ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

A 6-STEP SYSTEMATIC PROCESS FOR MODEL-BASED FACILITY DATA DELIVERY

SUBMITTED: August 2016
REVISED: April 2017
PUBLISHED: July 2017 at http://www.itcon.org/2017/6
EDITOR: Kumar B.

Walid Thabet, Professor,
Virtual Facilities Research Lab, Department of Building Construction, Virginia Tech, USA;
thabet@vt.edu

Jason D. Lucas, Assistant Professor,
Department of Construction Science and Management, Clemson University, USA;
jlucas2@clemson.edu

SUMMARY: *The use of BIM for FM by owners is growing, yet there are challenges that exist because of the need for customized data standards to fit each owner's need. This research examines the development of a model-based approach for capturing and handing over facility data. Previously completed research consists of a spread-sheet based documentation method for capturing identified facility-related information to support an owner's operation and maintenance of educational facilities. An approach was developed and piloted to validate a process that utilized milestone information submissions for documenting appropriate information throughout the design and construction of a facility using a spreadsheet based approach with direct input into the Computerized Maintenance Management System (CMMS). Using a pilot project approach, this paper builds on the spreadsheet based approach by identifying how the facility information could be captured throughout the project using a model based approach. A six-step systematic process is defined for BIM-FM integration to capture facility data and integrate the information into a CMMS. Various challenges and considerations to capture and deliver facility data are discussed. The paper also discusses the need for further validation of the proposed process and summarises ongoing study to test the proposed approaches using a second pilot project.*

KEYWORDS: *facility management, BIM, data collection, information handover*

REFERENCE: *Walid Thabet, Jason D. Lucas (2017). A 6-step systematic process for model-based facility data delivery. Journal of Information Technology in Construction (ITcon), Vol. 22, pg. 104-131, http://www.itcon.org/2017/6*

1. INTRODUCTION

Facility management activities require relevant, accurate, structured and accessible facility data created during the facility's design and construction phases and maintained throughout the operations and maintenance phase. Incorrect data or lack of timely access to information have a significant impact on the FM group's ability to effectively maintain equipment and achieve intended service life. This can result in cost overruns, inefficient building operations, and untimely resolution of client request (Becerik-Gerber et. al, 2012, Gallaher et. al, 2004, Hardin and Mccool, 2015). A large portion of facility data needed to support FM is created throughout the design and construction processes. Collection and verification of this data should commence early starting with end of design and concurrent with construction to ensure quality of the data.

In recent years, the use of Building Information Modeling (BIM) has demonstrated its return on investment in the design and construction phases. The most recent McGraw Hill SmartMarket Report (Berstein, 2012) indicated that the Architecture/Engineering/Construction (A/E/C) industry wide adoption of BIM surged from 28% in 2007 to 71%, with contractors (74%) ahead of architects (70%) and engineers (67%). Recently, facility owners expressed great interest in the use of BIM for post-construction facility management and members of the design and construction community in collaboration with owners have begun to tackle BIM's potential post-occupancy uses.

By integrating BIM into FM, two major benefits can be achieved:

1. Operations and maintenance staff will be able to use 3D models to graphically visualize all major aspects of the facility for planning, asset management, scheduling and analysis.
2. Ability that BIM provides to bring data directly into a facilities management system. BIM models can serve as intelligent repository of facility data generated across the facility life cycle. This data can be queried, searched then extracted and linked to FM systems (e.g. CMMS/CAFM/IWMS) saving owners time and money spent looking for the data at the end of construction.

Realizing the benefits of BIM by owners has been slow as a result of many challenges. A recent survey by IMAGINiT Technologies (2015) reported on the various challenges in providing BIM data to owners. The lack of understanding of BIM by owners (also identified by Gleason, 2013), differing file formats, and lack of collaboration with project stakeholders are the top three main reasons that challenges the A/E/C industry to handover digital data at project hand-off. The survey also reported on the challenges in using BIM data in facility management software systems. Cost issues, the inconsistency in models delivered by the contractor and integration of model/data into the FM system are the top three reasons hindering a BIM-FM integration.

McArthur (2015) lists four key challenges to the use of BIM in facility management as: (1) a need to identify critical information necessary for operational performance, (2) management of the information transfer between the model and FM tools, (3) management of model creation, and (4) how to handle issues where building documentation is complete. But owners cannot mandate and gather BIM project data without the understanding of how it can be used in their workflow (Dougherty, 2015).

Additional challenges have been identified. Dias and Ergan (2016) identify the need for customized facility information for each operator as a challenge for using BIM for FM tasks. Since each operator has their own needed set of data to complete FM tasks, it is difficult to make a standard dataset that would be usable. Kiviniemi and Codinhoto (2014) confirmed the need for clear guidelines for implementing BIM into FM, standard BIM protocols, and key deliverables for the purpose of managing the facility. Lui and Zettersten (2016) found that a clear analysis and understanding of FM work processes is needed if BIM-based automated data collection was to be utilized. Parsanezhad and Dimyadi (2014) also identified that a lack of guidelines and efficient technologies for capturing BIM models of existing facilities and a range of terminologies and taxonomies are challenges for successfully adopting BIM into FM&O activities.

Efforts of utilizing BIM for FM include a development of a Level of Development (LOD) specification specifically for HVAC (Heating Ventilation and Air Conditioning) maintenance through the customization of as-built models that support specific FM tasks that include corrective and preventative maintenance (Dias and Ergan, 2016) and a data integration strategy for incorporating GIS (Geographic Information System) and BIM-based information into a FM System (Kang and Hong, 2015). Lee et. al (2016) developed a collaborative BIM-based system for FM for data importing and processing. Lui and Zettersten (2016) investigated the ability to automate FM data collection from a BIM for as-built data as more a cost effective method then manually retrieving the data and determined that even though the process shows promise, FM work processes would need to be analysed and information needs would need to be determined before BIM-based data collection is fully feasible. Without clearly defined information standard, clarity of information handed over to the owner by project participants is greatly impacted (Ghosh and Chasy, 2013).

This research is defining BIM for FM processes for a large educational institution who currently are lacking the defined, structured information at facility turnover. The research includes a data needs analysis, the creation of a data collection strategy based on project milestones for owner approval of received information, and the creation of a BIM-based data collection and FM integration process. The final result of the research will be an owner specific BIM-FM Guidelines to collect structured information for new construction on campus.

This paper discusses how BIM is integrated into facility management to leverage its post-construction benefits as an intelligent repository of facility data. A six-step process strategy for digital facility data handover is presented describing how facility data can be defined, captured and stored into the BIM and further exported and automatically linked to the FM system. Future research steps beyond this paper will include the development of a hand-over mechanism that will link the BIM to the FM System.

2. PROPOSED STEPS FOR IMPLEMENTING BIM-FM INTEGRATION

As depicted in Fig. 1, this research proposes a 6-step process to a BIM-FM integration for digital handover of facility data.

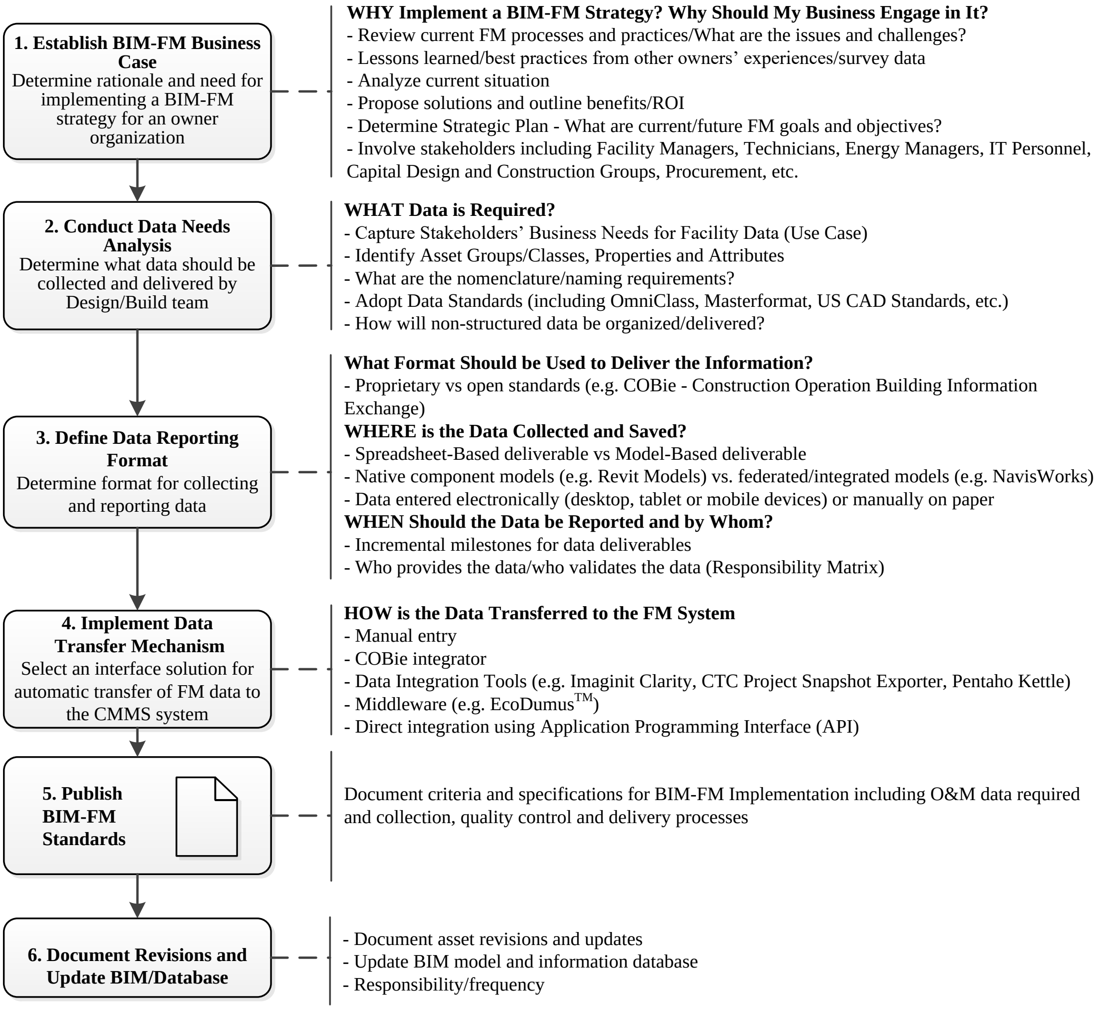

FIG. 1: Six-Step Process for Implementing a BIM-FM Integration for Data Handover

2.1 Establish BIM-FM Business Case

The objective of this step is to convince the decision maker (e.g. owner, facility manager, etc.) of adopting a life cycle building information strategy for the organization and to approve the implementation of the strategy. This involves several tasks. First, Determine the problem. Existing issues and challenges with current asset data capture practices should be identified. This may include inaccurate or incomplete captured data, inadequate format, the current process is costly and time consuming, etc. Lessons learned from other owners or facility managers who recognized gaps and implemented changes should be evaluated to find any similarities. This task also involves reviewing existing literature providing any survey data and case studies regarding inefficiencies and cost losses to help make the case to the facility owner.

Second, analyse the current situation. This includes accessing existing organizational conditions for collection and entry of facility data to determine areas of focus for future implementation. When and how is asset data collected? When and how is asset data entered in the FM system? What are the critical issues that need to be fixed? What are the priorities? What are the future goals from utilizing FM data? What business objectives are needed and can leverage a BIM to FM integration? e.g. reduced operating and maintenance costs, improved service delivery, streamlined processes, better support for future building modifications, etc. Identify example cases and/or data from other owners and what approaches they have used to improve the process.

Third, identify alternative solutions for digital handover of structured, relevant and accurate life-cycle facility data and determine a strategic plan to carry over each solution. Benefits and ROI for each alternative should also be outlined. It is suggested to use a multi-tiered incremental implementation plan for making the changes. Determine options for data reporting format and transfer mechanisms. Determine who will support the implementation process? Is it internal or external? If internal, then what is the required technology and physical workspaces, what are the personnel roles and responsibilities and what education and training is needed? If external, then who should be contracted (GC, consultant, …) and what are their roles and responsibilities?

