

A CASE STUDY TOWARDS TRANSFERRING RELEVANT SAFETY INFORMATION FOR FACILITIES MAINTENANCE USING BIM

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SUMMARY: *Facilities maintenance (FM) personnel in the U.S. experience a much higher rate of injury and illness than the national average when compared to all other fields of employment. In order to aid in the mitigation of these incidences, a Safety for Facilities Maintenance Framework is being developed. This framework delivers safety relevant information to FM personnel through the use of a data processing and rule based system that processes safety relevant information stored within a comprehensive BIM model. One major issue associated with utilizing a comprehensive BIM model as a repository for FM data is the transfer of relevant information from the design and construction phases to the facilities management phase. This paper reviews the detailed issues surrounding data transfer, identifies current market solutions by others, and presents a case study in order to transfer data utilizing existing data exchange tools. Finally, utilizing an existing transfer mechanisms within Autodesk Navisworks, coupled with a newly developed framework, a method to get asset-specific safety information to FM staff prior to initiating an FM task is proposed. Although this method of data transfer may not be the most efficient, it utilizes existing functionality within Navisworks software. Using Navisworks minimizes the learning curve and execution in comparison to similar proprietary transfer mechanisms.*

KEYWORDS: *Data Transfer, Facilities Management, Safety, Framework, Rule Based System, Building Information Modeling*

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1 INTRODUCTION

Facilities management (FM) personnel in the United States have a much higher rate of injury and illness than the national average when compared to all other fields of employment (Bureau of Labor Statistics 2014a; Wetzel and Thabet 2015). Within the private sector, employers recorded 98,420 cases of non-fatal occupational injuries and illnesses between 2008-2012 (Bureau of Labor Statistics 2009b; Bureau of Labor Statistics 2010b; Bureau of Labor Statistics 2011b; Bureau of Labor Statistics 2012b; Bureau of Labor Statistics 2013b). During this same timeframe, 293 people lost their life in the FM field (Bureau of Labor Statistics 2009a; Bureau of Labor Statistics 2010a; Bureau of Labor Statistics 2011a; Bureau of Labor Statistics 2012a; Bureau of Labor Statistics 2013a). In an attempt to mitigate incidents with FM personnel, employers provide substantial training and documentation with relevant safety information (safety handbooks, Occupational Safety and Health Administration (OSHA) certifications, protocols, etc.); however, this information, coupled with the applicable safety information that is transferred from the design and construction phase (disconnect locations, power sources, O&M specific requirements, etc.) creates a myriad of fragmented data, presented in multiple resources, that must be reviewed or memorized in order to safely execute an FM task (Goedert and Meadati 2008; Lucas 2012). Research has shown that the inconvenience of obtaining fragmented, comprehensive applicable safety information, coupled with the often time sensitive nature of FM tasks, can be directly correlated to the fatalities, injuries, and illnesses that are present within the field (Godfrey et al. 1985; Wogalter et al. 1989; Zeitlin 1994). According to The Lawrence Berkley National Laboratory (2012), “Injuries due to time pressure are most often the result of a conscious or semi-conscious decision on the worker’s part to circumvent a known preventative measure to a known safety hazard in the interest of getting the task done on time or rushing to keep ahead of a process following close behind.”

In an attempt to mitigate safety hazards to FM staff, a mechanism for transferring relevant safety information from the design and construction phase to the FM phase is of paramount importance. An extensive literature review in previous research efforts and significant data collection and validation identified what safety hazards are common among FM tasks and what mitigation techniques are required in order to prevent injuries, illnesses, and fatalities within facilities management. Identifying this information was the first phase of a newly designed framework in order to identify, transfer, and efficiently present safety information to FM staff prior to executing an FM task (Wetzel 2016; Wetzel and Thabet 2015; Wetzel and Thabet 2016). This paper reviews the detailed issues surrounding data transfer, identifies current market solutions by others, and presents a case study in order to transfer data utilizing existing tools within a single modeling program, Autodesk Navisworks. Finally, utilizing an existing transfer mechanisms within Autodesk Navisworks, coupled with a newly developed framework, a method to get asset-specific safety information to FM staff prior to initiating an FM task is presented.

1.1 Proposed Framework

In order to support worker’s safety during the FM phase, a BIM-based framework to support safety during the facility management phase is developed to categorize, consolidate, process, and present job specific, relevant safety information to FM personnel prior to the start of a maintenance task (Wetzel and Thabet 2015). The proposed framework identifies and classifies safety information that is relevant to FM personnel through qualitative research (Wetzel and Thabet 2016). The relevant safety information is placed into a structured format and inserted into data storage (an appended BIM model) through various existing data transfer mechanisms. Utilizing a data processing and rule based system (DPRBS) in order to pull information from a data storage mechanism, relationships and knowledge (logic) can be added to the static safety information. In order for the FM personnel to interact with the DPRBS, a graphical user interface is utilized. *Fig. 1* graphically summarizes the safety framework.

The proposed safety framework delivers task specific, relevant safety information in six main steps:

1. Contract entities produce fragmented relevant safety information through the design and construction phases. This information is then consolidated into a structured format in order to be placed into native storage mechanisms.
2. Contract entities input and store structured safety information into BIM models or utilize non-graphical documentation.

3. Through interoperability or data exchange tools, information is imported into an appended BIM model. This model is utilized as a data storage repository for all applicable information. This portion of the framework is explained in much greater detail in Section 4.
4. Additional safety related information, input by the FM staff is placed into the data storage repository utilizing similar methods of data loading.
5. The data processing and rule based system interacts with the data in order to process and add relationships and knowledge to the information through data relational statements and protocols.
6. FM personnel interact with the DRRBS through a graphical user interface (interface), prior to beginning a maintenance task.

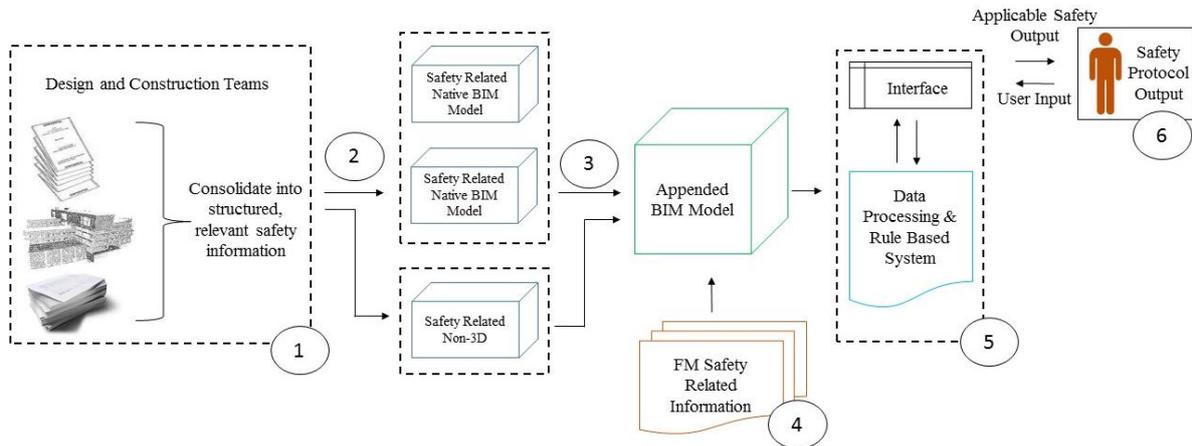


Figure 1: Safety Framework

1.2 Hazard Mitigation and Safety Data

To aid in the mitigation of fatalities, injuries, and illnesses in facilities management, safety relevant data was collected through qualitative methods and validated through interviews with industry experts in order to create lists of FM hazards and associated safety protocols (Wetzel and Thabet 2016). Utilizing the acquired safety data, the information was categorized into safety attributes for the three specific hazard areas that this research is attempting to mitigate, falls; harmful environments & substances; and contact with/struck by. Upon reaching data saturation and validating the collected data, the identified FM hazards, known as *safety inputs*, are associated with applicable hazard mitigation techniques, known as *safety protocols*. Identification of these safety inputs, in correlation with the associated safety protocol contributes to the effort to identify comprehensive safety information for mitigation of hazards related to falls; harmful environments & substances; and contact with/struck by.

In addition to associating safety inputs with safety protocols in order to mitigate the hazards, production information for the safety inputs needs to be identified. Production encompasses information relating to the identification of the phase of the building lifecycle the information is produced, who is typically responsible for the creation of the asset or area causing the hazard, and what method of data transfer is likely for that information. Using the production information, known as *data sourcing*, in correlation with the safety inputs and associated protocols creates the backbone for the transfer into the Appended BIM Model. **Table 1** presents the categorized (by hazard) safety inputs, the applicable safety protocols for each input, and the data sourcing information.

