to determine if it took significantly more time to reach the milestones using the Building-specific BIM template.
c) Transferring data: Time to transfer data to BIM model based on the time per 1000 square feet.

Chapter 4

Results

The results of the use of BIM templates and data transfer, and a comparison with the Loeh et al. (2021) method are presented in this chapter.

Table 2 shows a comparison of the Foster and Loeh method (Loeh et al. 2021). The Foster method was developed as part of this thesis. The Foster method starts by creating a building-specific BIM template from a Master BIM template. The building-specific BIM template includes the SEC_NAMEs for the building to be modeled. The model is created from the template. The Loeh method (Loeh et al. 2021) does not use a template to create the model. The SEC ID is added to each component after the model is created. Data transfer is accomplished using SEC_NAMEs in the Foster method, SEC_IDs in the Loeh method (Loeh et al. 2021).

In 2020-21 students created four Revit BIM models from existing buildings using the scan to BIM method. Following the Loeh et al. (2021) method they were not provided with a specific building-BIM template. They developed their own naming systems. The average area of the buildings was thirty thousand square feet. In 2021-22 students created four Revit BIM models from existing buildings also using the scan to BIM method. Following the Foster method, they were provided with a specific building-BIM template. This forced them to use the BUILDER SMS UNIFORMAT II naming convention. The average area of the buildings was forty thousand square feet.

Table 2

Table of Process

Foster Method	**Loeh Method (Loeh et al. 2021)**
Create Building-specfic BIM Template (SEC_NAMES)	Create Model
Create Model	Add SEC_ID values
Check Model SEC_NAMES	Check Model SEC_ID Values
Transfer Data	Transfer Data

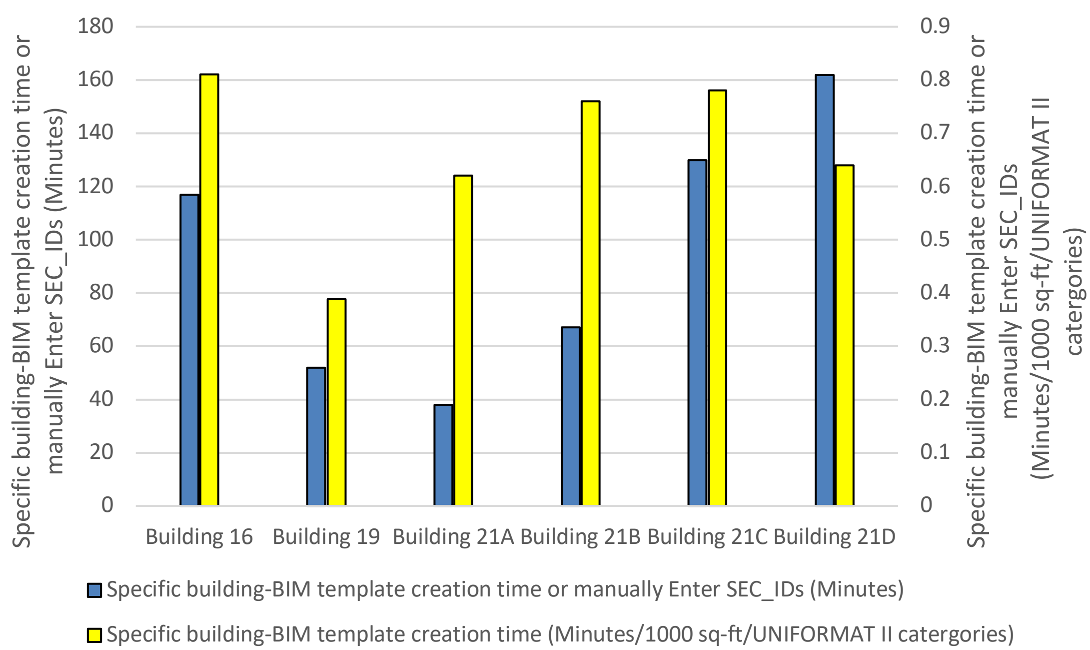
The process of creating the NJDMAVA master BIM template required 195 minutes. The master file contains the BUILDER SMS parameters found in NJDMAVA buildings. A Building-specific BIM template is created by manually inputting SEC_NAMEs from the BUILDER SMS database for a given building into to the corresponding Revit elements. This process is required for each building's Revit model because of the varying design of each building. The 2021-22 group used this approach for four buildings and kept track of the time required. Using the master template reduced the average building-specific BIM template creation time to 100 minutes. This time can differ depending on the complexity and size of the facility.

The total and normalized time to create building-specific Revit templates is shown in Figure 4. Time is divided by floor area and the number of UNIFORMAT II Categories. For the Loeh et al. 2021 method this is the time to manually enter the SEC_IDs into an already complete Revit model. Ensuring data transfer compatibility for the Loeh et al. 2021 method took just over 0.8 minutes per one thousand square feet per UNIFORMAT II Category. This was more than the Foster method buildings, which ranged from 0.4 to just under 0.8 minutes per one thousand square feet per UNIFORMAT II Category.

Two of the buildings, 21A and 21D, have significant open spaces. The Building 21A is a one-story without any office spaces. Building 21D has an indoor turf field. Building-specific BIM template creation time in minutes per one thousand square feet for Buildings B and C are higher than Buildings A and D. This is because Buildings A and D have more open space within their buildings. The average building-specific BIM template creation time is 3.5 minutes per one thousand square feet.

Figure 4

Time Needed to Ensure Data Compatibility



Student progress logs were compared for the two groups. The first milestone was the time to complete the BIM exterior of their building. The 2020-21 and 2021-22 groups completed this milestone in an average of 3.5 and 4.25 weeks respectively (330 minutes per week of work.). Figures 5 and 6 shows the number of weeks required for the 2020-21 and 2021-22 groups to complete the BIM exterior of each building.