2.2 Conduct Data Needs Analysis

This step is concerned with identifying the data sets critical to the facility owner for operation and maintenance of his facility and that should be included in the BIM-FM deliverables by answering WHAT data is required? WHAT data should be included in the BIM-FM deliverables? This includes structured and unstructured information (Fallon and Palmer, 2006) including:

- Asset groups/classes that are critical to the building systems and/or overall building (e.g. air handling units, fans, boilers, generators, etc.)
- Structured information including property data of each asset (e.g. model number, serial number, location served, location code, warranty start /finish dates, voltage, total air flow, cfm, etc.) needed for various functions such as maintenance, trouble shooting and replacement operations; space planning; energy analysis and so on.
- Unstructured information including catalogues, service manuals, specifications, submittals, testing and commissioning reports, etc.

To identify these data sets, it is necessary to clearly articulate goals of the facility organization including analysing what is required to keep the asset functioning and prevent disruption of services provided by the asset and determine information critical for the maintenance, trouble shooting and replacement operations. Starting with the end in mind insures that facility management goals and objectives drive information required. The “we want everything” syndrome should be avoided as it makes the process costly and inefficient.

Hosted meetings utilizing a use-case approach can be used to analyse and identify the required information that should be collected and capture business needs based on user end goals. Follow up alignment meetings with all stakeholders should be scheduled to confirm scope of work (Teicholz, 2013).

This step should also consider reviewing current industry standards for naming conventions, abbreviations and group classifications. This includes OmniClass (OmniClass, 2016.), Master Format (CSI, 2016), and US National CAD standards (NIBS, 2016).

2.3 Define Data Reporting Format

Information from the BIM process and stored in a BIM database could support FM practices in many ways but that information needs to be integrated into the FM systems. Currently the information for those FM systems are scattered (Bercerik-Gerber et. al, 2012). This requires a defined data formatting system be put in place. Questions to answer include: WHAT format should be used to deliver the information? WHERE is the data collected and saved? WHEN should the data be reported and WHO is responsible?

Data reporting format refers to the organizational structure used to store structured and unstructured asset information. Data organizational structure can be proprietary as specified by the owner or leverage open standards such as the COBIE standard (Construction Operation Building Information Exchange) (East, 2014).

This step also involves determine where the data is captured and saved. Structured information could be saved in various formats including spreadsheet-based or model-based formats. Model-based format encompasses attaching asset data to the graphical elements in the model and has the advantage of providing the user the ability to visually view the data directly linked to each asset in the model. Most of the facility management data is not geometric in nature. Data requirements for successful BIM use to support FM needs to be determined by the owner at the design stage and finalized before procurement and construction (Bercerik-Gerber et.al, 2012. Unstructured information can be linked to graphical elements in BIM models using hyperlinks. Native component models (e.g. Revit trade models) or integrated models (Navisworks federated model) are used to store the data. Data may be captured electronically (using a desktop environment or on-site via tablets/mobile devices), or manually on paper.

This step is also concerned with determining when the data should be collected and when the owner will assume responsibility for the data. The data is formed gradually and needs to be updated gradually through the stages of construction. Since the model is dynamic and constantly changing through the project, it is important to identify and link the data, level of detail, model purpose, and responsibilities of different parties used for each stage (Bercerik-Gerber et. al, 2012). Data collection should commence early with pre-defined incremental milestones for data capture and delivery across project design/construction and prior to final project completion. This would allow to keep the process manageable and provide the owner an opportunity to interact with the data and perform a data quality control and validation. Waiting until the end of construction and commissioning to deliver the data usually results in a large "data dump" (East and Brodt, 2007 and Gleason, 2013) causing inefficiencies and reducing a value added collaboration exercise into a mundane data entry.

Additionally, this step defines who is responsible for collecting the information from the design and construction teams and who will validate the information for completeness and quality from the owner team. Teicholz (2013) suggested the use of a "Gatekeeper" that insures that confidence in the data quality and configuration remains and validates the completeness of the deliverables. Swim lane diagrams (Gleason, 2013) can be used to outline the data collection and reporting process, and identify project participants involved and required milestones.

During this step, responsible project participants rely on project plans, submittals, installation and commissioning information as the primary sources to extract required facility data. The submission and approval process of submittals should be well tracked to insure timely delivery and reporting of facility data and minimize any delays.

2.4 Implement Data Transfer Mechanism

This step HOW is the data transferred to the FM system? What is the data handover mechanism that will be used to deliver FM information?

Various data integration strategies and software tools are used to link captured information saved in the different formats to the FM platform (CMMS, CAFM, IWMS, BAS, etc.). Alternative approaches to integration include:

- Manual entry from a variety of data sources
- COBie integrator utilizing the COBie data standard
- Data integration tools that link data from spreadsheet-based or model-based formats to the FM system. Some utilize an SQL data server Examples include Pentaho Kettle, Imaginit Clarity and CTC Project Snapshot Exporter.
- Proprietary middleware, such as EcoDomus FM, Onuma Systems and FM:Interact, provides two-way real-time integration between the data in a model-based deliverable and the FM system. Captured data

can be uploaded and modified in the software application and then directly linked to the FM platform. A visual interface also allows to upload the 3D model for ease of data visualization.

- Direct integration of the model data using Application Programming Interfaces (APIs). This provides an effective integration of both systems (Teicholz, 2013) and also allows for two-way real-time synchronization of the data.

2.5 Publish BIM-FM Standards

All requirements should be documented into a set of standards that defines criteria and specifications for BIM-FM implementation including O&M data required and collection, quality control and delivery processes.

2.6 Document Revisions and Update Database

Following construction completion and commissioning, things immediately begin to change and it is critical that the owner has the means and the resources to document these changes to maintain the BIM model and update the data on a regular basis.

3. THE CASE STUDY MODEL

In Thabet and Lucas (2017), a pilot study utilizing a classroom building on the campus of a large academic institution was conducted to identify assets that were mission critical to the University. Beyond identifying the asset groups, required specific properties and attributes associated with each asset group were also determined. These properties and attributes are utilized for managing the assets and the facility during post-construction maintenance activities. The pilot study that has been completed identified when within the project lifecycle the information was available for collection and how to import the information into the asset management system, AiM by AssetWorks. This pilot project was conducted using a spreadsheet-based form through the creation of an asset spreadsheet to document the necessary attributes and properties. To limit the work in the pilot study, five critical asset groups: air handling unit (AHU), boiler (BLR), emergency transfer switches (EMER-ATS), emergency generators (EMER-GEN), and fans (FAN) were selected to be studied. Specific attributes and properties were identified for each of the assets to include the necessary data to include in AiM for managing the asset after construction. Properties (common to all asset groups) included 27 parameters broken into five categories. Attributes (specific to each asset group) varied in number for each asset group. A spreadsheet was then developed to capture the asset information. The information was collected from various project documents during the construction phase of the building. Once the attributes and properties of these assets were documented in the spreadsheet, the spreadsheet was manipulated into a user-defined format that would work to directly import the information to AiM. The direct import of information then utilized a data integration tool, Pentaho*TM*, to draw the link between the spreadsheet columns and rows, and the placement of data in corresponding asset fields within AiM (Fig. 2).

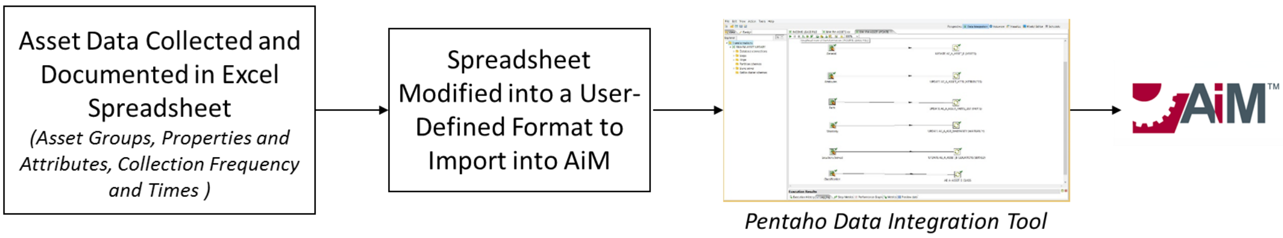

FIG. 2: Pilot Study Spreadsheet-based Deliverable Data Flow Process

The focus of this paper is to replace the spreadsheet-based process with a model-based approach for capturing, storing and transferring the information to AiM. In order to represent the project appropriately and test the defined properties and attributes of the designated assets, a model was created replicating the classroom building on campus that was used in the initial pilot study. The model is focused on the same five asset groups that were used for the spreadsheet-based study.

Using Autodesk Revit 2016, four component models were developed and linked; Architectural model, Mechanical model, Plumbing model and Electrical model. Excess detail was left out for the purpose of focusing on the five main asset groups being studied. The architectural model was developed first and included generic walls representing the shell, simple floors, and a simple roof. This model was then used as a reference model for developing the other three models that held the five asset groups that were being examined during the case study (Fig. 3). This process represented how models would be created by separate disciplines and then later combined for many purposes including construction planning and coordination activities. The goal was to test how these separate component models supplied by consultants/subcontractors could be used to supply the appropriate data to the owner at the end of the construction project.

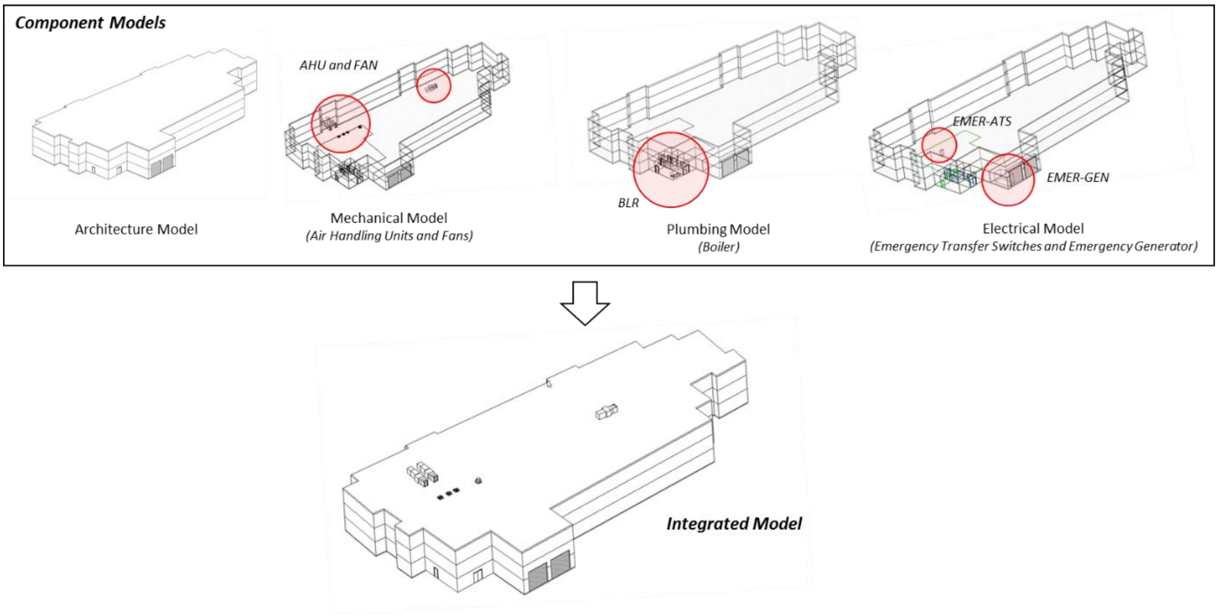

FIG. 3: Model Development Process

Since the properties and attributes were already identified from the prior study, the model was being created to ensure that these data sets could be represented and stored in the model. This was most important when identifying child-parent relationships of specific assets. For example, FAN, an asset group that is tracked independently by the facility owner, is also a child asset in some instances to the AHU asset group. This required the identification of a Level of Development (LOD) to allow for both asset groups to be properly identified. The LOD for the AHU became an issue because a lower level of detail typically seen in a model leaves an AHU as a large geometric box. The details of what components make up the AHU are only provided in shop drawings and not included graphically in the model.