Table 1: Safety Inputs with Applicable Protocols and Data Sourcing (adopted from Wetzel and Thabet (2016))

HARMFUL ENVIRONMENTS & SUBSTANCES

DATA SOURCING				
Safety Input	Typical Production Phase	Primary Developer	Method of Transfer	Knowledge: Relates to Safety Protocol
Hazardous Energy (Live Current)	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Arc Flash Protection
Elec. Disconnect Location(s)	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
Voltage	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
				Arc Flash Protection
				Permits
				Hot Sticks/Metering
Approx. Disconnect Distance	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
Asbestos Potential	FM	FM Staff	FM Safety Related Information	Asbestos Management
				Respiratory Protection
Environment Decibel Level	Construction	Manufacturer / Subcontractor	Non-3D	Hearing Protection / Noise Dampening
				Noise Monitoring
Environmental Air Quality	Design	Arch / Engineer	Native BIM Model	SDS / Chemical Management
				Respiratory Protection
				Refrigerant Management
				PCB Management
				Silica Management
				Asbestos Management
				Lead Management
				Permits
Manhole or Tank	Design	Arch / Engineer	Native BIM Model	Hearing Protection / Noise Dampening
				Noise Monitoring
				SDS / Chemical Management
				Air Monitoring
				Temperature Monitoring
				Valve Location(s)
				Confined Space Protocol
				Permits
Oxygen Deficient / Oxygen Enriched / Carbon Monoxide Environment	Design	Arch / Engineer	Native BIM Model	Ventilation
				Permits
				Air Monitoring
				Respiratory Protection

Particulate Environment	Design	Arch / Engineer	Native BIM Model	Air Monitoring
				Ventilation
				Respiratory Protection
Exhaust Producing Asset	FM	FM Staff	FM Safety Related Information	Ventilation
Flooding Potential	Design	Arch / Engineer	Native BIM Model	Inflatable Valve
				Valve Location
				Safety Line
Hazardous Asset Temperature	Design	Arch / Engineer	Native BIM Model	Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia
Outdoor Environment	Design	Arch / Engineer	Native BIM Model	Weather Considerations - Heat, Cold, Precipitation, Wind
				Nature - Animals, Allergens, Plant Life
Lead Potential	FM	FM Staff	FM Safety Related Information	Lead Management
				Respiratory Protection
Hazardous Chemical Production / Storage	Design	Arch / Engineer	Native BIM Model	SDS / Chemical Management
				Air Monitoring
				Secondary Containment
				Ventilation
				Respiratory Protection
Radiation	Design	Arch / Engineer	Native BIM Model	Monitoring
				Radiation Management
Polychlorinated Biphenyls (PCB) Potential	FM	FM Staff	FM Safety Related Information	PCB Management
				Respiratory Protection

FALLS

DATA SOURCING				
Safety Input	Typical Production Phase	Primary Developer	Method of Transfer	Knowledge: Relates to Safety Protocol
Working Height	All	All	Native BIM Model, Non-3D, or FM Safety Related Information	Lift System with Condition Assessment
				Fall Arrest System / Anchorage
Roof / Deck	Design	Arch / Engineer	Native BIM Model	Lift System
				Chemical Venting (Industrial Hygiene)
				Fall Arrest System / Anchorage
				Barricading / Notification
Ledge / Hole	Design	Arch / Engineer	Native BIM Model	Weather Considerations
				Lift System
				Fall Arrest System / Anchorage
				Safety Line
				Barricading / Notification



CONTACT WITH / STRUCK BY

DATA SOURCING				
Safety Input	Typical Production Phase	Primary Developer	Method of Transfer	Knowledge: Relates to Safety Protocol
Manual Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Barricading / Notification
Automated Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Barricading / Notification
Suction / Pressure Line	Design	Arch / Engineer	Native BIM Model	Safety Line
				Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia
				Valve Location(s)
				Barricading / Notification
Valve Location(s)	Design	Arch / Engineer	Native BIM Model	Line Isolation
Overhead Equipment	All	All	Native BIM Model, Non-3D, or FM Safety Related Information	Barricading / Notification
				Approach Vector
				Support Structure
				Equipment Weight
Approx. Valve Location Distances	Design	Arch / Engineer	Native BIM Model	Line Isolation
Asset Support Structure	Design	Arch / Engineer	Native BIM Model	Approach Vector

As shown in **Table 1**, applicable safety information is produced throughout the design and construction phases of a building. This information can transfer in various formats, with the most ideal being a native BIM model transfer; however, as is presented in **Table 1**, this type of ideal transfer is limited. In addition to the design and construction phases, as FM personnel renovate existing areas or acquire new equipment, a third, FM production phase is required. Among the numerous safety inputs, the ability to rely on complete system interoperability to transfer all the data from the various entities to an appended BIM model is unlikely. For the appropriate information to be placed within the data storage repository, processes for transferring relevant safety data from design and construction to the repository must be evaluated.

This paper will review the detailed issues surrounding data transfer, identifies current market solutions by others, and presents an alternative method of data transfer utilizing existing data exchange tools. Finally, the paper proposes a dataflow mechanism to allow for applicable safety information to be exchanged within the BIM-based safety framework.

2 DATA TRANSFER CHALLENGES AND CURRENT MARKET SOLUTIONS

2.2 Data Handover Issues

The transfer of data from the design and construction phases to the facility management phase has remained greatly unchanged for years. Hard copy/electronic O&M manuals, file sharing, and project management hubs, is currently the industry standard. The handover process of information necessary for facility management (e.g. as-built drawings, operations and maintenance manuals, parts list, etc.) continues to deliver such information using a



combination of paper printed documents and digital versions of printed documents. This combination of paper-based and digital-based formats have proved unsuitable for the use, maintenance, and management of such information. The majority of the information delivered is still held in documents that do not have a formal structure, making it difficult and time consuming for direct input and interpretation by the computerized facility management system. Those who need to utilize the information provided must go through the additional step of reading the documents, synthesizing and extracting the needed information, and transforming the data into a structured format before inputting the information into the FM system.

Moreover, design and construction documents are not typically turned over to the FM staff until the end of the construction phase. Waiting until the completion of the construction phase / project handover to deliver the needed information, in a largely unstructured format, results in several problems. Mainly, requiring FM staff to recreate and assemble information that has been developed by others, resulting in a slowed handover process, a reduction in the ability to find all the necessary information, and an increased chance of errors and omissions through the time-constrained transcription process.

In addition, issues associated with the current approach of information transfer is the suitability of the information format for later use during operations and maintenance. Fallon and Palmer (2006) defined four major categories of information forms and formats as shown in *Fig 2*. Information is either structured or unstructured. Both can be proprietary or standard.

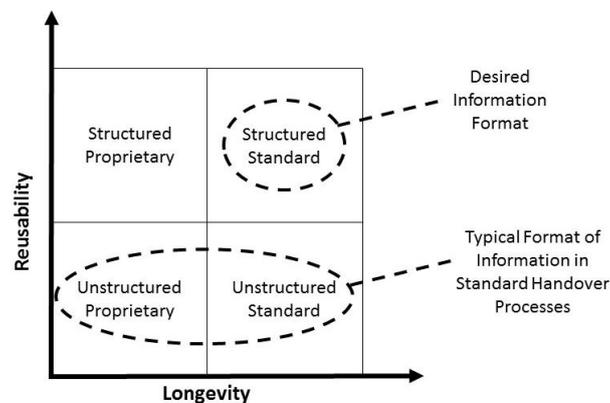


Figure 2: Longevity and Reusability of Information Forms and Formats (adopted from Fallon and Palmer, 2006)

“Structured data” can be accessed and manipulated directly by computer programs without human intervention and is the preferred form to be used in downstream automated processes or when regular updates are required. This form allows for automated—and therefore cost effective—search, retrieval, and update, while maintaining the intelligent information content. Structured information may be quantitative, descriptive, or graphical. There are a number of proprietary structured data models. Examples of structured data formats include information fields defined by the Construction Operation Building Information Exchange (COBie) (East 2007).

“Unstructured Data” is any data that cannot be machine-interpreted, requiring manually intensive interpretation and transcription by the facility staff. Examples include electronic images and electronic .pdf documents. This form of information is suitable for read only access but unsuitable for an automated framework.

Proprietary formats, also referred to as “native” formats, are created by and are the property of specific software vendors such as CAD programs. Longevity of such formats is sensitive to changes and modifications made by the vendor or discontinuation of the product, rendering the proprietary data unusable.