Figure 5

BIM Building Exterior Milestone Completion for 2020-21 Group

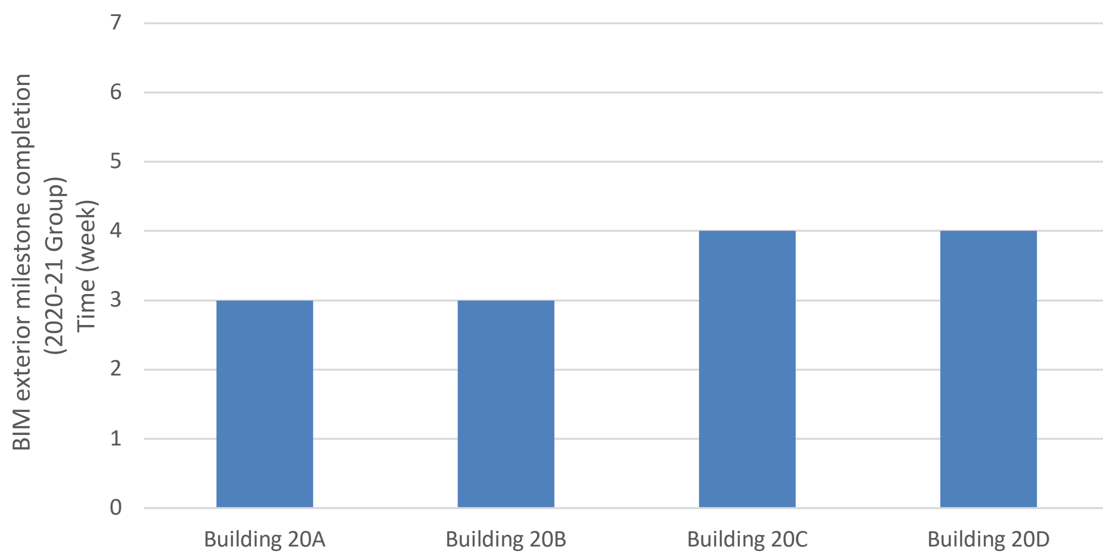
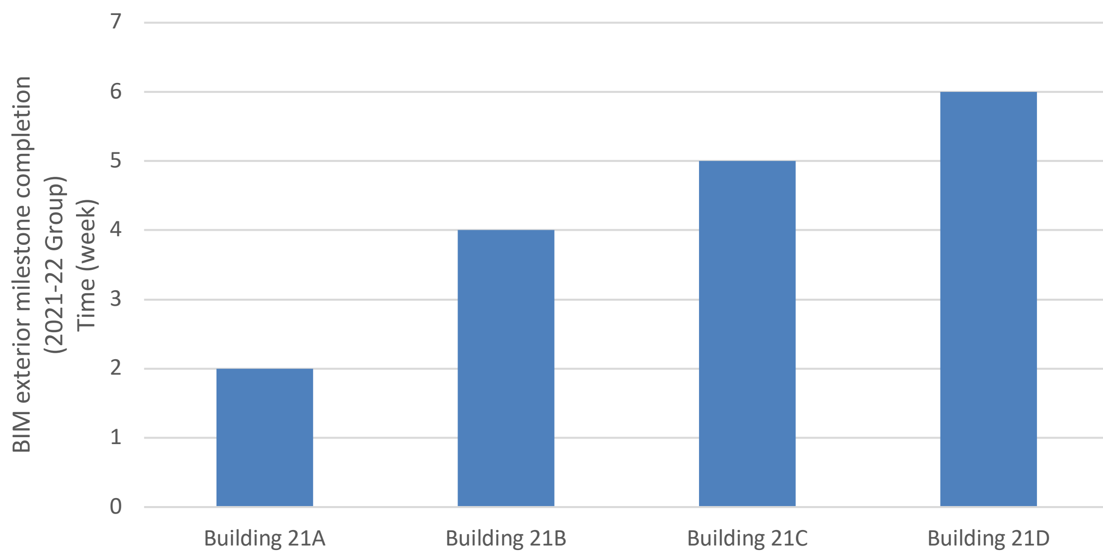


Figure 6

BIM Building Exterior Milestone Completion for 2021-22 Group



The second milestone compared between the two groups was the time to complete the BIM interior of their building. The 2020-21 and 2021-22 groups completed this milestone in an average of 4.75 and 4.75 weeks, respectively. Figures 7 and 8 shows the number of weeks required for the 2020-21 and 2021-22 groups to complete the BIM interior of their buildings after the exterior was completed.