For the purpose of the study, FAN, a separate component being tracked are commonly part of an AHU, so a higher LOD of at least 350 was determined to be necessary to have separate components make up an assembly. This allows for defining the properties and attributes of the AHU assembly as well as assigning specific and separate properties and attributes to the component FAN that are in the assembly. Within the Revit model, the separate components that made up the AHU were modelled and then an assembly was created out of the components to represent the entire AHU unit. This parent-child relationship is unique for the FAN and AHU, where even if a fan is a part of the AHU, it has its specific parameters data that are needed to support facility operations and maintenance.

Fig. 4 shows the graphic model of the different components that are grouped to form the AHU. There were a total of three AHUs in the mechanical model, AHU-1A and AHU-1B both contained a return and supply fan units (SF-1A, SF-1B, RF-1A and RF-1B), while AHU-2 which provided air to laboratory spaces and required 100% new air to be used only contained a supply fan (SF-2) only as no air was recovered in this AHU.

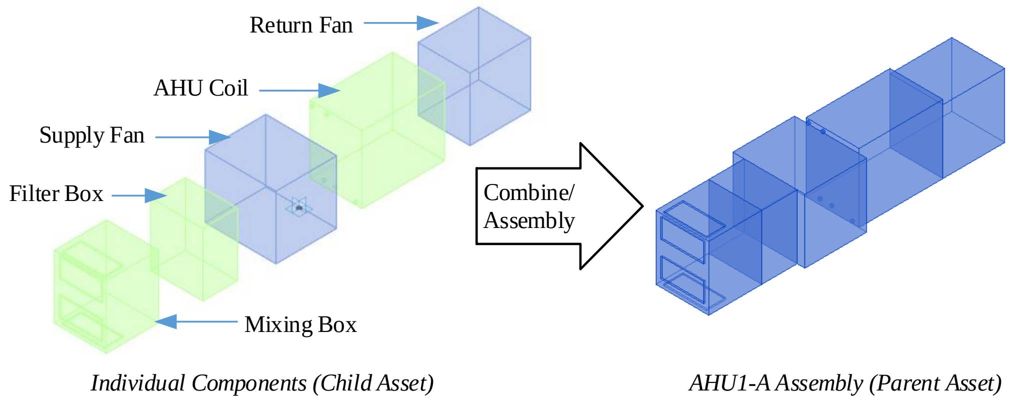

FIG. 4: Child to Parent Relationship of Components and Assemblies

4. DEFINE DATA REPORTING FORMAT

The model-based solution involves utilizing the facility BIM model to store the required asset properties and attributes identified during the pilot study (Thabet and Lucas, 2016). Fig. 5 summarizes the process workflow for the proposed data reporting format. The process involves six main steps. A detailed description of each step follows.

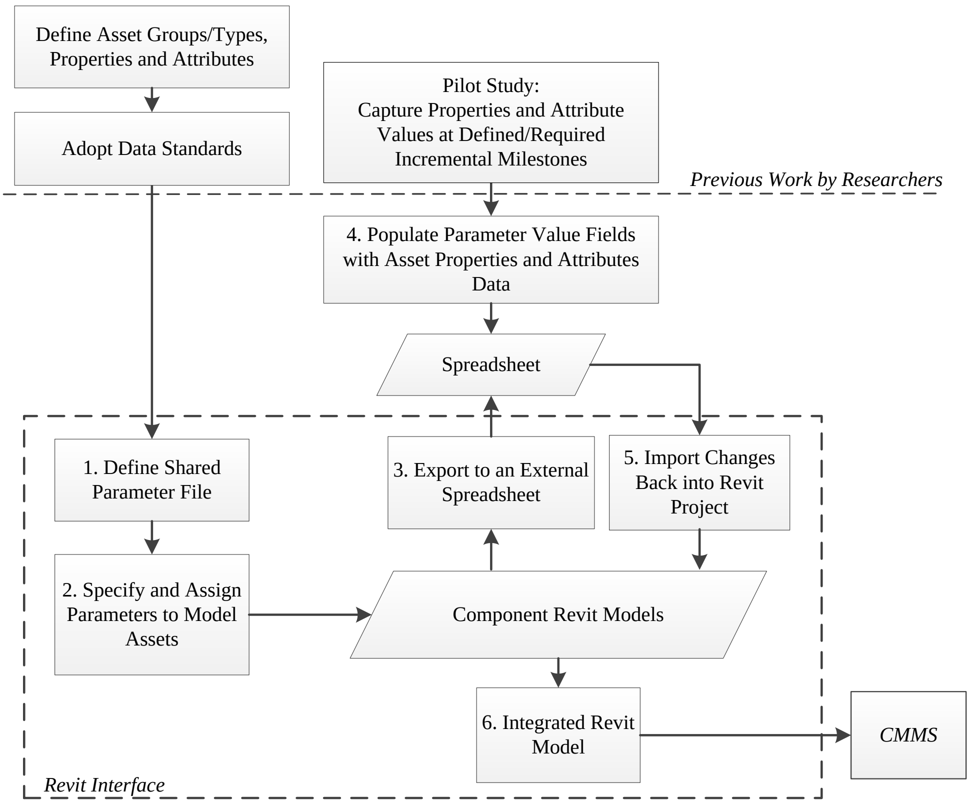

FIG. 5: Proposed Process Workflow for Data Reporting Format

Step-1: Define 'Shared Parameter' File

A Shared Parameter file is created to specify owner-required asset properties and attributes. Revit Shared Parameters can be assigned to Families/Categories based on user-defined criteria, and can be shared across multiple projects. This research proposes that a shared parameter file would be prepared by the owner to define his requirements and specifications for the shared parameters (properties and attributes) to the design and construction teams. The .txt file will be distributed to all project disciplines/trades to use during model development. Using an owner-defined shared parameter file allows to manage asset data content, reduce duplication of work and insure parameters' naming consistency across all native Revit trade models.

From the data collected during the pilot study, two asset groups are selected as a proof of concept for the purpose of this study; Air Handling Unit (AHU) and Fan (FAN). Two air handling units (AHU-1A and AHU-2) and three supply and return fans (SF-1A, RF-1A and SF-2) are used as example assets. Appendix 1 defines the needed properties and attributes for the selected assets. Properties are common among all asset groups. Attributes are specific to each asset group. The tables also specify the criteria used to assign these parameters to assets in Revit.

A Shared Parameter Manager plugin as part of the BIM Manager Suite (CTC, 2016) is utilized to create and manage the shared parameter file 'Project Shared Parameter'. The plugin allows for defining and re-organizing shared parameters via drag and drop, both within a single shared parameter file or between files. The shared parameters are organized under six main groups based on owner's specified categories for asset properties (five groups) and attributes (one group):

1. ASSET PROPERTIES_ GENERAL
2. ASSET PROPERTIES_ PARTS LIST
3. ASSET PROPERTIES_ WARRANTY
4. ASSET PROPERTIES_ LOCATION SERVED
5. ASSET PROPERTIES_ CLASSIFICATION STANDARD
6. ASSET ATTRIBUTES

Step-2: Specify and Assign Parameters to Model Assets

The Shared Parameter Manager plugin is again utilized to load the defined shared parameters into the case study project and assign the parameters to the selected five equipment.

Shared parameters (properties and attributes) are allocated to model elements belonging to a specific Revit family or category using filters. To assign the Properties parameters to all five pieces of equipment (two air handling units and three fans), the "Mechanical: Assemblies" and "Mechanical: Mechanical Equipment" filters are selected. To assign parameters for AHU Attributes to the two air handling units, only the "Mechanical: Assemblies" filter is used. To assign parameters for FAN Attributes to the three fans, parameters are assigned in the fan family window.

Using criteria specified in Appendix 1, user-defined reusable selection sets are defined to select and organize the various parameters, select the type of parameter (e.g. Text), if parameter is assigned as 'Type' or 'Instance', and the group where the parameters are visually organized (Revit provides various hard-coded groups to select from. This will affect where the parameter will appear in the Parameter Properties palate within the project environment). Parameters within each selection set is assigned to the appropriate Revit Categories or Families to allocate these parameters to the appropriate project equipment.

Fig. 6 illustrates an example of using the Shared Parameter Manager plugin to create a user-defined 'AHU and FAN Properties' selection set, assign the parameters of the selection set to the appropriate Revit categories, and loading the parameters to the project. Fig. 7 illustrates how the allocated shared parameters appear in the Properties Palate window in Revit under the user-selected discipline 'General'.

It should be noted that most of the parameters that were used were custom to the owner's needs so they were created shared and project parameters. However, there was also a need to include the OmniClass classification to the owner. Revit has OmniClass as a default parameter for most of the elements in the model, so instead of recreating this parameter, the native Revit parameter was used. Two issues came into play with using this native Revit parameter: (1) the OmniClass taxonomy shipped with Revit 2016 and its library of elements provides data from an older version of the standard and (2) OmniClass is not an inherent property to an assembly (the air handling units). In order to update the OmniClass taxonomy to the 2012 standards, the new version of the *OmniClassTaxonomy.txt* file was downloaded from the Autodesk's Knowledge Center (Autodesk, 2015) and used to update the elements' library. The challenge is that the new taxonomy does not automatically sync with the Revit library. This requires manually changing the number by identifying within the hierarchy what classification the element falls under. The second issue was solved by creating two parameters similar to the Revit native parameters (OmniClass Type and OmniClass Number) and applying it to the assembly to store the corresponding data.