Standard formats include “Ad hoc” standards or “Formal” standards. “Ad hoc” standards refer to proprietary formats that have been made publically available and are supported by multiple vendors with published specifications. This assures data longevity. Examples include DXF and PDF. “Formal” standards are supported and maintained by official standards organizations such as the Industry Foundation Classed (IFC) maintained by the Building Smart Alliance (National Institute of Building Sciences buildingSMART alliance 2014). In addition to longevity of data stored in this format, it is also more flexible and useful given the format is typically developed through a consensus process.

The majority of the information submitted at handover is unstructured, with some being proprietary, and others standard. This is represented by the two lower left and right quadrants in *Fig. 2*. The most efficient format for the purpose of supporting maintenance and operations is structured and standard information. As shown in the top right quadrant of *Fig. 2*. Utilizing a standard and structured format greatly mitigates the need to identify, synthesize, and transform the data.

Within the construction industry and amongst facility owners, there is an interest in the utilization of BIM during the FM phase (Becerick-Gerber et al. 2012). The use of BIM as a repository of information is an intuitive step in the evolution of the submittal and O&M process, however the usage of BIM for data transference continues to be rare. The minimal use of BIM as a data transference tool can be attributed to a number of issues. Issues such as model updates, a shortage of BIM skills by FM staff, a lack of collaboration between project and end user stakeholders, contract and legal framework, and interoperability, all contribute to the low utilization of BIM for FM (Becerick-Gerber et al. 2012; East and Brodt 2007; Kelly et al. 2013; Teicholz 2013).

Arguably, the most complex issue faced by project teams, and where a significant amount of research has taken place, is interoperability. Within any project, a number of software may be utilized to design the facility, plan the work, store and exchange the information, and execute FM tasks. This creates a mismatch of file extensions and proprietary systems that cannot communicate together (Cleveland 2014). Recently, a significant push has been made to incorporate operations and maintenance information into BIM models for facilities maintenance and the linking to FM software. Through the use of BIM interoperability, virtual databases, and add-ons such as COBie, an improvement in O&M storage and retrieval has been achieved to some extent; however, these systems are still not evolved enough to handle all the interoperability. Due to the remaining inefficiencies within the system interoperability, a number of current market solutions have been developed to work-around the issues.

2.3 Current Market Solutions

The industry is quite aware of the handover issues and a great deal of research and development has been done in order to mitigate the problems. To date, four broad strategies for data handover exist in order to circumvent current market deficiencies – hard entry, interoperability, middleware, and proprietary systems. The decision to utilize one or more of these strategies, independently or in tandem, is based on a number of factors including existing hardware and software infrastructure, worker training, budget, and user system goals. A greater explanation of each strategy are as follows:

- Hard Entry – Utilizes attribute and value data inputs. Inputs can be stored in a 3D model or non-model format (i.e. Microsoft Excel).
- Interoperability – Utilizes software compatibility to transfer relevant information from the native/design file to the repository/coordination model.
- Middleware – A compatibility “bridge” that allows for non-interoperable software applications to transfer information (i.e. EcoDomus).
- Proprietary Systems – Utilizing systems such as Open Database Connectivity and API to develop user defined links for data transfer.

Often, in order to effectively execute data handover, two or more strategies must be utilized in tandem. Although handover issues are complex and current market systems remain imperfect, many problems can be circumvented with proper planning. Utilizing data exchange frameworks, analysis, and modeling, researchers and developers are actively working to synthesize and seamlessly bridge the gap between design, construction, and FM.

This section reviews three real life examples that utilized data transference and data storage in order to utilize BIM for FM. All of the examples below were executed in order to transfer O&M information in lieu of the safety information that is transferred within the proposed safety framework. Although the variation on data type exists, the processes/procedures employed are still relevant. This section will not present all the possible methods or software combinations and is not intended to present a comprehensive list of all BIM-FM examples, rather it is intended to show that data transference is possible if the appropriate planning takes place. It should be noted that although these instances would be considered successful data transference examples, each case identified limitations and issues associated with the transfer.

The examples presented here utilize summaries and schematic graphics to present data transference. Schematic graphics are intended to present a general flow of data between phases and software. The following examples all utilize Autodesk Revit in some capacity as a design software and/or O&M information repository. This circumstance is a reflection of the software popularity, not an inclusion criteria of this section.

2.3.1 Case 1: Using Hard Entry, Interoperability, & Middleware [EcoDomus] for BIM-FM Data Exchange

The USC School of Cinematic Arts initiated a project in 2007 requiring the construction of six buildings in three phases (Teicholz 2013). BIM was utilized for architectural, structural, and MEP disciplines and the implementation of BIM-FM was required from the start of the project. The USC case study is unique in the fact that as the phases progressed, so too did the requirements for BIM-FM implementation. The dynamic nature of this case study was a function of the learning curve that many BIM-FM projects experience. This case presents a project team that evolved along with the technologies and transference limitations. **Fig. 3** graphically presents the data transference path for the USC Case Study.

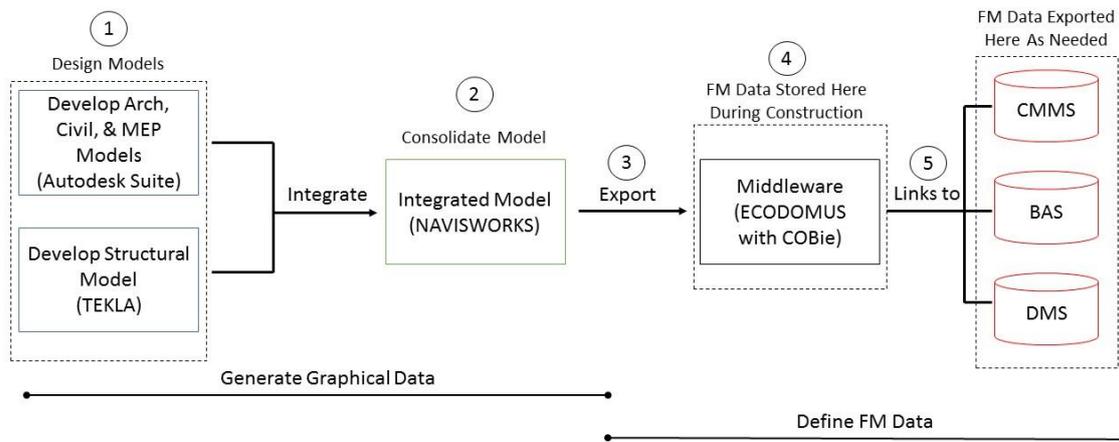


Figure 3: USC Case Study Data Transference Path

The following presents the flow of data utilizing the numbers presented within **Fig 3**.

1. Architecture, MEP, Civil, and some structural models were created in the Autodesk suite, while the structural engineer utilized Tekla for structural design.
2. The various models were appended into Navisworks to create a comprehensive model and utilize tools such as clash detective for trade coordination. The data being transferred at this point is largely graphical.
3. The comprehensive model along with some FM applicable data was exported to EcoDomus, a middleware software (EcoDomus Inc. 2016).
4. EcoDomus was the primary repository for FM applicable information, as well as the mechanism for transferring data to USC's three online based FM software (CMMS, BAS, and DMS). Much of the data placed into EcoDomus was hard entered into the system or transferred from models via COBie.
5. EcoDomus software also maintained direct links to the online based FM software for easy reference.

As previously mentioned, the project team was aware of the requirements for implementing BIM-FM, but a detailed understanding of what that entailed continued to evolve along with the project. Aside from these planning issues, a few software limitations were identified within this case study. These limitations are presented below.

- At the time of this case study, direct transference could not be executed between the BIM authoring tools (Revit & Navisworks) to the CMMS System. This required the use of EcoDomus, as a true middleware, for items created in Revit that are better suited to be stored in the CMMS System (i.e. component schedules).
- Not all subcontractors maintained a Revit license and therefore the use of 3D models during the construction phase needed to be exported as 3D DWGs and imported into compatible software.
- The use of COBie wasn't implemented until Phase 3 (the final phase) and therefore a definition of what data was needed to be transferred and how that data is stored was vague and disorganized leading up to that point.

This case study presents a number of complex software and planning issues. In spite of that fact, it stands as an excellent example of problem mitigation and team collaboration. This case successfully transferred and organized significant amounts of data utilizing software with minimal interoperability. The use of middleware (EcoDomus) played a large role in this implementation, as a data storage and transference mechanism. As interoperability continues to evolve between FM software and design/coordination software, the cost and software requirements for BIM-FM will likely improve.

2.3.2 Case 2: Using Interoperability & Middleware [FM Interact] for BIM-FM Data Exchange

Mathworks, Inc. initiated a project in 2005 to add a building to their existing corporate campus (Teicholz 2013). A major factor in the award of the contract was the implementation of BIM. Similar to many owners implementing BIM-FM for the first time, the level of development and requirements for data evolved along with the project. Additionally, many of the subcontractors had various levels of 3D modeling capabilities and therefore a third party BIM consultant was utilized to create a comprehensive Revit model. **Fig. 4** presents the data transference path for this project.