Figure 7

BIM Building Interior Milestone Completion for 2020-21 Group

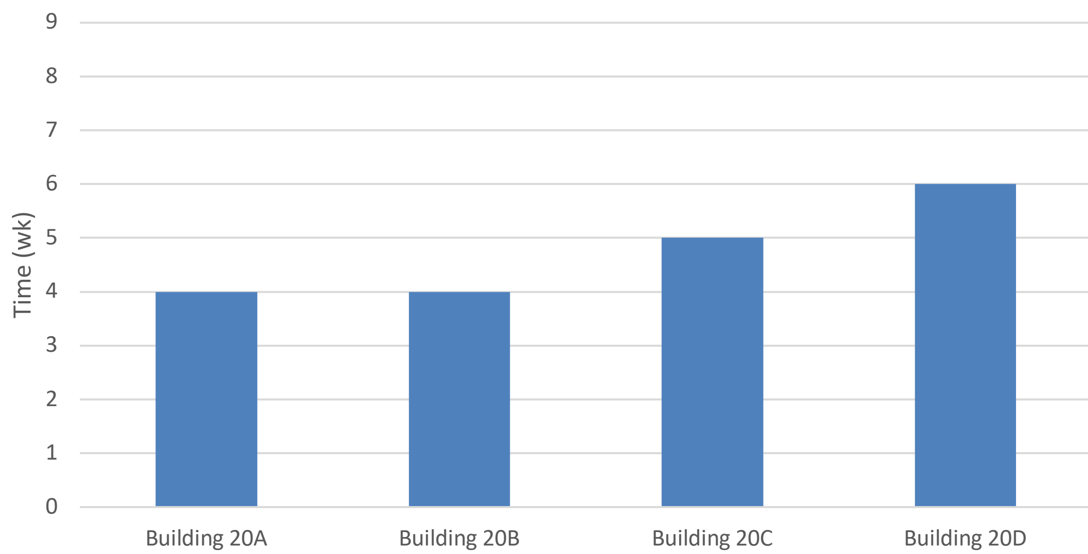
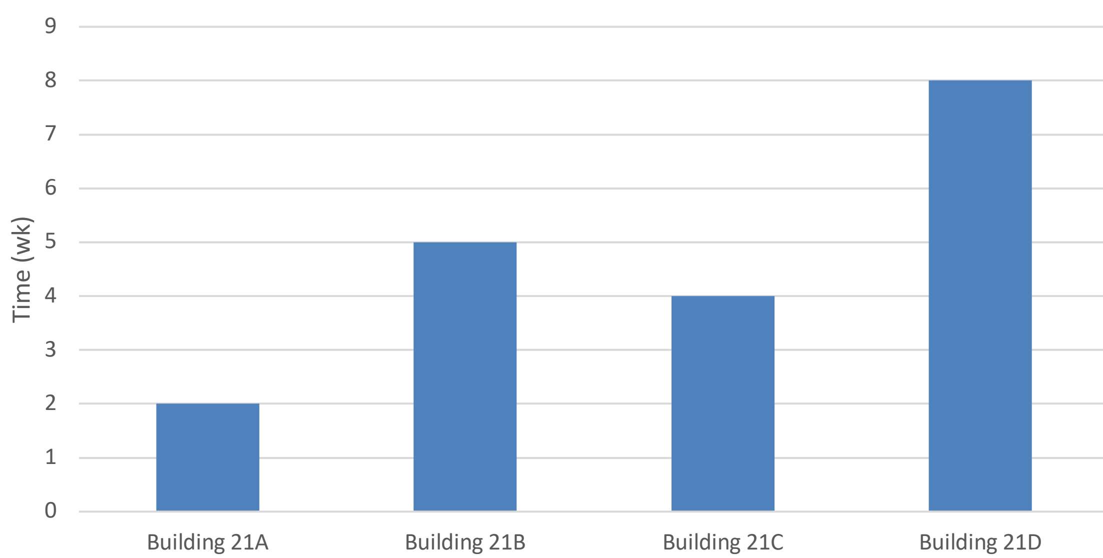


Figure 8

BIM Building Interior Milestone Completion for 2021-22 Group



Statistical comparisons of the completion of each milestone show no significant completion time difference between the two groups. The T-Test and ANOVA p-values (Appendix D) for the first milestone for the two groups were 0.46 and 0.44 respectively (Bulmer, 1979; Hogg & Tanis, 2002). The p-values for the second milestone were both 1. This was expected because the times to the second milestone were identical.

The 2021-22 group used Revit elements that were already saved within their model's specific template. This building-specific template contained the Uniformat II naming convention and SMS Builder parameters. 21B, 21C and 21D are Readiness Center that consist of a drill floor, offices, kitchen and cafeteria, storage rooms, bathrooms and mechanical room. The Readiness Centers varied in size from approximately 12,000 sq. ft. to 95,000 sq. ft. 21A is approximately 12,300 sq. ft. of general storage space. The 2020-21 group used the generic Revit elements from Revit's library. 20A, 20B, 20C and 20D Readiness Centers varied in square footage from approximately 18,000 sq. ft. to 35,000 sq. ft. Both groups were able to complete their models by the end of the two-semester project, working 6 to 10 hours a week. The results of the T-test and ANOVA (Bulmer, 1979; Hogg & Tanis, 2002) indicate that using the Building-specific BIM template did not take significantly more time.

The next step was the data transfer of the BUILDER SMS parameter groups into the Revit model. Microsoft Access was used to export the Component Section and Section Detail query from the BRED file to an excel file. The excel file is imported into the Revit model joined by the SEC_NAME parameter.

The UNIFORMAT II categories transferred for the 2021-22 Group:

- A10 Foundations

- B10 Superstructure
- B20 Exterior Enclosure
- B30 Roofing
- D30 HVAC

The average total completion time was 83 minutes. The average creation of the building-specific BIM template took 99 minutes. Exporting the Component_Section and Section_Details from the BRED database to an excel file took an average of 14 minutes. Exporting Revit element data to Excel for each of the categories required an average of 23 minutes. Combining the excel sheets from each database took 23 minutes. Importing the combined data into the Revit model took an average of 9 minutes. The data transfer task times are shown in Table 3.

Table 3

Data Transfer Task Time (minutes)

Task	Building			
	21A	21B	21C	21D
Creation of BIM-Specific Template	38	67	130	162
Exporting BRED Database	9	15	15	15
Exporting Revit Database	15	25	25	25
Merging Databases	15	25	25	25
Importing Database into Revit Model	6	10	10	10
Total	83	142	205	237

To compare the data transfer times between the Foster and Loeh et al (2021) methods, buildings with similar BUILDER SMS data needed to be evaluated. The 2021-22 Group models contained five of the nine BUILDER SMS categories used in the Loeh et al (2021) method. An additional building, Building 19, was selected for the comparison because it contained the same nine BUILDER SMS categories used in the Loeh et al (2021) method. The UNIFORMAT II categories are:

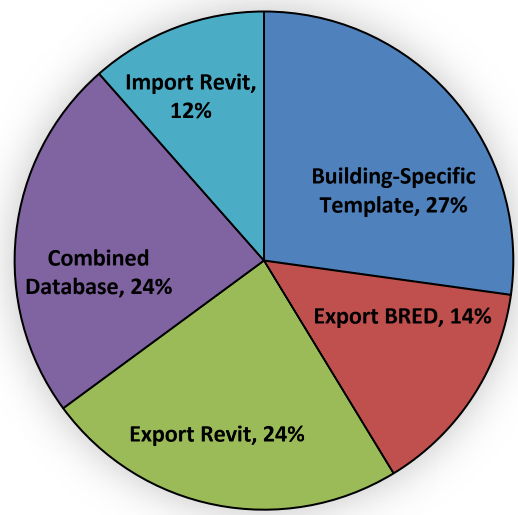
- B10 Superstructure
- B20 Exterior Enclosure
- C10 Interior Construction
- C20 Stairs
- C30 Interior Finishes
- D20 Plumbing
- D30 HVAC
- D40 Fire Protection
- D50 Electrical

The data transfer for Building 19 using the Foster method was completed in 189 minutes (13.5 minutes/1000 sq-ft). Creation of the building-specific BIM template took 52 minutes. Exporting the Componet_Section and Section_Details from the BRED database to an Excel file for each of the nine Level 2 UNIFORMAT II categories took 27 minutes.

Each category must be exported separately to avoid SEC_NAME conflicts. Exporting Revit element data to Excel for each of the categories required 45 minutes. Combining the excel sheets from each database took 45 minutes. Importing the combined data into the Revit model took 20 minutes. The percentage of time for the data transfer is shown in Figure 9.

Figure 9

Percentage of Time to Transfer Database



Loeh et al (2021) was able to complete the data transfer in 161 minutes (9.6 minutes/1000 sq. ft.). Loeh et al (2021) used the Builder SMS parameter "SEC_ID" for each component as the link between the BRED database and the Revit model elements. The SEC_ID from the BRED file was added as an additional parameter to each of the Revit elements (Loeh et al (2021). BUILDER SMS generates a SEC_ ID for each building element. This unique identifier is an alphanumeric value that allows for the transfer to be performed using a single file.

The Builder SMS parameter "SEC_NAME" was used for each component as the link between the BRED database and the Revit model elements. The SEC_NAME is a descriptive name that uses the UNIFORMAT II naming convention. The SEC_NAME is entered into BRED during the inventory and assessment of the building component. The SEC_NAME is derived from the cardinal direction for exterior components and room names for interior components (Engineer Research and Development Center 2017). Using the SEC_NAME method requires that each UNIFORMAT II Level 2 category is processed separately to avoid conflicts.

Using a building-specific BIM template to create the 3D BIM model has some advantages and disadvantages compared to the Loeh method (Loeh et al. 2021). The building-specific BIM template uses the same UNIFORMAT II naming convention as BUILDER SMS. By using the BUILDER SMS "SEC_NAME" instead of the BUILDER SMS "SEC_ID" it is easier to identify the location of elements in the model. This is useful when creating a complex building.

The initial data transfer using the SEC_NAME takes longer than using the SEC_ID. This is because each Level 2 UNIFORMAT II category has to be imported and exported individually when transferring data using the SEC_NAME. Data transfers using the SEC_ID can import all Level 2 UNIFORMAT II categories at one time. The initial time commitment of doing the data transfer using the building-specific template with BUILDER SMS parameter "SEC_NAME" naming convention will create a BIM model with the BUILDER SMS parameter "SEC_ID" added to each Revit element. Additional data transfers will use the more time efficient BUILDER "SEC_ID" parameter when transferring data.

The BUILDER SMS parameter "SEC_NAME" naming convention makes it easier to identify errors. The BUILDER SMS parameter "SEC_NAME" naming convention includes location information about each component. The BUILDER SMS parameter “SEC_ID is a unique alphanumeric value that is generated for each component. Using the BUILDER SMS naming convention in the Revit model makes it easier to identify component’s locations in the model.