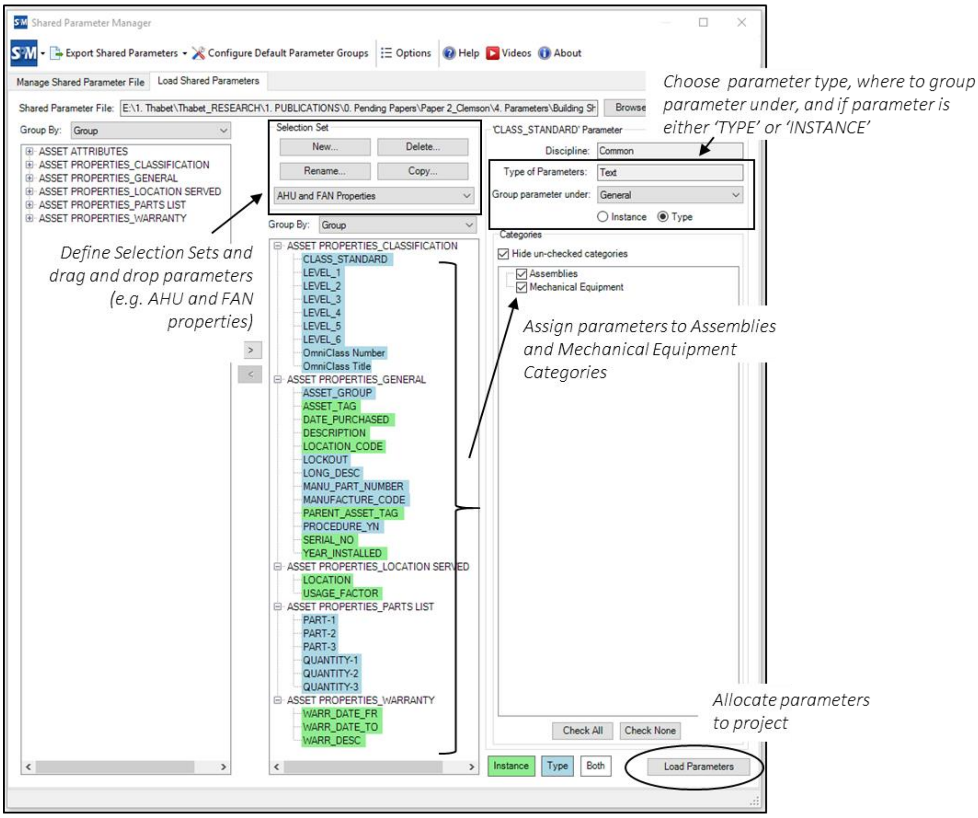

FIG. 6: Allocating Shared Parameters to Project

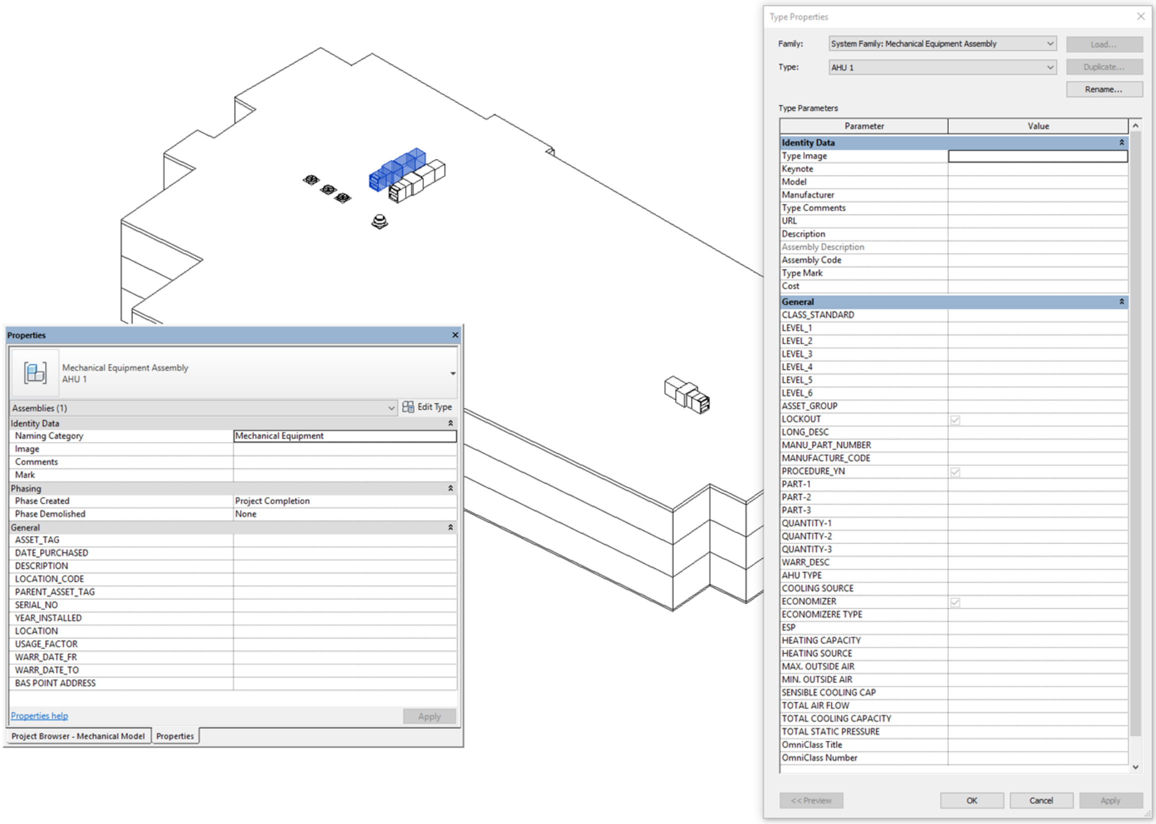

FIG. 7: Allocated Shared Parameters as they appear in the Instance and Type Parameter Palates

Step-3, 4 and 5: The purpose of these steps is to populate asset parameter value fields with properties and attribute data collected from the pilot study. Appendix 2 list the properties and attribute values collected from the case study for the selected equipment used in this case study example.

Populating parameters one equipment at a time directly in the Revit interface is time consuming. Various plugins are available to exchange Revit data with an external spreadsheet to allow for mass data input and modifications and speeds up the process. The research utilized the Spreadsheet Link plugin from BIM Manager Suit (CTC, 2016) to enter the information using a spreadsheet format. Using the Spreadsheet Link plugin, parameters data from Revit elements is exported to a spreadsheet where the parameter values are input and then imported and applied back in to the Revit model.

As depicted in Fig. 8, parameters for equipment category 'Assemblies' (comprising AHU-1A and AHU-2) and category 'Mechanical Equipment' (comprising SF-1A, SF-1B, RF-1A and RF-1B) are exported to an external spreadsheet. Data from Appendix 2 is entered in the spreadsheet and then imported into Revit and applied back in to the model. The result of these steps is a component Revit model that is rich with asset properties and attribute values.

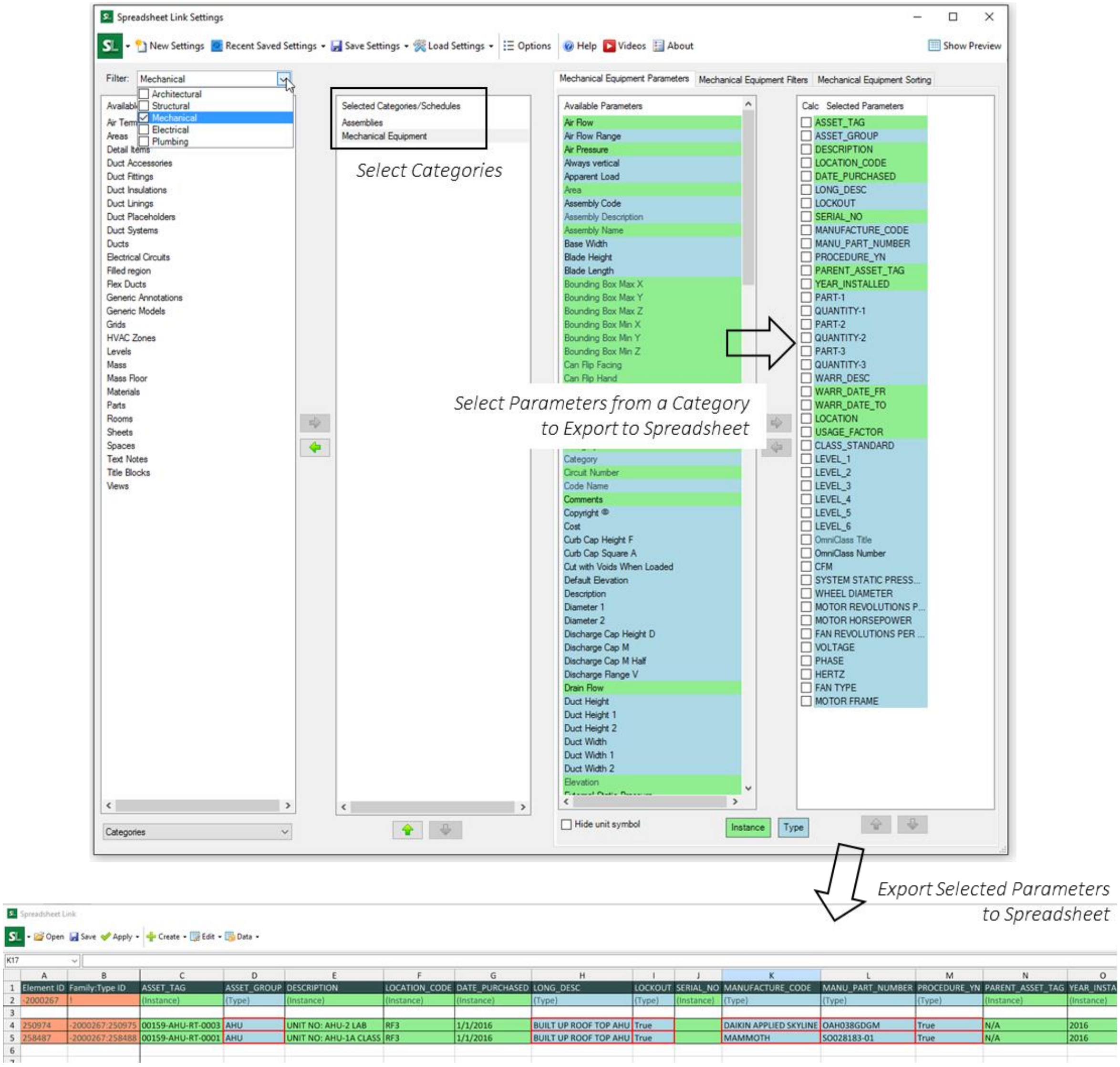

FIG. 8: Using the Spreadsheet Link Plugin to Export Parameters to a Spreadsheet Format for Mass Editing and Import Back into Revit

Step 6: Combine Component Models into an Integrated Model

Once all component models are populated with properties and attribute information, the models are combined, or linked, to allow for consolidating the data into a single integrated model to transfer the data to the CMMS.

With all the component models updated with the correct properties and attributes, the base architectural model was used as a way to collect and compile the data. When the files are linked, you can identify the parameters from the elements within the model that you are working in and those of the linked files. Using the linked model, the next step is to transfer the data to a CMMS.

5. IMPLEMENT DATA TRANSFER MECHANISM

Manual data entry to upload asset data into the CMMS is time consuming and open for errors and since the time will be taken to document all the necessary information throughout the project lifecycle within the BIM, it sets the groundwork for automated data transfer. In this research, a more automated approach is desirable over a manual entry of data into the system.

Teicholz (2013) identified four common approaches for data transfer from the construction phase to facility management systems. In this research, several data transfer methods were identified that range from semi-automated approaches to fully automated. Methods included one-directional and bi-directional integration of data (Fig. 14). In bi-directional integration, two-way synchronization of data between the BIM and the CMMS is achieved. Several of these methods utilize the Revit integrated model as the basis for the data transfer mechanism. One approach considers the integrated model via a Navisworks platform.

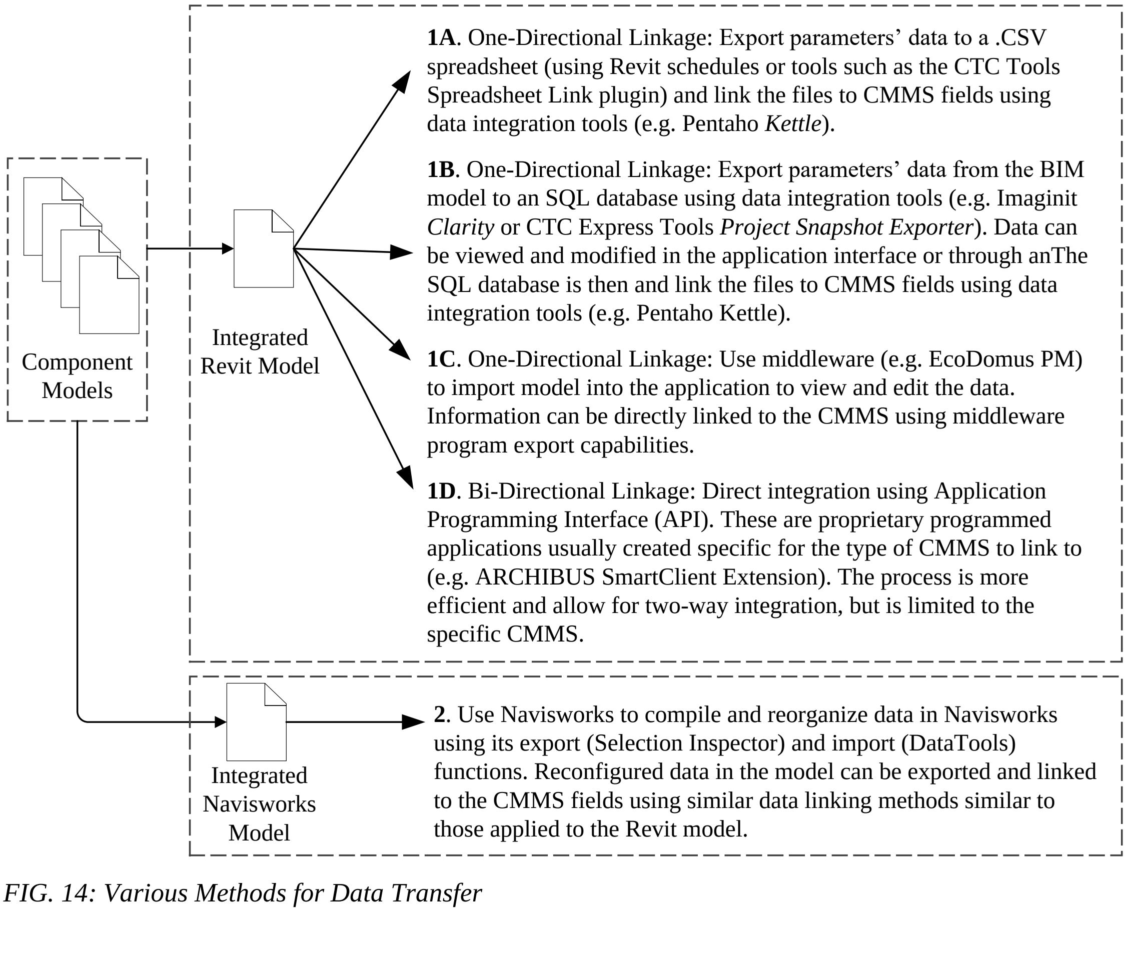

FIG. 14: Various Methods for Data Transfer

5.1 Data Integration Tools with the Revit Model

Data integration tools have been explored in Thabet and Lucas (2016) where a spreadsheet-based approach was used on a pilot project as the data reporting format. The pilot project utilized Pentaho Kettle™ to link a manually-populated excel data spreadsheet to the FM system AiM. Pentaho allowed for mapping data cells within the spreadsheet with corresponding asset fields in AiM, however, the spreadsheet still required specific formatting to translate the data. Additional system required fields needed to be added to the spreadsheet for correct linking to the CMMS.