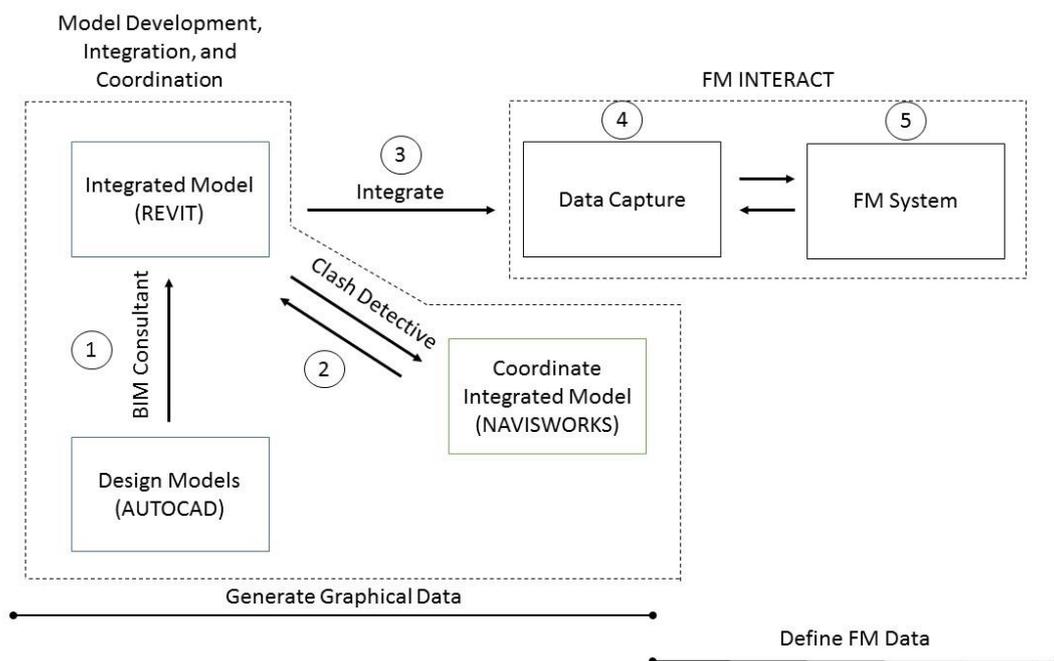


Figure 4: Data Transference Path for MathWorks, Inc. Case Study

The following presents the flow of data utilizing the numbers presented within **Fig. 4**.

1. A BIM Consultant is contracted to develop 2D AutoCAD models, completed by the various project team entities, into a comprehensive 3D model with a link to the existing 3D architecture shell, core, and interiors. Ultimately, a linked Revit model would serve as the final comprehensive model. Data during this phase of the project is almost exclusively graphical.
2. The linked model uses clash detective within Navisworks to prevent conflicts within the 5 linked models.
3. The BIM model, along with the equipment model, properties, and manufacturing information assigned to each piece of equipment, is integrated into FM Interact. These systems have built in interoperability.
4. Once integrated into FM Interact, data can be added or adjusted within the Revit model through the FM Interact add-in.
5. FM staff can access important FM data and model graphics through the FM Interact online portal.

The limitations encountered by the project team are as follows.

- As with many projects involving subcontractors, not all project entities had 3D capabilities. In many cases, implementation of BIM-FM would require the 2D drawings be developed into a 3D model. In addition to the need to redesign the subcontractor’s drawings into a 3D model, which takes time and money, relevant data needs to be added later as the 3D models become available.
- Initially, the owner was not aware of the information they would need for FM. COBie was later used as a reference source, but not as a data transfer mechanism. Without using COBie as a data transfer mechanism, applicable information had to be hard entered into the system.

This case study is a good example of a project that contains varying levels of 3D modeling capabilities. The implementation of BIM-FM requires that all applicable systems be modeled. Without these capabilities, additional considerations and cost allocations are needed to get these systems into the appropriate format.

2.3.3 Case 3: Using Interoperability and Proprietary Systems [BIMFMM] for BIM-FM Data Exchange

The BIMFMM Case study is a research project executed by Lin and Su (2013) that utilizes Revit, Navisworks, Open Database Connectivity (ODBC) and a number of subsystems to create the BIMFMM mobile system. The BIMFMM system was designed to allow for FM staff to access real-time BIM models and relevant FM data within the field utilizing a mobile device. *Fig. 5* presents the data path of relevant FM information when implementing the BIMFMM system.

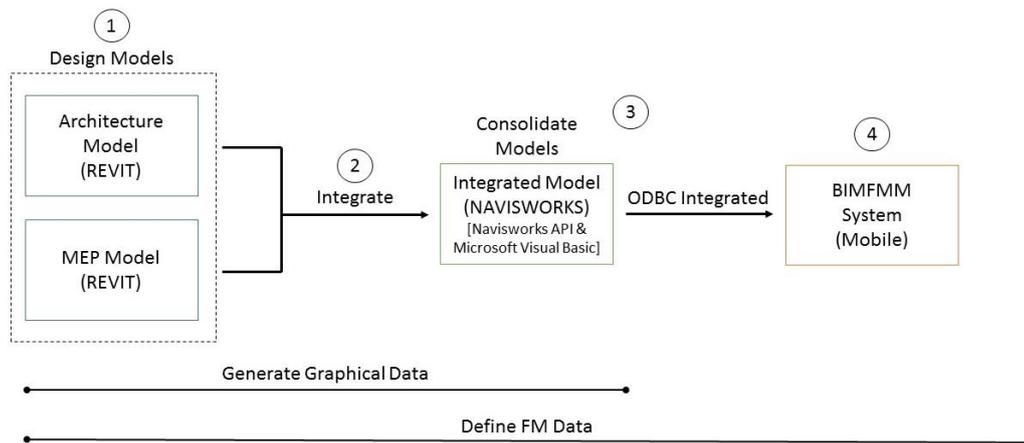


Figure 5: Data Transference Path for BIMFMM Case Study

The following presents the flow of data utilizing the numbers presented within *Fig. 5*.

1. Revit Architecture and Revit MEP are utilized for graphical representation of the facility, as well as data storage. The BIM models retained basic description data, parameter-related information, maintenance records, and facility maintenance management reports.
2. Navisworks was utilized as a model integrator to create a comprehensive model.
3. Information integration between the 3D models was achieved by writing code using the Navisworks API and Microsoft Visual Basic.NET programming language. This was done in order to filter the needed information and eliminate the information that was not relevant to the system. Lin and Su (2013) describe the system integration as follows,
“The BIMFMM system was developed by integrating the 3D BIM models of facilities and maintenance-related information using Navisworks API programming. Open Database Connectivity (ODBC) was utilized to integrate acquired data from different software programs and all maintenance information, such that BIM files can be exported to an ODBC database for connection with the BIMFMM system.”
4. The BIMFMM system utilizes a number of internet-based subsystem modules and SQL servers to provide up-to-date information to the mobile devices in the field.

The limitations encountered by the project team are as follows.

- BIM models require constant updates as new equipment is purchased, maintained, or replaced. A system needs to be in place to address these future updates.
- As data is integrated within the BIM models, the NWD files become quite large and cumbersome to download from the SQL servers. Downloads would range from 2-5 minutes.

2.4 Summary

As the above examples show, there are multiple ways to circumvent the interoperability issues inherent with varying software applications and various levels of modeling capabilities. To date, there is no single accepted method of data transfer between platforms. By continuously testing new and varying transfer processes, valuable “take-aways” can be identified from a given system based on the success or failure of a transfer mechanism. Through the lessons learned, the data transfer mechanisms employed within the proposed safety framework is developed. This research provides a mechanism for data transfer that utilizes existing tools within a single modeling software and Excel, without the need for middleware or proprietary software. This will minimize the learning curve and cost of effective data transfer.

3 DATA TRANSFER MECHANISM FOR THE BIM-BASED SAFETY FRAMEWORK: A CASE STUDY

For this research, two basic input phases are utilized as shown in *Fig. 6*, a combined design and construction phase and a FM phase. Through multiple avenues of input, from different contract entities, at various times in a building’s lifecycle, safety relevant information can be stored within the appended Navisworks model.