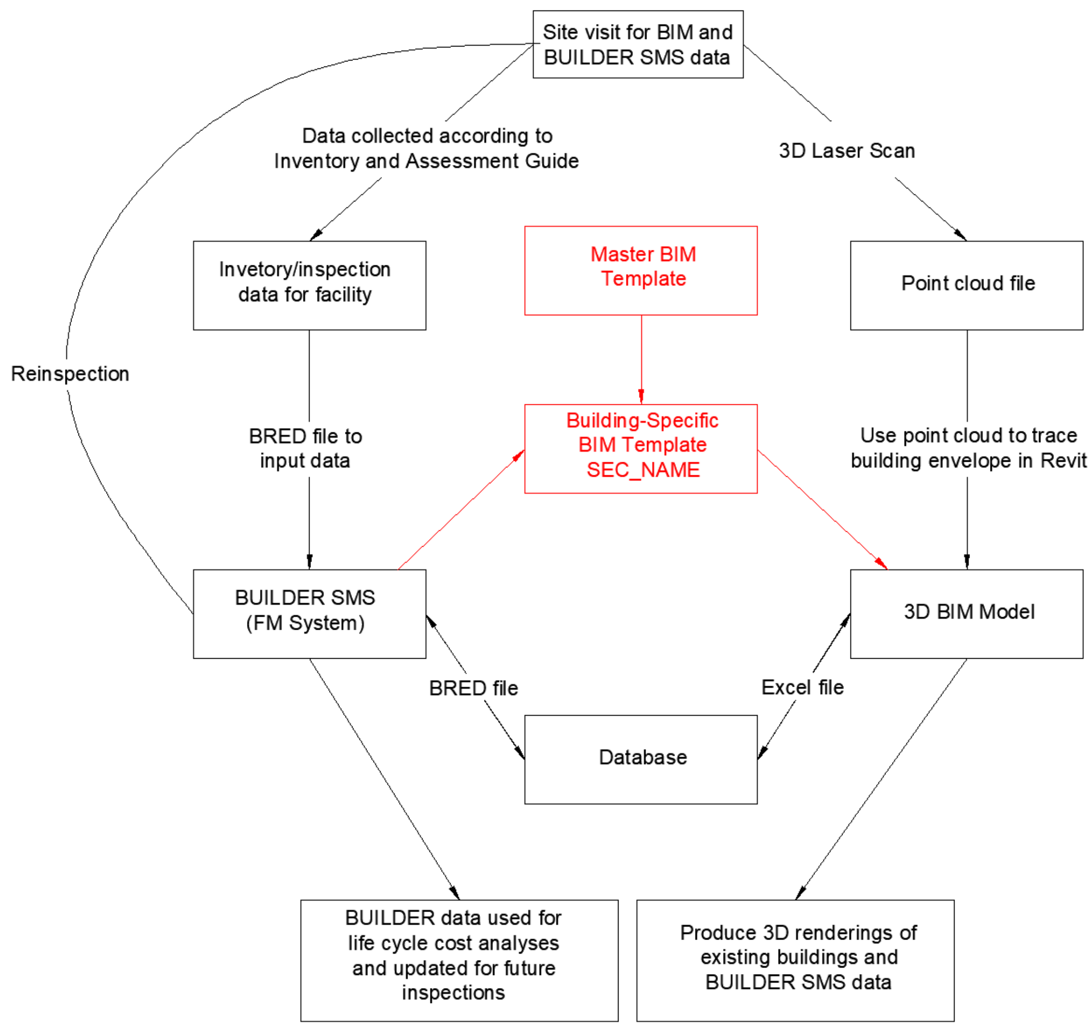
BIM models created using the building-specific template are developed with BUILDER SMS parameters. BIM models created using the Loeh method (Loeh et al. 2021) are developed without BUILDER SMS parameters, they are added after the model is created. BIM models using the Loeh method (Loeh et al. 2021) do not have the BUILDER SMS “SEC_NAME” for each component transferred to Revit elements. For complex buildings with several components, for example Building 21D, adding the BUILDER SMS parameters after the model is created can be time consuming. If the building is not complex, for example Building 21A, adding the BUILDER SMS parameters after the model is created will not take much time.

Using the Foster method is effective when creating several 3D BIM models for complex buildings. Using the building-specific BIM template to create the 3D BIM models allows for a BIM author to create 3D models that are ready to transfer data with BUILDER SMS. The Loeh method (Loeh et al. 2021) is effective when creating a 3D BIM model for a simple building.

The improved workflow for creating a 3D BIM model that integrates BUILDER SMS data is shown in Figure 10. Red elements are modified from Loeh method (Loeh et al. 2021). 3D laser scans are taken of the building. An inventory of all building components and condition assessment is performed. Inventory and inspection data are input into a BRED file. The BRED file is imported into BUILDER SMS. A Master BIM template is created if none exists. A building-specific BIM template is created using the BUILDER SMS parameter “SEC_NAME” naming convention from the BRED file. The point cloud is created from 3D laser scans. A 3D BIM model is created using the building-specific template. The 3D BIM model data and BUILDERSMS data are merged using an intermediate database. The merged database is imported into the 3D BIM model creating a 3D BIM model of the existing building that contains the BUILDER SMS data.

Figure 10

SFM BIM Workflow



Future data transfers consist of exporting updated BRED file data into the intermediate database and importing updated data into Revit model using the BUILDER "SEC_ID" parameter. This process took 15 minutes, exporting the Componet_Section and Section_Details from the BRED database to the intermediate database took 10 minutes. Importing the data into the Revit model took 5 minutes.

Chapter 5

Conclusion

An improved workflow for creating SFM-enhanced BIM models using building-specific templates for existing buildings was developed. The proposed workflow improves on the Loeh method (Loeh et al. 2021) for integrating Revit and BUILDER SMS databases.

Building-specific BIM model templates were created with SFM parameters. BIM operators developed BIM models from the building-specific template. SFM data were transferred to BIM models; thus, creating SFM-enhanced BIM models.

The proposed workflow improves on the Loeh et al. method by using building-specific BIM templates to develop the BIM model. The BIM template is used to increase the compatibly between the Revit elements and the associated BUILDER SMS components. The improved method creates a BIM model with elements that shared the same naming convention used by the SFM database. Using the same naming convention in BIM and AMS software makes it easy to identify components when working with complex buildings. It also makes possible data transfer based on naming conventions, rather than ID numbers.

The initial data transfer using the Foster method takes longer than the Loeh method (Loeh et al. 2021). That initial time commitment results in a BIM model that includes the BUILDER SMS parameter SEC_IDs and SEC_NAMEs added to each Revit element. The Loeh method (Loeh et al. 2021) only adds SEC_IDs. Additional data transfers using the Foster method will have comparable times to the Loeh method (Loeh et al. 2021), as they can use the SEC_ID.

Developing the Revit model with the BUILDER SMS naming convention in mind creates a compatible BIM model for transferring data. Evaluating the 2020 and 2021 groups' progress logs milestone completion times using the T-test and ANOVA indicated that using the building-specific BIM template did not take significantly more time than allowing model builders complete freedom regarding naming conventions.

The BUILDER SMS parameter "SEC_NAME" naming convention includes location information about each component. It used an internal logic that makes it easy to follow. The BUILDER SMS parameter "SEC_ID" is a unique alphanumeric value that is generated for each component. Inputting the SEC_ID into the BIM model to set up the data transfer has a higher chance of user input error over using the SEC_NAME.

The initial data transfer time for all five buildings averaged 2.35 minutes per 1000 squared feet. Subsequent data transfers averaged 0.43 min per 1000 square feet. The first data transfer required exporting and importing each BUILDER SMS category separately to avoid conflicts with the SEC_NAME. The categories are combined for subsequent transfers and the SEC_ID obtained from the initial transfer can be used.