A similar approach can be utilized here with a model-based approach. Equipment parameter data from the integrated model is exported as a .CSV file (Fig. 15). With this process, the approved integrated Revit model with all the integrated asset data would be formatted into a schedule and exported or parameters would be exported directly using an export plugin (e.g. CTC Tools Spreadsheet Link plugin). Using Pentaho Kettle, data cells in the Revit .CSV file would then be mapped to corresponding asset fields in AiM (or any other CMMS system). The data would then be imported into AiM directly after required formatting and additional system fields are added.

With this method, consideration of how the schedules are formatted and compiled within Revit would need to be taken into consideration, otherwise the spreadsheets may require more manual manipulation. If separate component models contain different pieces of information, the formatting of the spreadsheets will also be an issue.

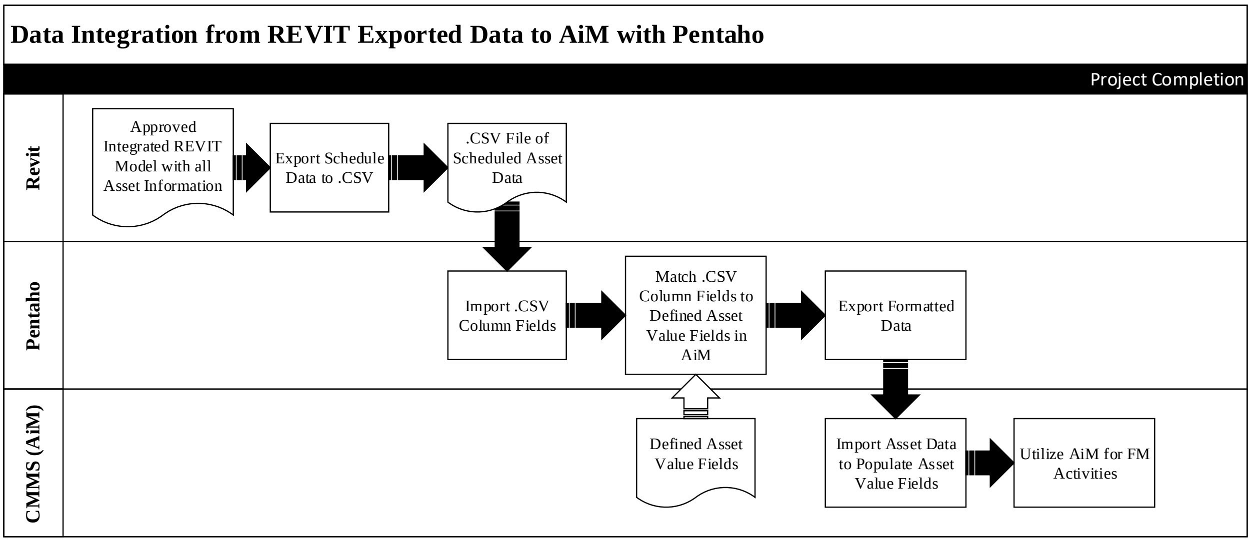

FIG. 15: Data Integration from Revit Using Schedules

5.2 Middleware with the Revit Model

Another automated approach to integrating data from the BIM into AiM is with a third party software. This option allows for a one-way integration of data between the model and FM system. Data integration between the middleware and the FM system could be two-way integration depending on the capabilities of the application. Model and data are captured by the software and then exported to the FM system after review and modifications in the middleware's user interface (Fig. 16).

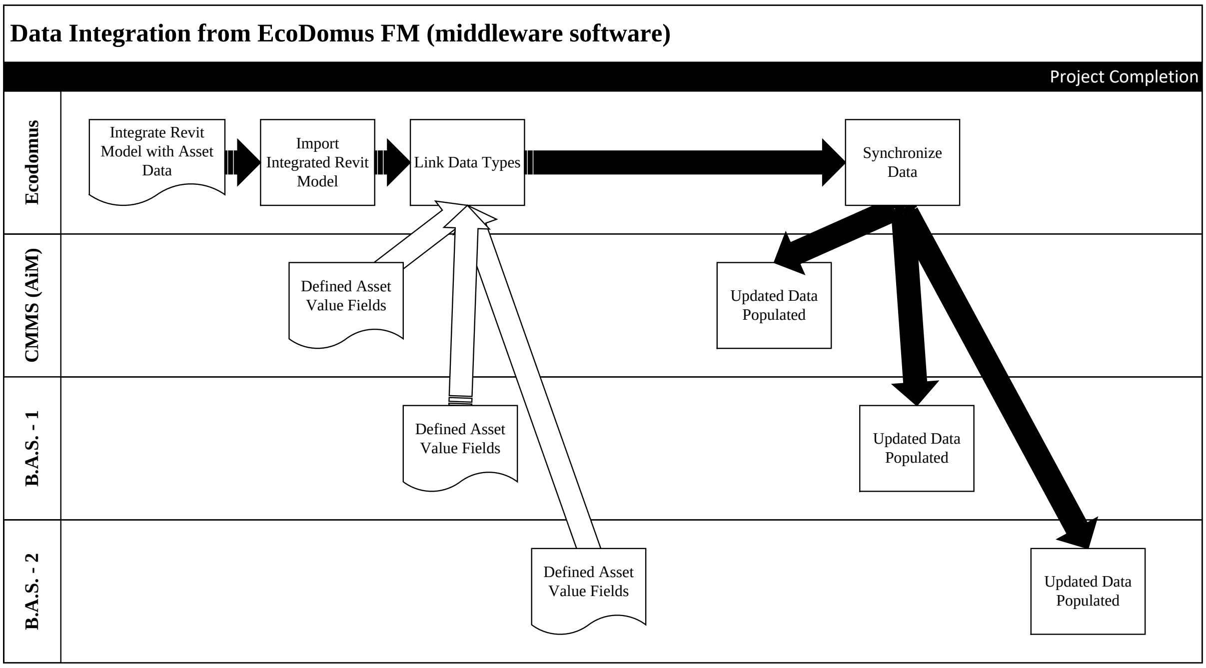

FIG. 16: Data Integration through Middleware Software (EcoDomus FM)

An example of this application is EcoDomus FM. EcoDomus FM is a software application that provides real-time integration of BIM with Building Automation Systems (BAS) and other Computer Maintenance Management Systems (CMMS) such as AssetWorks AiM. One benefit of this system, is if FM utilized multiple different systems, making changes to data within EcoDomus FM will automatically sync the data across the systems. For instance, if AssetWorks AiM is used to track maintenance, but the owner also utilizes a fire protection system by Honeywell and an HVAC monitoring system by Johnson Controls, making one change in EcoDomus FM will update the data in all relevant systems that are connected to it. EcoDomus FM and other software systems allow for a centralized place to manage the FM data and keep it updated. They do not provide the function of the BAS and FM systems; however, EcoDomus FM offers a method to link with BIM data without the need to change all the FM systems may be using to manage and operate their facilities. The benefit of middleware software is that it is a way to integrate the BIM data into existing workflows without the need to transfer large amounts of existing data to a new system. There is the added cost for an additional piece of software that needs to be maintained and would require some level of training for the employees in charge of maintain the data integration, but the end users of the original systems would still be working with the same workflows as before.

5.3 Direct Integration Tools with the Revit Model

With a direct integration link from BIM to a CMMS, the owner can have the benefit of consistently update information in both locations. In order for this to happen, there is typically a plug-in developed and installed in the modelling software to allow for linking the data within the model to the CMMS system. One method for this direct link would be to develop a customized plug-in by using the program's Application Programming Interface (API). An API allows for a user to program specific interactions with the model's data that are not developed as out of the box functions for the program. The other method for a direct link would be to utilize a CMMS software platform that has already developed the link.

The challenge with the direct link exists when the software that is currently used as a CMMS, such as AssetWorks AiM in the case of the educational institution, does not have the plug-in for linking the model data, in this case Revit, to the CMMS system. This would require time and money be spent in order to develop a customized interface with Revit's API. There would also be time needed to test the interface and support its long-term use.

To overcome the challenge of not having an API plugin already developed for the specific CMMS used, owners may opt to switch to an FM system with the available direct integration capabilities. In the case of a large educational institution with dozens or even hundreds of buildings being managed and maintained, facility data has been developed over time in a specific software platform. In this case, it is very difficult and time consuming to switch to a different CMMS system.

The benefit of an API based interface would include technical and customer support, the ability to set up a system and know how it works because of a proven record, and working within a developed and tested workflow. There would not be any bugs associated with a customized API. Another benefit of a direct link is access to updated information, in real time, between two systems. The user does not have to worry about making sure that the model is updated with changes that were entered into the CMMS and vice versa.

An example of a user plug-in for Revit that links the model data directly to the CMMS is the ARCHIBUS Smart Client Extension for Revit. ARCHIBUS is a CMMS platform that allows for real estate and facility management through various developed modules. The Smart Client Extension allows for data transfer from the model to the CMMS. It allows for a graphical connection in the form of a plug-in for Revit where information from the BIM can be put into the CMMS and used immediately. Once the information is updated, it updates in both the BIM and CMMS as a direct link. The Smart Client system allows for the creation of rules based on the owners needs to link the data. It also allows for some information, such as location, to be automatically populated based on where the asset is in the model. The system will update if a new asset is added within Revit, based on the location that model is imported.

5.4 Navisworks Integrated Model

A similar process can be achieved using the integrated model via a Navisworks platform. In Navisworks, equipment data can be filtered (using 'Selection Set's or 'Search Sets') and exported using the export function 'Selection Inspector' to a CSV file (Fig. 17). In this method, data from multiple component models can be brought together in Navisworks and appended to create an integrated (or federated) model. Asset parameters may show up on separate tabs in Navisworks depending upon how the Revit model was configured and what format the file is saved in. Using 'Selection Inspector', data can be exported to a .CSV file. The .CSV file then needs to be opened in Excel, saved to a native Excel file format, and data can be manually edited or new data can be added. Using the 'DataTools' function, the modified data can be imported back in Navisworks. This process also allows for consolidating the data into a single tab with a user-defined name. Using iConstruct (www.iconstruct.com), a plugin for Navisworks, similar results can be achieved using a faster and more robust process.