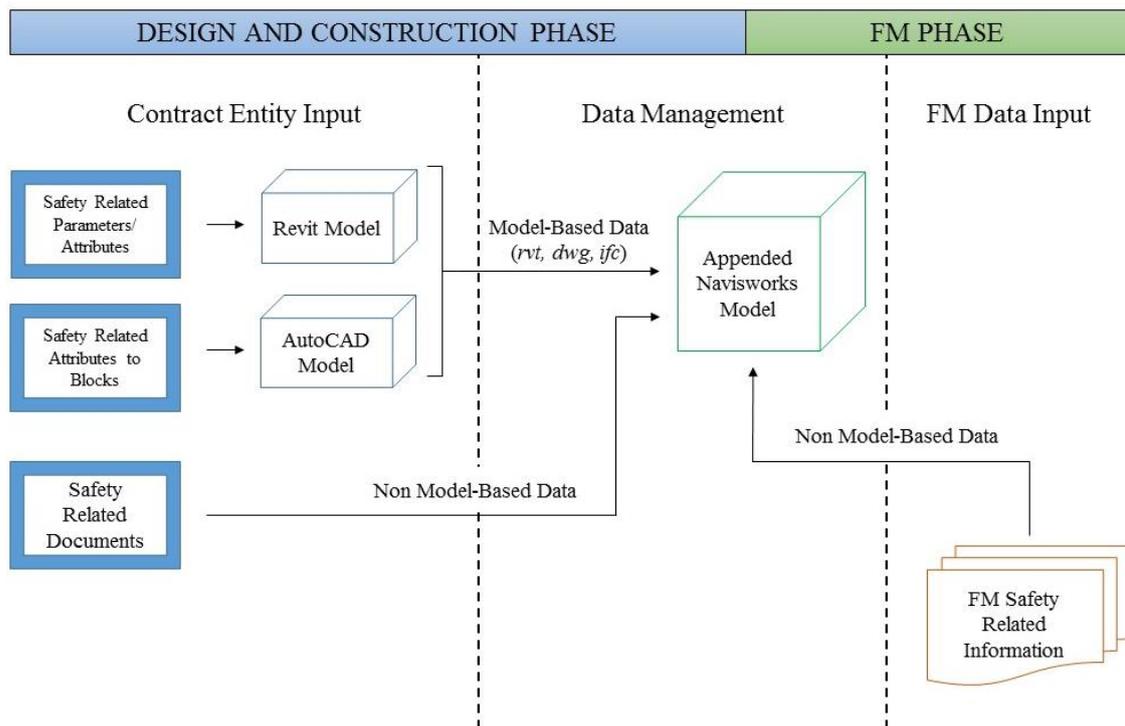


Figure 6: Data Inputs at three input phases

In conjunction with the multi-phased input, this research incorporates two of the four data handover strategies presented in Section 3.2 – Interoperability & Hard Entry.

1. Data Input Through Interoperability:

Relevant safety information captured by the design/build team (i.e. contract entity input) are stored as parameters or attributes in the native models that are directly imported (i.e. appended) into the federated Navisworks model. This model-based approach for data capture and exchange can use various file formats for the 3D model (populated with the necessary safety relevant data) including .rvt and .dwg, or .ifc formats.

2. Hard Entry:

Non model-based relevant safety data produced during the design and construction phases or additional needed safety information defined by FM staff during the O&M phase are entered into the appended Navisworks model using direct input, utilizing two data entry tools: Selection Inspector and DataTools.

Fig. 7 graphically presents the overall data transfer mechanism employed within the BIM-based safety framework, while Section 3.1 provides a proof concept example.

The following is a detailed description of the different steps of **Fig. 7**:

1. Relevant safety information generated by various contract entities (designers, consultants, GC, and trades) are captured and stored as parameters/attributes in corresponding native models and appended into a single federated BIM using Navisworks. This model-based approach of data loading a model is efficient, as interoperability between many file extensions and Navisworks allows for a graphical and data transfer.

When appended in the Navisworks environment, safety data from each model is grouped under a different tab with a system-defined name dependent on the native file format imported.

In order to make changes to the model-based data, add other non model-based data (generated by contract entities or FM staff), or reorganize and group all data under a single tab with a user defined name, data needs is exported, modified, and imported back to the federated model. This is achieved using the export and import data manipulation tools from Navisworks: Selection Inspector and DataTools respectively.

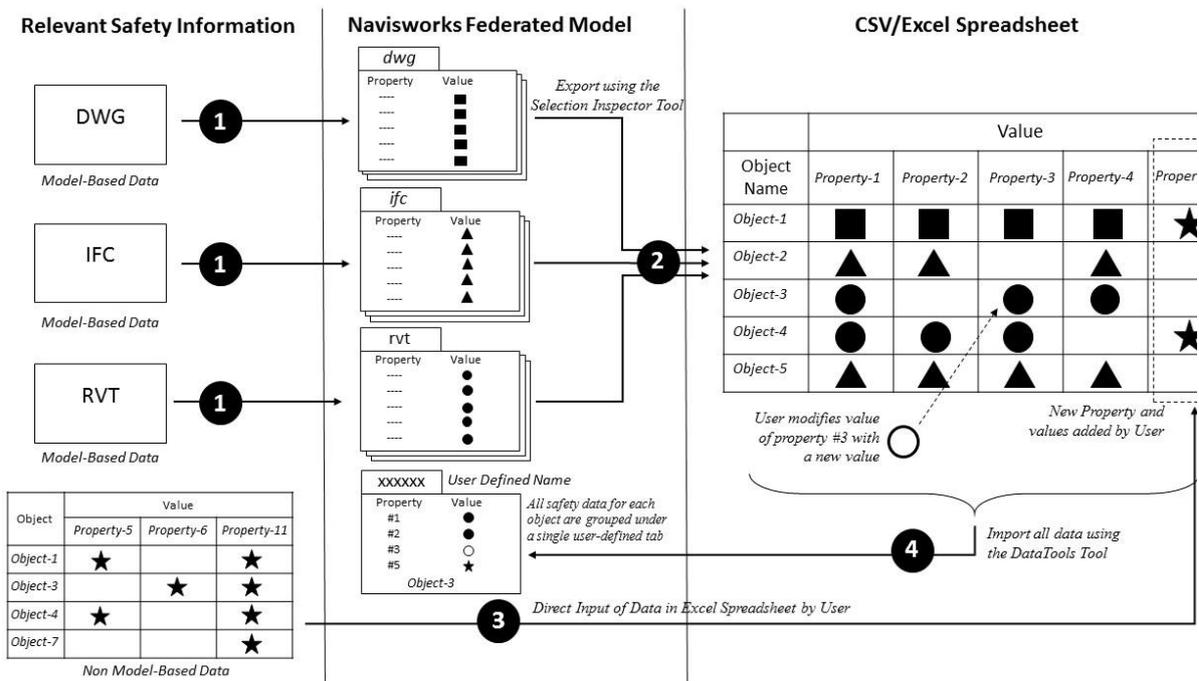


Figure 7: Data Transfer Mechanism within the Safety Framework

2. Using the Selection Inspector tool in Navisworks, appended safety information is filtered for graphical objects representing the specific equipment targeted for maintenance. Data is then exported to a CSV file and saved as an Excel file for modifications. Edits to the data can be manually entered in the Excel spreadsheet
3. Non model-based relevant safety data is directly input by the user in the excel spreadsheet. The user can define new properties (columns) and values for the corresponding objects, or can modify existing properties exported.
4. Once all modifications have been made and new properties and values are added, all data is imported back into the appended Navisworks model using the DataTools function. A user-defined name is given for the new tab under which all appended safety information will be saved for each graphical object.
 - a. Additional safety data can be added directly within Navisworks with the Add New User Data Tab function. This allows for some flexibility of data input as long as the amount of information to be added is small.

Once all data modifications and manipulation are complete, all relevant safety information for the equipment targeted for maintenance is exported and used to interact with the DPRBS.

3.2 Data Transfer Mechanism Proof of Concept

This section presents an example of the data transfer mechanism described in *Fig. 7*. The proof of concept model, presented in *Fig. 8*, is a representative model of a compressor room in an ice skating rink. This model presents a partial compressor package and electrical system with many of the room and compressor elements removed in order to provide clarity to the equipment being utilized within the proof of concept. By presenting a compressor room, a number of hazards can be presented in a single space. Hazards present within an ice skating compressor room include hazardous energy, chemicals (ammonia), automated rotating mechanisms (motors), hazardous decibel levels, overhead equipment, pressurized lines, and heat producing assets. In addition, *Fig. 8* presents the equipment that this proof of concept will utilize, a 480V electrical panel, a pump, and a compressor.