Work in this study specifically investigates creating BIM models using building specific templates for existing buildings. However, the same principals can be applied to BIM models for new construction. New construction BIM models should be created using the same naming convention as the AMS. Using the same naming convention during the design phase of the BIM model will facilitate the data transfer between the AMS and the BIM model.

Future work can focus on making it easier to create the building-specific template. A plugin for Revit that can create a building-specific template from a BUILDER SMS BRED file would be advantageous.

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Appendix A

Standard Operating Procedures

Master BIM Template

1. Open Revit New Project

    Select Template File → Architectural Template
2. Go to Manage Tab

    Select Project Parameters → Add
    In the Parameter Data window enter:
        Name ("Name of Parameter")
        Type of Parameter = Text
        Group Parameter = Text
        Value can vary by group Instance
        Filter list checkbox = Architecture
        Check All Categories
    Close Window
3. Repeat step 2 for the following Parameters:
    SEC_NAME
    SEC_ID
    SEC_YEAR
    SEC_DATE PAINTED
    SEC_COMMENT
    SEC_REMAIN LIFE
    SEC_PAINT RSL
    SEC_CI
    SEC_CII
    SEC_REPLACE_COST
    SEC_PAINT_COST
    SEC_NEXT YEAR CI
    SD_SEC_ID
    ID_NUMBER
    EQUIPMENT_TYPE
    EQUIPMENT_MAKE
    CAPACITY
    DATE_MANUFACTURED
    DATE_INSTALLED
    CONTROL_TYPE_MAKE
    WARRANTY_DATE
    WARRANTY_COMPANY LOCATION
4. Save Revit file as Master BIM Model Template.

Building-specific BIM template

Open Files

1. Open BUILDER SMS BRED file in Access and export the following queries to Excel file:

    - Component Section
    - Section Details

2. Open exported Excel file. Identify the SEC_NAME column.

3. Open Master BIM Model Template in Revit

Populate Exterior Walls with SEC_NAME

1. Select Architect Tab → Walls

2. Select Exterior – Brick on CMU

3. Select Edit type → Duplicate
   Name = NJDMVA – Brick on CMU – "SEC_NAME"
   Click Ok.

4. Repeat steps 1 – 3 for all walls.

Populate Exterior Door/Window with SEC_NAME

1. Select Architect Tab → Door or Window

2. Select Door or Window Type

3. Select Edit type → Duplicate
   Name = NJDMVA – DOOR OR WINDOW – "SEC_NAME"
   Click Ok.

4. Repeat steps 1 – 3 for all Door and Windows.

Populate Foundation with SEC_NAME

1. Select Architect Tab → Floor

2. Select Floor: Structural

3. Select Edit type → Duplicate
   Name = NJDMVA – FOUNDATION – "SEC_NAME"
   Click Ok.

Transferring Parameter Data

1. Open BUILDER SMS BRED file in Access and export the following queries to Excel file:

    - Component Section

    - Section Details

2. Open exported Excel file. Identify the SEC_NAME column.

3. Open Revit Project

4. Go to DiRoots Tab

Select SheetLink

In the Select Categories Window → Select Walls

In the Available Parameters Window → Select the Following Parameters:

Family Name
SEC_NAME
SEC_ID
SEC_YEAR
SEC_DATE PAINTED
SEC_COMMENT
SEC_REMAIN LIFE
SEC_PAINT RSL
SEC_CI
SEC_CII
SEC_REPLACE_COST
SEC_PAINT_COST
SEC_NEXT YEAR CI
SD_SEC_ID
ID_NUMBER
EQUIPMENT_TYPE
EQUIPMENT_MAKE
CAPACITY
DATE_MANUFACTURED
DATE_INSTALLED
CONTROL_TYPE_MAKE
WARRANTY_DATE
WARRANTY_COMPANY LOCATION

Click Export → Export to Excel → Save Excel File

5. Create New Excel workbook

   Open "Power Query"

   Select Data tab → Get Data → From File→From Excel Workbook
   Select "Component_Section" Excel File Exported from BUILDERSMS.
   In Navigator Window select Load to→ Only Create Connection
   Click OK

   Select Data tab → Get Data → From File→From Excel Workbook
   Select "Walls" Excel File Exported from Revit.
   In Navigator Window select Load to→ Only Create Connection
   Click OK

6. Merge BUILDERSMS Excel Workbook with Revit Excel Workbook

   Select Data tab → Get Data →Combine Queries→Merge
   In Merge Window
   Select Revit Excel file as Destination (Top)
   Select BUILDERSMS file as Source (Bottom)

   Select SEC_NAME as matching column.
   Join Kind→ Left Outer (all from first, matching from second)

   Click OK

   Merge 1 – Power Query Editor Window

   Component_Section column → Uncheck (Use original column name as prefix)

   Click OK

   Click Close & Load

   Save Merged Excel File.

7. Open Revit Project

8. Go to DiRoots Tab

   Select SheetLink→Import→Import from Excel

Select Merged Excel File.

9. Go to Preview/Edit Tab

   Click Update Model

10. Repeat Steps 1 – 9 for each BUILDERSMS UNIFORMAT II category

Appendix B

ASTM UNIFORMAT II

Table B1

ASTM UNIFORMAT II Classification of Building Elements (E1557-97)

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A. SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations A1020 Special Foundations A1030 Special Foundations
	A20 Basement	A2010 Basement Excavation A2010 Basement Walls
B. SHELL	B10 Superstructure	B1010 Floor Construction B1020 Roof Construction
	B20 Exterior Closure	B2010 Exterior Walls B2020 Exterior Windows B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings B3020 Roof Openings
C. INTERIORS	C10 Interior Construction	C1010 Partitions C1020 Interior Doors C1030 Specialties
	C20 Staircases	C2010 Stair Construction C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes C3020 Floor Finishes C3030 Ceiling Finishes
D. SERVICES	D10 Conveying Systems	D1010 Elevators D1020 Escalators D1030 Material Handling
	D20 Plumbing	D2010 Plumbing Fixtures D2020 Domestic Water D2030 Sanitary waste D2040 Rain Water Drainage D2050 Special Plumbing
	D30 HVAC	D3010 Energy Supply D3020 Heat Generating systems D3030 Cool Generating systems D3040 Distribution systems D3050 Terminal & Package Units D3060 Control & Instrumentation