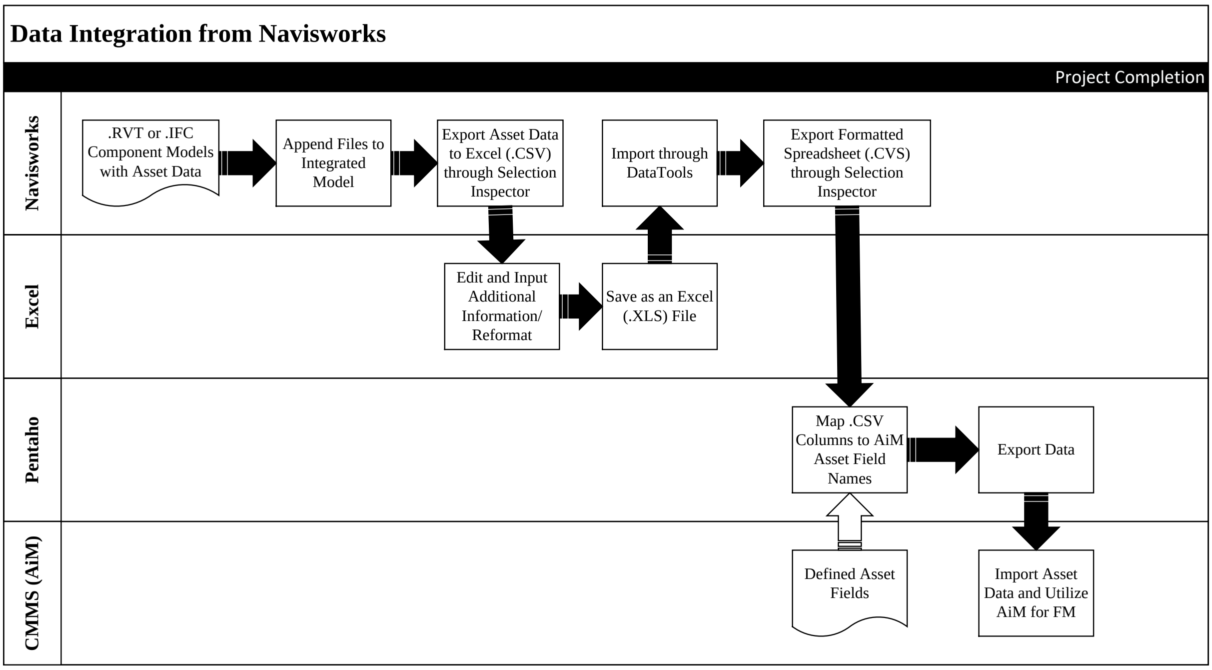

FIG. 17: Data Integration through Navisworks Selection Inspector and DataTools Link

Data in the Navisworks model can then be linked to AiM through similar methods used for an integrated Revit model including the use of data integration tools or an API. Middleware can also be utilized to import the model and subsequently link the data to AiM.

An alternative to the use of DataTools and the available plug-ins, Navisworks as part of BIM 360 allows for additional layers of data integration. Using 360 Field to plug data into specific fields within the model that is hosted on 360 Glue, a cloud platform, can allow for the Glue model to then be opened in Navisworks.

The use of a Navisworks integrated model has some advantages. Since Navisworks is a model viewer, it is capable of reading multiple file formats. This allows for specialty subcontractors to utilize their software of choice with a little more flexibility of not being restricted to a native Revit file. Another advantage is the ability to manipulate the way the data appears. In working with the 'Selection Inspector and 'DataTools' function, or the iConstruct plugin, the data can be brought together from the different models and easily updated and modified as needed. The main drawback for using a Navisworks model it places more of the data management and responsibility functions on the contractor who would be receiving models from the subs to ingrate their data into the Navisworks file and also the added effort required to reconfigure data tabs.

6. OVERALL DATA FLOW PROCESS FOR THE FACILITY INSTITUTION

From the earlier pilot study and identification of asset attributes and properties, it was decided that data will be requested based upon major milestones of the project. These milestones include: Completion of Design, Approval of Submittals, Installation of Asset, and Substation Completion/Commissioning (Thabet and Lucas, 2016). The data types were colour coded based on the milestone phase in which that piece of data should be recorded. The colour coding is based on when the information would become available during the project's lifecycle. There are several pieces of data that have been identified with two colours. The owner is requiring this information at an earlier phase, such as the Completion of Design, but there are times when this information might be modified at a later period, such as during Approval of Submittals. In this case, the information would need to be verified in the second phase after it was first entered into the model.

The process to collect and review the information is identified in Fig. 18 as a process model. The horizontal lanes represent the major project participants while the vertical columns represent the designated milestone phases of information collection. The diagram is designed with the assumption that a project delivery of design/build, construction manager at risk, or other type of integrated project delivery approach is used. The process identifies the contractor, or entity responsible in managing the building of the project, as the one to coordinate the information documentation and approval process with the owner.

The process starts with the designers, who would include the architect and design engineers (structural engineer and mechanical engineer), developing the drawings and creating specific assets with the model (1). These assets, once identified, have defined properties and attributes sets as defined by the owner and specified in the BIM-FM Guideline and Specifications. Once design is complete and the assets are created the specific properties and attributes for each asset are recorded by the designers in their respective models and submitted for coordination and review (2). The contractor collects the models and develops and integrated model to send to the owner for review and approval (3). The owner would either return the data rich model for revisions or approve the asset properties and data that have been provided (4). Once the milestone data has been approved the designers deliver the schematic models for further detailing by specialty contractors and the process continues through the next milestone (5).

During the submittal phase, specialty contractors will be adding more detail to the model or possibly taking the modelled data from the engineers and developing their own detailed models for manufacturing and construction (6). These detailed component models are then coordinated into a federated model by the contractor for other construction planning processes. With the coordinated federated model, the contractor organizes the submittal process (7). This involves collecting both graphical and non-graphical information to perform preconstruction planning tasks. As a result of some of these tasks, submittals are developed and submitted for approval by the owner or owner's agent. The detailed process of what happens during this step would depend on the contractor and type of project. This is not unique to the information data collection phase. The information that comes from these preconstruction processes is what is being specified by the owner. The submittals then go through the approval process with owner (8).

Once the submittals are approved, the asset properties and attributes within the model are finalized by the specialty trade contractors and sent to the contractor (9). The contractor coordinates the different component models and submits the model and data for approval by the owner. The updated model with appropriate asset data is reviewed by the owner (10). If revisions are needed they are sent back to the appropriate parties.

Once the submittals are approved the assets are ordered from the respective manufacturers (11). The procurement process would be tracked by the contractor and dependent upon the contractor, materials ordered, and type of project. After the asset is received and installed additional attribute asset information that was not previously identifiable is added to the model by the contractor (12). The contractor then sends the updated model and asset data to the owner for approval. The owner would then reject for revisions or approve the collected data.

Once the information is approved and after the asset is tested and commissioned the final information is added to the model and attributes are reviewed (13). The contractor then submits the model to the owner for final approval.

After final approval of the model with all the asset information, the information is then turned over to the owner as a compiled model (14). The data is then transferred utilizing one of the described methods into a Computerized Maintenance Management System (CMMS) where it can be used to manage the operations and maintenance of the building.

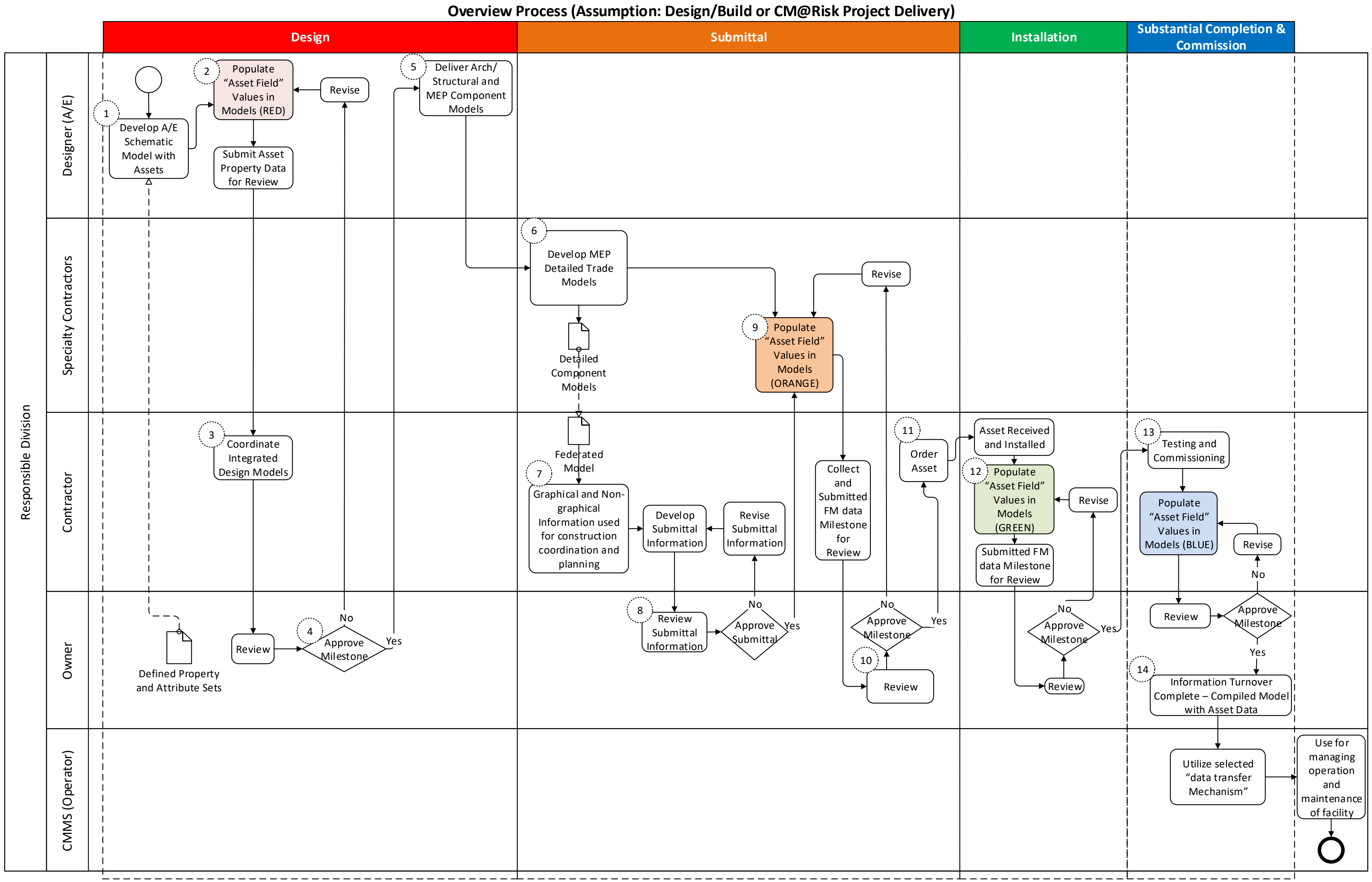

FIG. 18: Proposed Process Workflow for Data Reporting Format

7. FUTURE VALIDATION STUDY

The authors are currently exploring and testing various methods for data reporting formats and transfer mechanisms outlined earlier using a recently completed $1.74 million renovation 2-story project on the campus of the educational institution. Renovation of the CMMID (Center for Molecular Medicine and Infectious Diseases) building involved replacing the mechanical system for both floors of the main part of the building. The newly added mechanical system included components from 9 asset groups: Air Handling Units, Energy Recovery Unit, Fans, Fan Coil Units, Heaters, Humidifiers, Pumps, Separators and Tanks.

The existing building did not have a record BIM model. A basic architecture Revit model with all the mechanical components belonging to the 9 asset groups was created as shown in Figure 19.