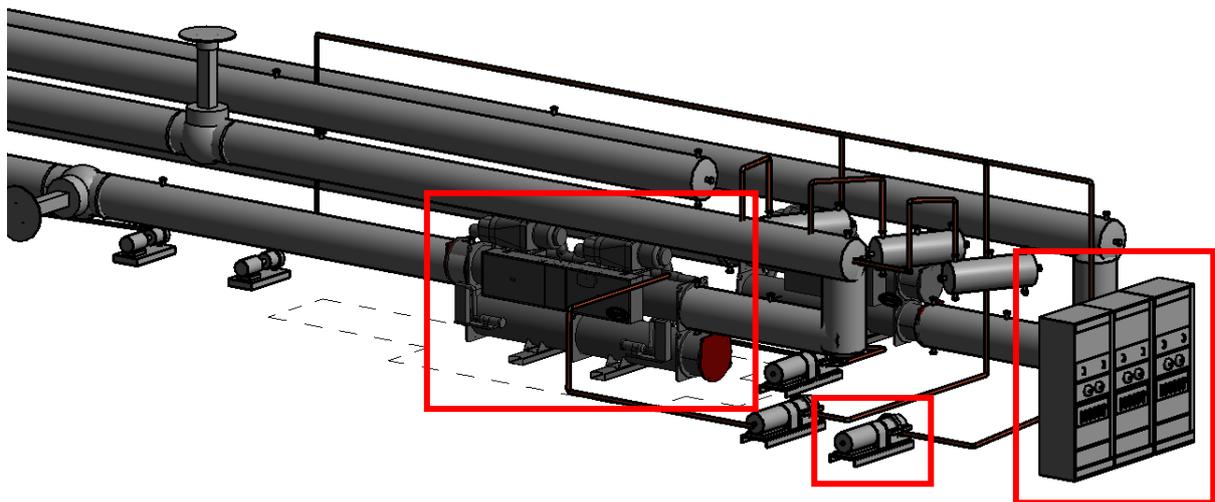


Figure 8: Proof of Concept Model – Compressor Room

In this proof of concept, applicable safety information is loaded into the graphical model through three data transfer mechanisms. First, existing information is input into the native design file developed in Revit 2016. This is executed through the use of shared/project parameters that are assigned to pieces of equipment. This phase simulates the input of data at the design/construction phase, or the “Native BIM-Model” method of transfer presented in *Table 1*. Once shared or project parameters are added to the project and input into the various applicable equipment, the properties and associated values can be manipulated through Schedules/Quantities in

Revit 2016. Completion of the “Native BIM-Model” input phase is succeeded by a model export from Revit 2016 into Navisworks Manage 2016. Bringing the design model into Navisworks allows for other models in compatible formats (.rvt, .ifc, .dwg), executed by others, to be brought into a single model space for coordination. Once appended into Navisworks, the safety inputs within the various models are available in the “Properties Tabs” of each piece of equipment. The name of this tab, the presentation of the safety inputs, and the other properties available within each tab is a function of the native file extension being brought into Navisworks.

Table 2 presents the “Native BIM-Model” inputs utilized in this proof of concept and **Fig. 9** presents how the information is presented in Navisworks Manage 2016.

Table 2: Proof of Concept Data Inputs

Equipment	Property	Value
Pump	Electrical Disconnect Location	Panel 103A
	Voltage	460V
	Approx. Disconnect Distance (in feet)	4
	Valve Location	V106
	Approx. Valve Distance (in feet)	8
	Heat Producing Asset	Caution - Hot
Electrical Panel	Voltage	480V/3-0 VA
	Electrical Disconnect Location	Local
	Approx. Disconnect Distance (in feet)	0
Compressor	Voltage	480V/3ph/60Hz
	Electrical Disconnect Location	Panel 103B
	Approx. Disconnect Distance (in feet)	12
	Automated Rotation	Yes
	Heat Producing Asset	Caution - Hot

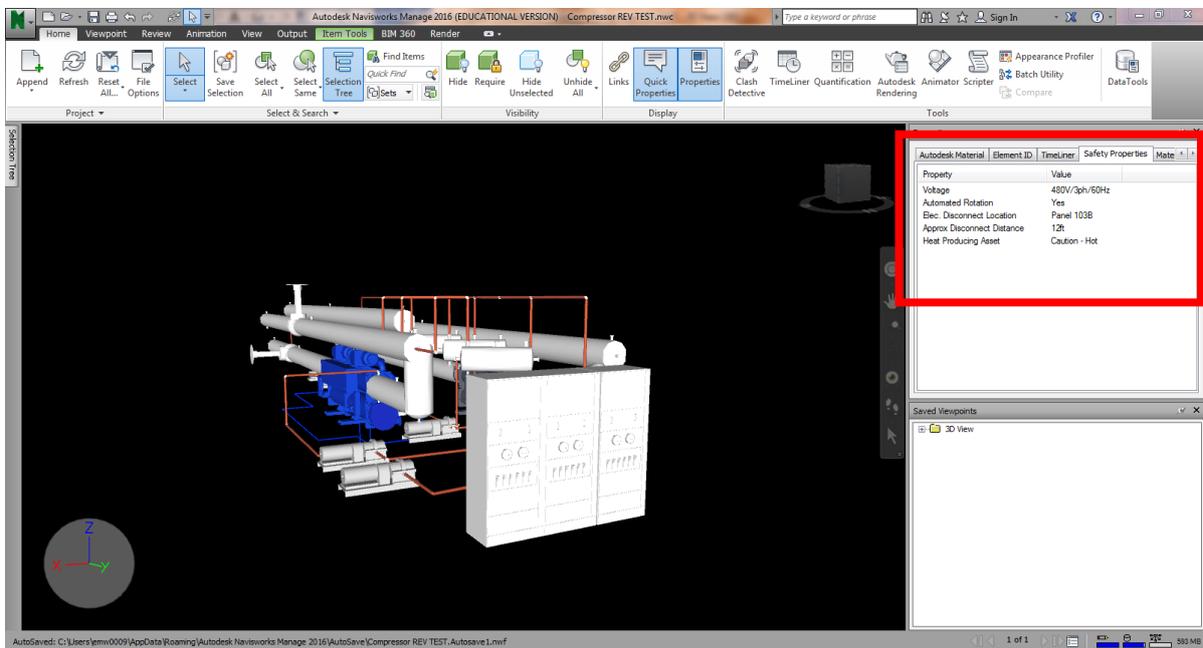


Figure 9: “Native BIM-Model” Inputs in Navisworks Manage 2016

Beyond the “Native BIM-Model” inputs, and as additional safety inputs become available throughout the building’s lifecycle, two additional mechanisms of data transfer can be utilized. “Non 3D” and “FM Safety Related Information” data inputs from **Table 1**, are both represented within this phase and are executed using one of two data transfer mechanisms:

1. Add New User Data Tab in Navisworks 2016
2. Using Selection Inspector and DataTools to add data externally in an Excel file and re-import into the model.

Although both data transfer mechanisms result in the same comprehensive, safety data loaded model, the selection of which mechanism is important for efficiency and organization. The use of Add New User Data Tab is most efficient when inputting safety inputs for a single, standalone piece of equipment. This scenario is likely when FM staff install a new or updated piece of equipment and the safety inputs need to be added to the graphical element. Using Selection Inspector and DataTools is utilized when bulk additions or inputs are required for a system. This transfer mechanism is also recommended for most “Non 3D” data inputs as the information is likely in various formats (.doc, .pdf, .xls, etc.) when being submitted to the FM entity.

3.2.1 Add New User Data Tab

Once appended into the Navisworks model, additional relevant safety data that was not input into the native model, can be added using Properties > Add New User Data Tab. The use of Add New User Data Tab is a viable solution for adding information to individual pieces of equipment. For bulk data loading, the utilization of DataTools and Selection Inspector is recommended. This is discussed further in Section 3.1.2. In this proof of concept, the safety property “Automated Rotation” will be added to a new Properties Tab titled “Additional Safety Properties.” To add a new tab, right click in the properties space and Add New User Data Tab. This creates a blank tab titled “User Data.” Right clicking in this new tab allows the user to Rename Tab and Insert New Property. **Fig. 10** presents the new safety property input into the compressor package.