Table B1 (Continued)

ASTM UNIFORMAT II Classification of Building Elements (E1557-97)

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
	D40 Fire Protection	D4010 Fire Protection Sprinkler D4020 Stand-Pipe & Hose D4030 Fire Protection Specialties
D. SERVICES	D50 Electrical	D5010 Electrical Service D5020 Lighting & Branch Wiring D5030 Communication Systems D5040 Special Electrical Systems

Appendix C

Progress Logs

(Green shading shows start and end of envelop creation; yellow shading id for interior)

<u>Building 20B</u>

- 9/10/20 - Took scans of Rowan Hall and began manually registering XXXXX scans in Recap Pro.
- 9/15/20 - Continued working on the XXXXX Recap project. Had some trouble identifying the XXXXX scans in the Google File Stream (I think this is when Rachel and I took the XXXXX scans and XXXXX scans on the same SD card).
- 9/17/20 - Continued working on the XXXXX Recap project. About 75% complete on merging all of the scans.
- 9/22/20 - Finished merging scans; began indexing the XXXXX Recap project. Created Google Doc for 25% Progress report that's due next week.
- 9/22/20 - XXXXX Recap point cloud was successfully indexed. Began removing the noise from the point cloud and began writing the 25% progress report.
- 9/29/20 - Continued to work on 25% report and was having difficulty working with the XXXXX Recap file. It is running really slow and taking forever to load; i've tried to restart my computer many times but no luck.
- 10/1/20 - Finished writing 25% report. Still having difficulties with Recap (I believe it's because we are working off of Google File Stream). I'm mostly done with cleaning up the noise in the XXXXX Recap file and tried to import the point cloud into Revit to see how it looked.
- 10/6/20 - Still no luck with the XXXXX Recap file and tried to import it into Revit with no luck. I am now restarting on the XXXXX Recap file stitching the scans together but will be saving it onto my desktop instead of File Stream. Hopefully I will complete the point cloud by Thursday. Did some research about the problems we've been having working off of File Stream and it's apparent that it's a common thing for people to have trouble working off of File Stream using Autodesk products and these programs aren't compatible.
- 10/8/20 - 75% done stitching together XXXXX scans on my desktop and not thru File Stream. Still no luck using the original Recap file that was copied from File Stream to my desktop; would run slow when imported into Revit so I just decided to re-do the point cloud. Should be completed early next week.
- 10/13/20 - Began working on the midterm presentation; 90% done merging scans (ran into a few issues with the scans so going back over and making sure the scans are merged properly). Will index point cloud on Thursday and hopefully have the point cloud completed and cleaned up by the end of this week.
- 10/15/20 - Had difficulties merging the exterior scans to the interior scans so I decided to create 2 different point clouds, one for the interior scans and one for the exterior scans. I completed the interior scans point cloud and will begin on the exterior scans point cloud next week. Completed some slides in the midterm presentation google slides.

- 10/20/20 - Successfully completed the interior and exterior scan point clouds; was able to import them into Revit and began updating the elevations of this readiness center (floor, roof, and drill hall roof); completed my slides in the midterm presentation; copied the completed point clouds from my desktop on google file stream.
- 10/22/20 - Completed slides in midterm presentation; began updating 50% report; began creating building envelope in Revit.
- 10/27/20 - Completed midterm presentation and practiced with the team; finished updating my sections in the 50% report; walls and floors completed for the building envelope.
- 11/3/20 - Completed my section in the 50% report, submitted midterm presentation and peer evaluation for midterm presentation. Continued to work on the XXXXX Readiness Center building envelope; started adding doors and windows to the building envelope.
- 11/10/20 - Continued to work on the XXXXX Readiness Center building envelope in Revit; have been making adjustments to the walls, floors, and ceilings to match the point cloud. Inserted some windows and doors too. Saved copy of current Revit file to Google File Stream.
- 11/12/20 - Completed building envelope of the XXXXX Readiness Center with all exterior windows and some exterior doors. Added some grass to make it look better. All floors, walls, ceilings, and roofs should be accurate compared to exterior and interior point clouds and the floor plan that was provided for this building. Saved onto File Stream and will continue to add more exterior and interior doors. Completed my part of the 75% report.
- 11/17/20 - Finished adding interior doors and wall openings into the XXXXX Revit file. Building envelope about 95% complete, just have to add some more doors and make sure I have all the windows completed. Will start working on the 100% report this week.
- 11/19/20 - Completed XXXXX building envelope and labeled every room to create a floor plan. Took screenshots in Autodesk Viewer and added to 100% report.
- 11/24/20 - Continued working on 100% report.
- 12/1/20 - Continued working on 100% report and began working on final presentation.
- 3/2/21 - Forgot to log progress from the beginning of Spring 2021 Semester but have finished building envelope and have been working on the implementation of plumbing systems to my building envelope. I created a separate file just for Plumbing 'XXXXX_Plumbing' in Google Drive and have added toilets and urinals for men's and women's bathrooms. Added a domestic water supply pipe route and a drainage pipe route for the water closets.
- 3/9/21 - Revised 33% report and began on midterm presentation draft. Continued to implement plumbing system into building envelope.
- 3/16/21 - Continue working on midterm presentation. Finished plumbing system in Revit. Can be found in File Stream under 'XXXXX_Plumbing'. Began to work on electrical system in Revit in a separate file 'XXXXX_Electric'.
- 3/18/21 - Midterm presentation.