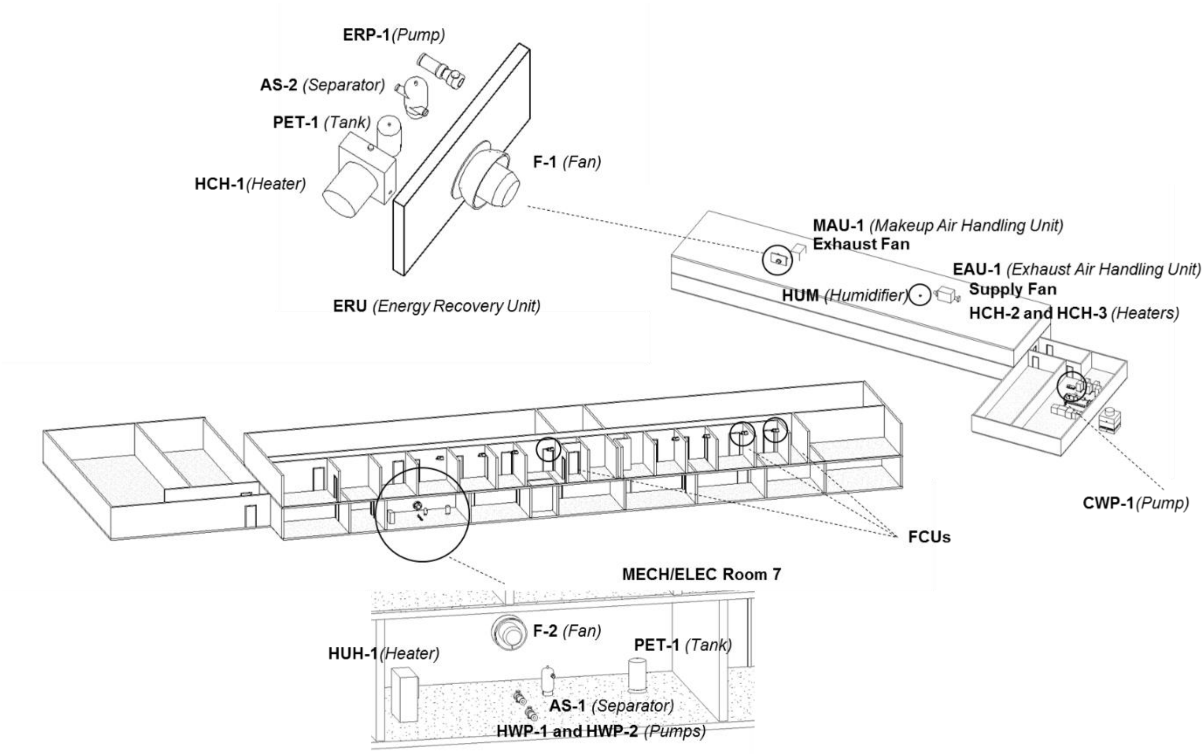

FIG. 19: Revit Model for the CMMID Project Showing New Mechanical Components Installed

The validation study is currently testing the following areas:

1. Work with the facilities department of the academic institution to verify and finalize the required properties and attributes of their asset groups and adopt US CAD Standards for group naming abbreviations.
2. Determine efficient methods to define and load asset parameter information (properties and attributes) into Revit models.
3. Review current available tools to export asset parameter information from Revit models to Excel spreadsheets and SQL data tables. Tools being investigated include Autodesk Dynamo, CTC BIM Data Suite: Project Snapshot Export and Imaginit Clarity.
4. Test linking asset parameter data from spreadsheets and SQL data tables to CMMS using Pentaho Data Integration tools.
5. Test direct linking of asset parameter data between Revit models and CMMS using proprietary data connectors such as the Archibus plugin.

Details of this work along with results of the validation will be reported in future publications.

8. CONCLUSION

The research began by looking for a better method for fulfilling the owner's information need in terms of project information to support post-construction activities. Previous steps of the research identified the assets that were needed to be tracked and the parameters and attributes of each of the assets to collect. A spreadsheet-based method that utilized a four milestone approach was then explored and tested with a case study. Once the information types and associated milestones of when the information was available was validated, a model-based documentation of hand-over information was explored. This model-based approach is presented in this paper.

This paper examines a six step process for utilizing Revit as a method for documenting project information at various milestones. The process included defining the necessary asset parameters within the modelling environment, capturing and updating the project information, and compiling the information from various component models. Challenges exist with the model-based documentation with how parameters within the model space can be edited, stored, and compiled. To reduce the tedious nature of the work different plug-ins were analysed.

Once the data is collected ad stored in the model, it is necessary for the owner to be able to get that captures data into the format to support their CMMS. In the situation of the case-study, the CMMS system is AssetWorks AiM and there is no direct link between a model and the software currently available. The various methods explored include:

1. Output of specific schedule data into a .CSV file with manipulation of the spreadsheet to allow for importing the data into the appropriate fields within AiM. This method leads to a one directional link and significant data manipulation which can lead to delays in data availability, additional errors, and non-value added cost.
2. Output the data through middleware that is already developed. Most middleware can offer a bi-directional link of data, however a third piece of software is adding cost to the overall infrastructure and would require an additional piece to be recommended.
3. A direct link through an API or Plug-in for the model data to link to the AiM system. This method works best with any workflow as it simplifies the middle steps, however there are limited plug-ins available on the market and APIs can be expensive to develop.

Due to the benefit of having a direct link between the model and CMMS, the educational institution of the case study as decided to explore the development of a plug-in that will allow for tracking the data between the model and CMMS. This direct link will remove the necessity of a 3rd party software, reduce the amount of time to get the data up and running, and allow for easy updating of data in both the model and CMMS. In future research, when the plug-in is being developed, the following will need to be considerations:

- Ability of the plug-in to work with various component models and import the data into the CMMS through a single user interface. This will allow for component models to be utilized by the different responsible parties and allow all data types and custom parameters to be read through one interface within a central model. Whereas many developed plug-ins and Revit natively are limited as to the types of data you can include in a schedule when it comes to component models.
- A scalable interface to allow for expansion beyond the initial five critical assets that are part of the study.
- The ability for utilizing a model file other than .RVT. If the plug-in is developed for Navisworks instead of Revit, it may be easier to include model types from trades that are not natively .RVT. Otherwise, there would need to be a requirement for specific version of Revit files that would limit the interoperability of the plug-in.

With the model-based approach and development of the plug-in planned as the future research steps, the goal of providing a consistent method for data delivery of newly constructed facilities on the educational institution's campus is becoming a reality. The goal of having a systematic way to capture all relevant facility data for post-construction management of the facility is being realized. Once the plug-in is developed, complete BIM-FM guidelines for the owner will be developed to document the identified information needs and the methods to capture that information that will allow the owner to fully utilize it.

9. ACKNOWLEDGEMENTS

The work presented in this paper is made possible by the support of Virginia Tech Facility Services and the Eller Group. The views expressed in this paper do not necessarily represent the views of these supporters and are purely those of the authors.

10. REFERENCES

Autodesk (2015). Update OmniClass Taxonomy File. Autodesk Knowledge Network, Retrieved on 8/17/2016 from <<https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2015/ENU/Revit-Troubleshooting/files/GUID-BA0B2713-ADA0-4E51-A7CD-85D85511F3ED-htm.html>>

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2012). Application Areas and Data Requirements for BIM-Enabled Facility Management, Journal of Construction Engineering and Management, 138(3): 431-442.

Bernstein, H. M. (2012). The Business Value of BIM in North America: A Multi-Year Trend Analysis and User ratings (2007-2012). McGraw-Hill Construction: Smart Market Report. Bedford, MA.

CAD Technology Center (CTC). (2016). BIM Manager Suite 2017. Retrieved on 8/17/2016 <<https://ctcexprsestools.com/product/bim-manager-suite-2017/>>

Construction Specifications Institute (CSI) (2016). *MasterFormat*, retrieved on 4/7/16 <<www.csinet.org/masterformat>>

East, B. (2014). Construction –Operations Building Information Exchange (COBie), Whole Building Design Guide, National Institute of Building Sciences, retrieved from <<https://www.wbdg.org/resources/cobie.php>>

East, E. and Brodt, W. (2007). “BIM for Construction Handover,” Journal of Building Information Modeling (JBIM), January.

Dias, P. and Ergan, S. (2016). The Need for Representing Facility Information with Customized LOD for Specific FM Tasks, Construction Research Congress 2016, 2563-2672

Dougherty, J. (2015) “BIM for Facilitates Management (BIM_FM): First Steps Before the First Steps,” *TechBrief*, AGC of America.

Fallon, K. and Palmer, M. (2006). Capital Facilities Information Handover Guide, Part 1. National Institute of Standards and Technology.

Gallaher, M. P., O’connor, A.c., Dettbarn, J.L., Jr., & Gilday, L.T. (2004). Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry (NIST GCR 04-867), National Institute of Standards Testing (NIST), Gaithersburg, Md.

Gleason, D. (2013). “Getting to a Facility Management BIM,” *Lake Constance 5D-Conference*, Constance, Germany, October 29-29.

Ghosh, A. and Chasey, A. (2013). “Data Handover for Healthcare Facilities Management,” *Building Innovation 2013, Expo and Conference*, National Institute of Building Sciences.

Hardin, B. and McCool, D. (2015). *BIM and Construction Management: Proven Tools, Methods, and Workflows*, John Wiley & Sons, Inc.; Indianapolis, Indiana.

IMAGINiT Technologies (2015). BIM and FM Gap Survey Results, retrieved on 8/17/2016 <<http://blogs.rand.com/architectural/2015/10/infographic-bim-and-fm-gap-survey-results.html>>

Kang, T.W. and Hong, C. H. (2015). A study on software architecture for effective BIM/GIS-based facility management integration, Automation in Construction, 45 (2015): 25-38.

Kiviniemi, A. and Codinhoto, R. (2014). Challenges in the Implementation of BIM for FM – Case Manchester Town Hall Complex, Computing in Civil and Building Engineering, 665-672.

Lee, W., Tsai, M, Yang, C., Juang, J., and Su, J. (2016). V3DM+: BIM interactive collaboration system for facility management, Visualization in Engineering, 4: 5.

Lui, R. and Zettersten, G. (2016). Facility Sustainment Management System automated Population from Building Information models, Construction Research Congress 2016, 2403 – 2410.

McArthur, J. J. (2015). A building information management (BIM) framework and supporting case study for existing building operations, maintenance, and sustainability. International Conference on Sustainable Design, Engineering, and Construction, Procedia Engineering 118 (2015): 1104-1111.

National Institute of Building Sciences (NIBS), (2016). *United States National CAD Standard – V6*, National institute of Building Science buildingSMART alliance, retrieved on 4/7/16 <<www.nationalcadstandard.org/ncs6>>OmniClass (2016) *OmniClass: A Strategy for Classifying the Built Environment*. OmniClass Construction Classification System (OCCS) retrieved on 4/7/16 <<www.omniclass.org>>

Parsanezhad, P. and Dimyaidi, J. (2014). Effective Facilities Management and Operations via a BIM-Based Integrated Information System, CIB Facilities Management Conference 2014, 442-453.

Teicholz, P. (2013). BIM for Facility Managers. Hoboken, New Jersey, USA: John Wiley & Sons.

Thabet, W. and Lucas, J. (2017). Asset Data Handover for a Large Educational Institution: Case Study, Journal of Construction Engineering and Management (In Press).

APPENDIX 1

TABLE 1: Criteria for Defining Asset Properties as Revit Parameters

	REVIT PARAMETER NAME	Field TYPE	FAMILY/ PROJECT	TYPE / INSTANCE	GROUP UNDER
GENERAL	ASSET_TAG	TEXT	PROJECT	INSTANCE	GENERAL
	ASSET_GROUP	TEXT	PROJECT	TYPE	GENERAL
	DESCRIPTION	TEXT	PROJECT	INSTANCE	GENERAL
	LOCATION_CODE	TEXT	PROJECT	INSTANCE	GENERAL
	DATE_PURCHASED	TEXT	PROJECT	INSTANCE	GENERAL
	LONG_DESC	TEXT	PROJECT	TYPE	GENERAL
	LOCKOUT	YES/NO	PROJECT	TYPE	GENERAL
	SERIAL_NO	TEXT	PROJECT	INSTANCE	GENERAL
	MANUFACTURE_CODE	TEXT	PROJECT	TYPE	GENERAL
	MANU_PART_NUMBER	TEXT	PROJECT	TYPE	GENERAL
	PROCEDURE_YN	YES/NO	PROJECT	TYPE	GENERAL
	PARENT_ASSET_TAG	TEXT	PROJECT	INSTANCE	GENERAL
	YEAR_INSTALLED	TEXT	PROJECT	INSTANCE	GENERAL
PARTS LIST	PART	TEXT	PROJECT	TYPE	GENERAL
	QUANTITY	INTEGER	PROJECT	TYPE	GENERAL
WARRANTY	WARR_DESC	TEXT	PROJECT	TYPE	GENERAL
	WARR_DATE_FR	TEXT	PROJECT	INSTANCE	GENERAL
	WARR_DATE_TO	TEXT	PROJECT	INSTANCE	GENERAL
LOCATION SERVED	LOCATION	TEXT	PROJECT	INSTANCE	GENERAL
	USAGE_FACTOR	TEXT	PROJECT	INSTANCE	GENERAL
CLASSIFICATION	CLASS_STANDARD	TEXT	PROJECT	TYPE	GENERAL
	LEVEL_1	INTEGER	PROJECT	TYPE	GENERAL
	LEVEL_2	INTEGER	PROJECT	TYPE	GENERAL
	LEVEL_3	INTEGER	PROJECT	TYPE	GENERAL
	LEVEL_4	INTEGER	PROJECT	TYPE	GENERAL
	LEVEL_5	INTEGER	PROJECT	TYPE	GENERAL
	LEVEL_6	INTEGER	PROJECT	TYPE	GENERAL