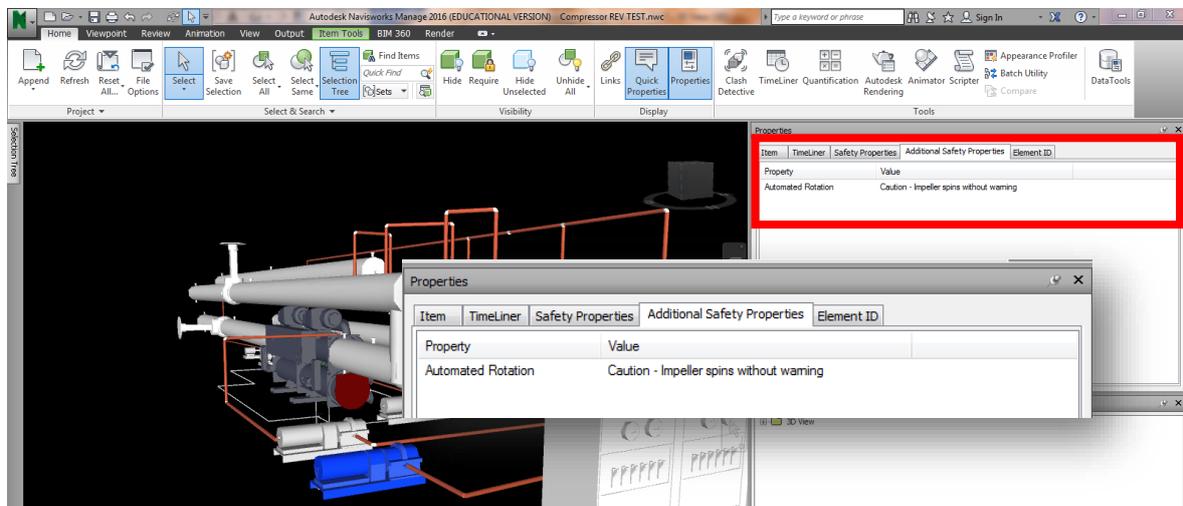


Figure 10: User Defined Safety Property Using “Add New User Data Tab”

3.2.2 Selection Inspector and DataTools

The utilization of Selection Inspector and DataTools within Navisworks is a viable option to add or adjust multiple properties to a number of graphical elements. This process, although more labor intensive than previously presented processes, allows for data loading of multiple graphics. For this proof of concept model, a typical concern within a compressor room is the significant environmental decibel level that is generated when the compressor system is running. Because of this, hearing protection is required in the compressor room. In order to

add this safety property to the environment (room), all pieces of equipment will inherit this safety property. By doing this, the safety property will be presented regardless of the user's equipment selection.

In order to add additional safety properties or adjust existing user defined properties to each piece of equipment, Selection Inspector and DataTools are utilized export and re-import safety information. Selection Inspector allows for the filtering of specific properties for selected pieces of equipment. This step is important in order to identify which properties a user wants to adjust or place into a new properties tab. DataTools is utilized in order to re-import the added/adjusted information back into the graphical model. **Fig. 11** presents the relevant information that needs to be exported using Selection Inspector for this proof of concept, while **Fig. 12** shows the added information in the exported CSV file. It is important to note that this type of data manipulation requires Microsoft Office 64-bit.

- Property: Environment Decibel Level (dBA)
- Value: 105

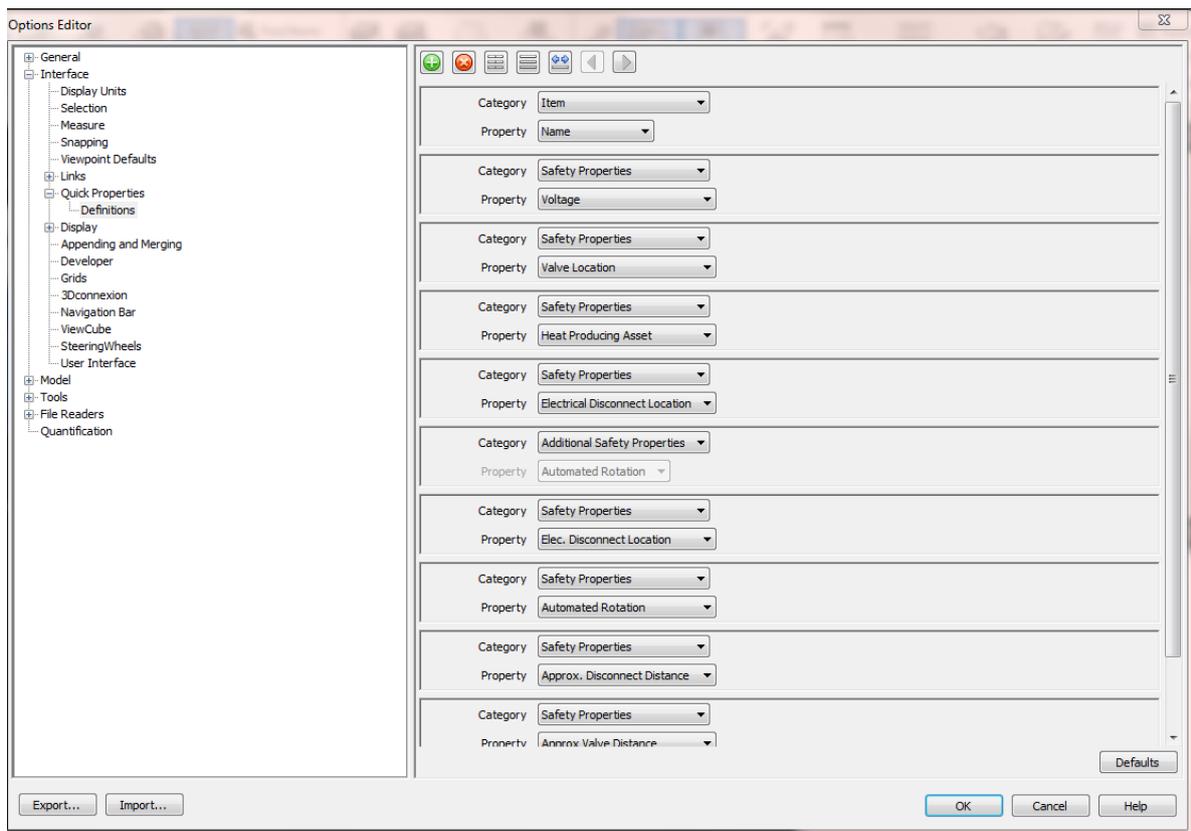


Figure 11: Selection Inspector Export

Item Name	Environment Decibel Level (dBA)	Safety Properties Voltage	Safety Properties Valve Location	Safety Properties Heat Producing Asset	Safety Properties Electrical Disconnect Location	Additional Safety Properties Automated Rotation
Compressor1	105	480V/3ph/60Hz		Caution - Hot	Panel 103B	
Centrifugal Pump	105	460V	V106	Caution - Hot	Panel 103A	Caution - Impeller spins without warning
M_Panel103A	105	480V/3-0 VA			Local	

Figure 12: Exported Safety Information and Added “Environment Decibel Level (dBA)” Data

Once the new information is added to the Excel Worksheet, the file needs to be saved as an XLS. This needs to be done in order to reimport using DataTools. At this stage, Navisworks should be reopened and Data Tools launched. A new DataTools Link needs to be added. **Fig. 13** presents the information that must be added in order to map the Excel file to the graphics of the Navisworks file.

Name: Safety Properties

Connection: ODBC Driver
Microsoft Excel Driver (*.xls, *.xlsx, *.xlsm, *.xlsb) [Setup...]

DBQ: C:\Users\jmmw0009\Desktop\Dissertation\ITCon Paper 2016\S.I. Export.xlsx;DefaultDir=C:\Users\jmmw0009\Desktop\Dissertation\ITCon Paper 2016;Driver={Microsoft Excel Driver (*.xls, *.xlsx, *.xlsm, *.xlsb)};DriverId=1046;FIL=excel 12.0;MaxBufferSize=2048;MaxScanRows=8;PageTimeout=5;ReadOnly=1;SafeTransactions=0;Threads=3;UID=admin;UserCommitSync=Yes;

Hold open for application lifetime

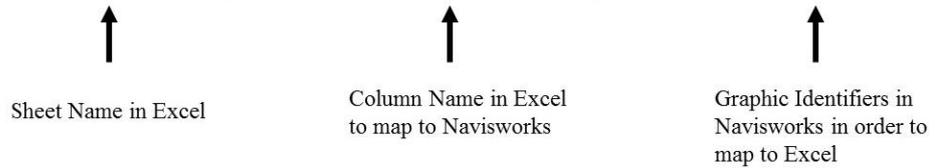
SQL String: SELECT * From [S.I. Exports] Where "Item Name"= %prop ("ITEM", "NAME") ;

Field Name	Display Name
Name	Name
Environment Decibel Level (dBA)	Environment Decibel Level (dBA)
Voltage	Voltage
Valve Location	Valve Location
Heat Producing Asset	Heat Producing Asset
Electrical Disconnect Location	Electrical Disconnect Location
Automated Rotation	Automated Rotation
Approx. Disconnect Distance	Approx. Disconnect Distance
Approx. Valve Distance	Approx. Valve Distance

Figure 13: Data Tools Information

1. A name is given to the new DataTools Link. This name will become the name of the properties tab in Navisworks that includes all of the properties identified in the “Fields” area.
2. Using an ODBC Driver connection, a link is made between the Excel file and the Navisworks file. Upon selecting the file in Setup. The mapping of the two files is automatically generated.
3. An SQL String needs to be written in order to link the information in the Excel file to the applicable graphics in the Navisworks file. This is executed by mapping the specific equipment name, known as “Item Name” in Navisworks, to the “Item Name” column in Excel. The SQL String reads as follows:

```
SELECT * From [S.I. Export$] Where "Item Name"= %prop ("Item", "Name")
```



4. User needs to input the Field Name they wish to see under the new developed “Safety Properties” tab. For this example, the “Name” of the piece of equipment and the added “Environment Decibel Level” property will be mapped to the graphics. Only properties that have values will be transferred to individual graphics. **Fig. 14** presents the added safety properties in the newly developed “Safety Properties” tab for the electrical panel upon the execution of the DataTools process.