- 3/23/21 - Continued working on Electrical by placing lighting fixtures.
- 3/25/21 - Continued working on Electrical by placing lighting fixtures, light switches, and electrical panels. Began creating switch and energy systems. Discovered how to connect systems to panels (make sure the voltages of the fixtures and switches match the voltage of the panel).
- 3/30/21 - Began working on 66% report and finished updating my sections of the report. Added another component to the plumbing system because I realized that I had forgot to add a sink in the utility closet, completing the plumbing systems for XXXXX. Completed electrical systems too but couldn't figure out how to display the electrical circuits without hovering over the circuit.
- 4/1/21 - Completed electrical circuits and systems for envelope. Had to finish drill hall ceiling. Continued working on 66% report.
- 4/6/21 - Started new Revit file for the HVAC systems; having some difficulty knowing which components to use for baseboard radiators,etc. Added 'MEP Systems' section to 66% report and finished my section in the report.
- 4/8/21 - Finished working on 66% report. Continued to work on HVAC Revit. Didn't know how to include a ceiling plan in Revit so I downloaded a MEP system template and saved it as 'XXXXX_HVAC2' and restarted in this file. I kept the other HVAC Revit file b/c it had location of baseboard radiators that I would like to copy over into the template.
- 4/13/21 - Continued working on HVAC revit.
- 4/15/21 - Finished placing HVAC components in Revit and decided not to add any duct layouts because it's arbitrary in the grand scheme of things. Started adding final things to final report and presentation. Will begin fire protection systems next week hopefully.
- 4/20/21 - worked on final report and final presentation.
- 4/22/21 - finished sections in final report and final presentation. Started watching tutorials to add fire protection systems to building envelope. Not sure if this will be implemented during this semester.

Building 21B

9/7 - Met with group and got a basic understanding of what BIM is, logged into autodesk account and set up autorecap, then chose what building I would be stitching together which was XXXXX, then we took the scanner out and did a few sample scans

9/9 - received presentation in room 240, got a demo on how to stitch files together in recap, began stitching files together

9/14 - continued stitching files together in recap for the duration of the class

9/16 - received sustainable presentation 2 in room 240, continued and finished stitching scans together, began indexing scans for class on 9/21

9/21 - scans finished indexing, gave progress update to professor YYYYY, looked at samples for 33% memo and presentation explored point cloud, cleaned up the point cloud a bit, watched the first revit tutorial and explored revit and some of its commands

9/23 - received sustainable presentation, copied recap file into the bim drive, watched the rest of the revit tutorials and began messing around with some of the commands in revit, had some computer issues at the beginning of class

9/27 - absent

9/30 - absent

10/5 - gave a short summary of the work we have been doing to professor YYYYY, worked on the 33% report and presentation

10/7 - continued working on the 33% report and presentation, received sustainable presentation

10/12 - had computer issues, couldn't get point cloud into revit cleanly, realized i needed to clean up the point cloud more

10/14 - cleaned up point cloud, finalized and sent in presentation and report

10/19 - gave sample presentation to professor YYYYY, photographers came in and took pictures, began working on the revit file

10/21 - worked on revit, discussed with john earlier in the week about leaving early, left around 2:00

10/25 - mid semester presentations

10/28 - finished floor plan and walls in revit

11/2 - began learning how to place doors, left early due to a migraine

11/4 - finished placing doors, learned how to place windows for next class

11/9 - got some extra practice with windows before starting to place them in revit, had to change some of the window models in revit to fit my buildings needs, edited some wall heights and door placements

11/16 - struggled to size windows correctly to the ones on the point cloud, got a few windows placed

11/18 - made more progress with windows, finalized 66% report

11/23 - continued working on the exterior model in revit

1/25 - began placing walls for interior model, placed some doors in interior model

1/27 - finished interior walls and continued placing doors into interior model, ran into a problem with some of the door types to figure out next class

2/1 - continued interior model, touched up some walls and continued adding doors, had to leave early due to an interview

2/3 - finished placing doors and created some openings in certain walls that needed to be created

2/8 - continued interior model and read one HVAC SOP

2/15 - figured out how to create model of chain link fence for storage area, still have to learn how to add doors and poles if necessary

2/17 - finished implementation of fence model and created doors for fence cage, plan for next week is to have the full cage done with posts if necessary

2/22 - continued working on fence model, created mid semester presentation slideshow

2/24 - looked into the HVAC systems and placed toilets and sinks for bathrooms

3/1 - worked on revit model, worked on fence, worked on mid semester presentation

3/3 - worked on mid semester presentation, worked on 33% report

3/22 - began working on identification and addition of HVAC systems, went over resume and accomplishment memo comments with professor YYYYY
3/29 - added some hvac systems and explored what systems need to be added for the building model, began looking at insight in revit

3/31 - basic insight model, generated fully optimized insight model for building

4/14 - worked with insight modeling, basic floorplan work

4/21 - final presentation, hvac systems, changed mistake on roof

Appendix D

T-Test and ANOVA p-values

Table D1

Milestone 1 T-test Data

2020	2021	0.455993	t-test (Significant Difference if < 0.10)
3	4		
4	2		
4	5		
3	6		
3.5	4.25		

Table D2

Milestone 1 T-test Summary

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	4	14	3.5	0.333333
Column 2	4	17	4.25	2.916667

Table D3

Milestone 1 ANOVA Data

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.125	1	1.125	0.692308	0.437237	5.987378
Within Groups	9.75	6	1.625			
Total	10.875	7				

Table D4

Milestone 2 T-test Data

2020	2021	1	t-test (Significant Difference if < 0.10)
4	5		
6	2		
5	4		
4	8		
4.75	4.75		

Table D5

Milestone 2 T-test Summary

Groups	Count	Sum	Average	Variance
Column 1	4	19	4.75	0.916667
Column 2	4	19	4.75	6.25

Table D6

Milestone 2 ANOVA Data

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	1	0	0	1	5.987378
Within Groups	21.5	6	3.583333			
Total	21.5	7				