Table 2: Criteria for Defining Asset Attributes as Revit Parameters

	REVIT PARAMETER NAME	Field TYPE	FAMILY/ PROJECT	TYPE / INSTANCE	GROUP UNDER
AHU ATTRIBUTES	BAS POINT ADDRESS	TEXT	FAMILY	INSTANCE	GENERAL
	HEATING SOURCE	TEXT	FAMILY	TYPE	GENERAL
	HEATING CAPACITY	TEXT	FAMILY	TYPE	GENERAL
	TOTAL AIR FLOW	TEXT	FAMILY	TYPE	GENERAL
	ESP	TEXT	FAMILY	TYPE	GENERAL
	MIN. OUTSIDE AIR	TEXT	FAMILY	TYPE	GENERAL
	MAX. OUTSIDE AIR	TEXT	FAMILY	TYPE	GENERAL
	COOLING SOURCE	TEXT	FAMILY	TYPE	GENERAL
	TOTAL COOLING CAPACITY	TEXT	FAMILY	TYPE	GENERAL
	SENSIBLE COOLING CAP	TEXT	FAMILY	TYPE	GENERAL
	ECONOMIZER	YES/NO	FAMILY	TYPE	GENERAL
	ECONOMIZER TYPE	TEXT	FAMILY	TYPE	GENERAL
	TOTAL STATIC PRESSURE	TEXT	FAMILY	TYPE	GENERAL
	AHU TYPE	TEXT	FAMILY	TYPE	GENERAL
FAN ATTRIBUTES	CFM	TEXT	FAMILY	TYPE	GENERAL
	SYSTEM STATIC PRESSURE	TEXT	FAMILY	TYPE	GENERAL
	WHEEL DIAMETER	TEXT	FAMILY	TYPE	GENERAL
	MOTOR REVOLUTIONS PER MINUTE	TEXT	FAMILY	TYPE	GENERAL
	MOTOR HORSEPOWER	TEXT	FAMILY	TYPE	GENERAL
	FAN REVOLUTIONS PER MINUTE	TEXT	FAMILY	TYPE	GENERAL
	VOLTAGE	TEXT	FAMILY	TYPE	GENERAL
	PHASE	INTEGER	FAMILY	TYPE	GENERAL
	HERTZ	TEXT	FAMILY	TYPE	GENERAL
	FAN TYPE	TEXT	FAMILY	TYPE	GENERAL
	MOTOR FRAME	TEXT	FAMILY	TYPE	GENERAL

APPENDIX 2

Table 1: Air Handling Units (AHU) Data Specifications – PROPERTIES

	AHU-1A (Class and General Areas)	**AHU-2 (Lab Areas Only)**
GENERAL and REFERENCE		
ASSET_TAG	00159-AHU-RT-0001	00159-AHU-RT-0003
ASSET_GROUP	AHU	AHU
DESCRIPTION	UNIT NO: AHU-1A CLASS	UNIT NO: AHU-2 LAB
LOCATION_CODE	RF3	RF3
DATE_PURCHASED	1/1/2016	1/1/2016
LONG_DESC	BUILT UP ROOF TOP AHU	BUILT UP ROOF TOP AHU
LOCKOUT	YES	YES
SERIAL_NO	xxxxxx	xxxxxx
MANUFACTURE_CODE	MAMMOTH	DAIKIN APPLIED SKYLINE
MANU_PART_NUMBER	SO028183-01	OAH038GDGM
PROCEDURE_YN	YES	YES
PARENT_ASSET_TAG	N/A	N/A
YEAR_INSTALLED	2016	2016
PART LIST		
PART	AAF PerfectPleat M8 2" Filter (MERV8)	2" Pleated Pre-Filter (MERV8)
QUANTITY	6	30
PART	Vertical RF SH 12" Filter (MERV14)	12" Varicel SL Cartridge Filter (MERV14)
QUANTITY	2	30
PART	AmAir 1300 2" Filter (MERV13)	
QUANTITY	2	
WARRANTY		
WARR_DESC	ONE YEAR PARTS & LABOR	ONE YEAR PARTS & LABOR
WARR_DATE_FR	9/1/2016	9/1/2016
WARR_DATE_TO	9/30/2017	9/30/2017
LOCATION SERVED		
LOCATION	FLOOR 1, FLOOR 2, FLOOR 3	23.33.25.11.13
USAGE_FACTOR	40%, 40%, 20%	100%
CLASSIFICATION		
CLASS STANDARD	Master Format	Master Format
LEVEL_1	23	23
LEVEL_2	74	74
LEVEL_3	13	13
LEVEL_4		
LEVEL_5		
LEVEL_6		
CLASS STANDARD	OmniClass	OmniClass
LEVEL_1	23	23
LEVEL_2	33	33
LEVEL_3	25	25
LEVEL_4	11	11
LEVEL_5	13	13
LEVEL_6		

Table 2: Supply and Return Fans (FAN) Data Specifications – PROPERTIES

	SF-1A (Supply Fan for AHU-1A)	**RF-1A (Return Fan for AHU-1A)**	**SF-2 (Supply Fan for AHU-2)**
GENERAL and REFERENCE			
ASSET_TAG	00159-FAN-SUP-0005	00159-FAN-RAF-0008	00159-FAN-SUP-0007
ASSET_GROUP	FAN	FAN	FAN
DESCRIPTION	UNIT NO: SF-1A	UNIT NO: RF-1A	UNIT NO: SF-2
LOCATION_CODE	RF3	RF3	RF3
DATE_PURCHASED	1/1/2016	1/1/2016	1/1/2016
LONG_DESC	CENTRIFUGAL FANS	CENTRIFUGAL FANS	CENTRIFUGAL FANS
LOCKOUT	YES	YES	Y
SERIAL_NO	xxxxxx	xxxxxx	xxxxxx
MANUFACTURE_CODE	xxxxxx	xxxxxx	xxxxxx
MANU_PART_NUMBER	xxxxxx	xxxxxx	xxxxxx
PROCEDURE_YN	YES	YES	Y
PARENT_ASSET_TAG	0159-AHU-RT-0001	0159-AHU-RT-0001	0159-AHU-RT-0003
YEAR_INSTALLED	2016	2016	2016
PART LIST			
PART	N/A	N/A	N/A
QUANTITY	N/A	N/A	N/A
WARRANTY			
DESCRIPTION	ONE YEAR PARTS & LABOR	ONE YEAR PARTS & LABOR	ONE YEAR PARTS & LABOR
WARR_DATE_FR	9/1/2016	9/1/2016	9/1/2016
WARR_DATE_TO	9/30/2017	9/30/2017	9/30/2017
LOCATION SERVED			
LOCATION	N/A	N/A	N/A
USAGE_FACTOR	N/A	N/A	N/A
CLASSIFICATION			
CLASS_STANDARD	Master Format	Master Format	Master Format
LEVEL_1	23	23	23
LEVEL_2	34	34	34
LEVEL_3	16	16	16
LEVEL_4			
LEVEL_5			
LEVEL_6			
CLASS_STANDARD	OmniClass	OmniClass	OmniClass
LEVEL_1	23	23	23
LEVEL_2	33	33	33
LEVEL_3	31	31	31
LEVEL_4	19	19	19
LEVEL_5	13	13	13
LEVEL_6			

Table 3: Air Handling Units (AHU) Data Specifications – ATTRIBUTES

ID	ATTRIBUTE	AHU-1A (Class and Public Areas)	AHU-2 (Lab Areas)
1	BAS POINT ADDRESS		
2	HEATING SOURCE	STEAM	STEAM
3	HEATING CAPACITY	1043.3 MBH	1157.7 MBH
4	TOTAL AIR FLOW	26000 CFM	15500 CFM
5	ESP	4 IN.H20	2.50 IN.H2O
6	MIN. OUTSIDE AIR	17000 CFM	15500 CFM
7	MAX. OUTSIDE AIR	26000 CFM	15500 CFM
8	COOLING SOURCE	CHILLER	CHILLER
9	TOTAL COOLING CAPACITY	1470.2 MBH	182.038 MBH
10	SENSIBLE COOLING CAP	990.3 MBH	182.038 MBH
11	ECONOMIZER	YES	YES
12	ECONOMIZER TYPE	DRY BULB/WET BULB	DRY BULB/WET BULB
13	TOTAL STATIC PRESSURE	8.15 IN.H20	6.26 IN.H2O
15	AHU TYPE	RT	RT

Table 4: Fans (FAN) Data Specifications – ATTRIBUTES

ID	ATTRIBUTE	SF-1A (Supply Fan for AHU-1A)	RF-1A (Return Fan for AHU-1A)	SF-2 (Supply Fan for AHU-2)
2	CFM	26000 CFM	24500 CFM	2 X 7750 CFM
4	SYSTEM STATIC PRESSURE	8.15 IN.H2O	4.31 IN.H2O	4.72 IN.H2O
5	WHEEL DIAMETER	8 x 16"	8 x 16"	20"
6	MOTOR REVOLUTIONS PER MINUTE	3525 RPM	3515 RPM	3600 RPM
7	MOTOR HORSEPOWER	8X15 HP	8X8 HP	2 X 10 HP
8	FAN REVOLUTIONS PER MINUTE	1750 RPM	1189 RPM	1735 RPM
9	VOLTAGE	460 VOLTS	460 VOLTS	460 VOLTS
10	PHASE	3	3	3
11	HERTZ			
12	FAN TYPE	SUP	RAF	SUP
13	MOTOR FRAME			254T

APPENDIX 3

Table 1: Summary of Software Applications and Plug-ins Referenced in Text

	Publisher	Notes
BIM Software		
Revit	Autodesk, Inc. – https://www.autodesk.com	BIM Authoring Software
Navisworks	Autodesk, Inc. – https://www.autodesk.com	BIM Analysis Software
CMMS Software		
AiM	AssetWorks – http://www.assetworks.com	Operation and maintenance software that leverages facility building data for other work flows to support FM activities
Stand Alone Data Manipulation		
Pentaho Kettle	Pentaho: A Hitachi Group Company – http://community.pentaho.com	A data integration tool that allows for graphically dragging and dropping series of metadata to make connections between multiple databases
IMAGINiT Clarity	IMAGINiT Technologies – http://www.imaginit.com	Link to Revit data to allow for manipulation of data through a database overlay. Also allows other workflow functions to be automated within Revit
EcoDomus FM	EcoDomus, inc. – http://www.ecodomus.com	Allows linking to Revit, CMMS, and BAS platforms to transfer, keep track of, and synchronize facility management data
Plug-ins For Data Manipulation		
iConstruct	iConstruct – https://iconstruct.com	Plug-in for Navisworks – Suite of tools, exporting and interoperability tools used for case study project
Shared Parameter Manager	CTC Express Tools by CAD Technology Center, Inc. – https://ctcexpresstools.com	Part of BIM Manager Suit – A plug-in tool for Revit that manages shared parameter files and assists with batch loading parameters into projects.
Spreadsheet Link	CTC Express Tools by CAD Technology Center, Inc. – https://ctcexpresstools.com	Part of BIM Project Suit – A plug-in tool for Revit that exports/imports project data between Revit and a spreadsheet program.
Project Snapshot	CTC Express Tools by CAD Technology Center, Inc. – https://ctcexpresstools.com	Part of BIM Data Suite – A plug-in tool for Revit that allows for extracting data in neutral formats that can more easily be utilized in other platforms
Dynamo	Autodesk, Inc. – https://www.dynamobim.org	Plug-in and overlay for Revit to allow for visual programming that can create custom manipulations of data and modelled objects
ARCHIBUS – Smart Client Extension for Revit	ARCHIBUS – https://www.archibus.com	Plug-in that allows for a graphical bi-directional link utilizing Web Services to link BIM data to ARCHIBUS applications