This process can be repeated to add or update information.

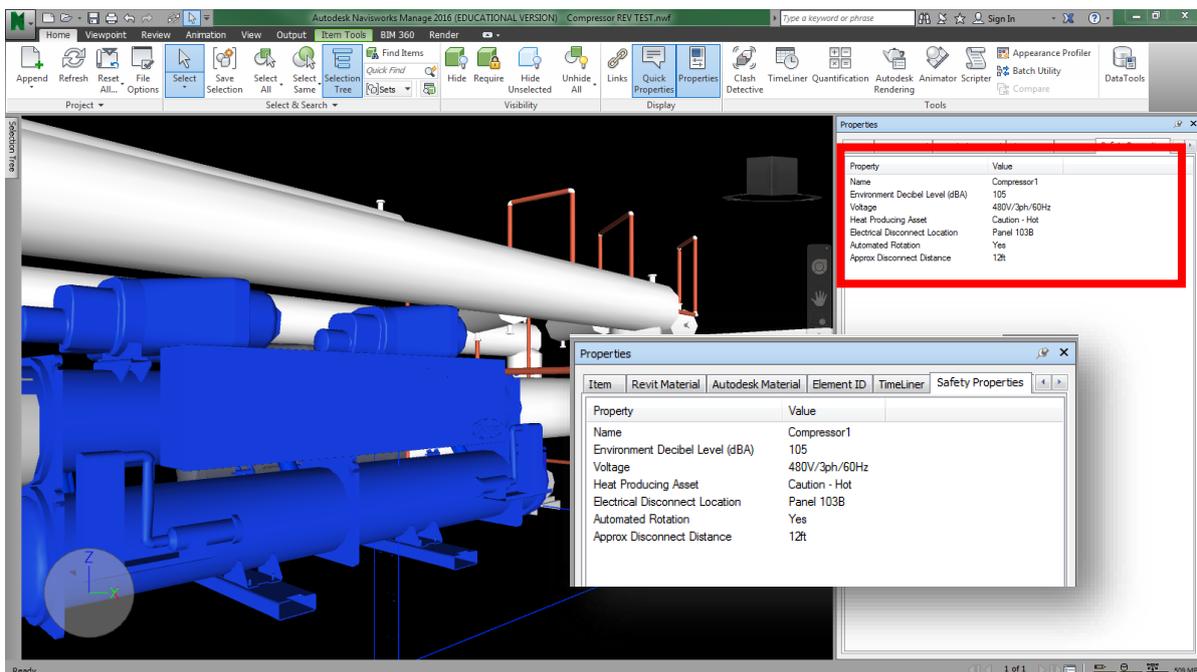


Figure 14: Added Safety Properties Under New “Safety Properties” Tab

3.3 Stored Safety Data to DPRBS

Once all the relevant safety information is stored in the Integrated BIM Model, launching the DPRBS adds logic and guides the information exchange of the safety data. As described in Wetzel and Thabet (2015), “Based on the values assigned to the properties, rules and process models guide the information logic and present the information via a graphical user interface (interface). The interface is developed to produce applicable safety protocols based on two factors:

- a. The information present in the asset selected, known as a “Direct Command.”
- b. The responses given by the user to a series of questions that the GUI is programmed to ask, known as a “Launch System.”

A “Direct Command” automatically sends the relevant safety information to the safety protocol sheet stored in the system. Additionally, “Direct Command” launches a query system to identify task specific protocols based on the values associated with a specific piece of equipment. For example, the maintenance elevation of valve within a

given system is at 10ft above finished floor. At 10ft, a lift system would be necessary in order to access the valve. The DPRBS would recognize the valve at an elevation that requires a lift system and execute a “Launch System.”

The “Launch System” queries the user in order to provide a safety protocol that is specific to the impending task. A “Launch System” query regarding a lift system would ask the user what type of lift system they intend on using, for example, a ladder, a manlift, scaffolding, etc. Depending on which selection the user chooses, a safety protocol output is sent to the safety protocol sheet describing the safety process for the selected lift system. *Fig. 15* schematically presents this portion of the safety framework.

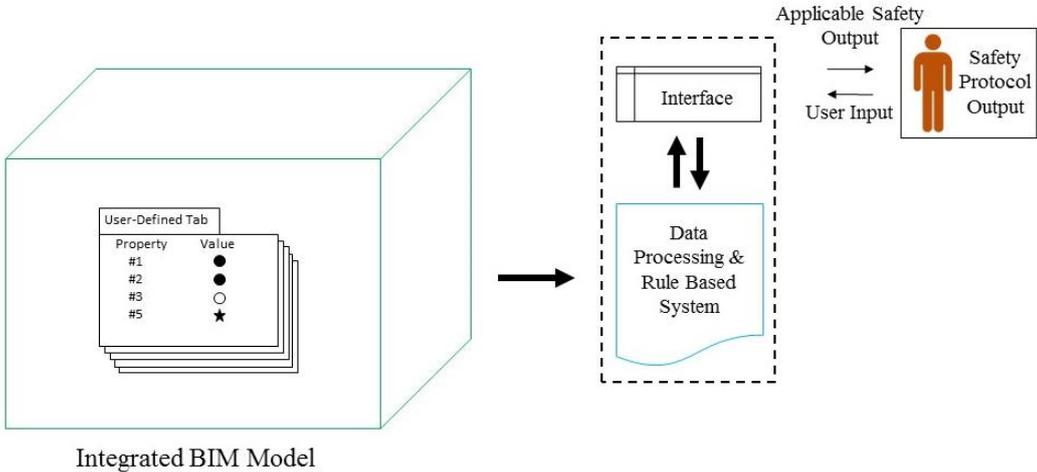


Figure 15: Stored Safety Data interacting with the DPRBS and Interface

4 CONCLUSION AND DISCUSSION

A significant portion of the Safety for Facilities Maintenance Framework relies on the dataflow of information from the design phase through the FM phase of a building’s lifecycle. Reviewing existing literature provides a basis for current market trends in data flow and provides an accounting for the various formats, contract entity technology availability, and input time; all of which are vital to the implementation of the SFFM Framework. The case study used in this research focuses on existing tools in Revit and Navisworks to transfer relevant safety information. As the research has shown, using a single modeling program application, with existing tools is a unique approach. Research efforts to date, have had to write proprietary algorithms or use multiple software (e.g. middleware) to achieve data transfer. Utilizing existing tools within Navisworks, eliminated the need for proprietary software or current market middleware, minimizing the learning curve for FM users; however, this method of data transfer may not be the most efficient. There are multiple steps needed in order to transfer the data and requires a thorough understanding of Excel and Navisworks. Using the Selection Inspector function of Navisworks to export relevant data to an external Excel Spreadsheet to be reviewed and modified, then using the Datatools function of Navisworks to import the modified data back to the model is a tedious process due to the many manual entry steps required by the user, particularly during the data import. This is mainly because the Datatools function requires many setup steps by the user including a lengthy SQL string in a specific format making the process tedious and subject to misspelling errors that would prevent the import function from working.

The researchers have explored the use of other methods for exchange of data between Navisworks and external data sources. NavisTools™ is a plugin for Navisworks that allows linking Navisworks to external data sources, including Excel and SQL databases, to exchange data in a seamless approach requiring minimal user-friendly steps (CodeMill 2017). If used, Navistools would replace the Selection Inspector and Datatools functions and would make the data exchange process easier and more efficient. Dynamo™ is another tool that is being explored by the researchers to export data from Revit. While not geared to work for Navistools, Dynamo is a

visual programming tool that provides flexibility and powerful functionality allowing the user to export data from a Revit model to an Excel spreadsheet in various user defined formats (Autodesk Inc. 2017).

Upon completion of data loading the model with asset-specific safety information, users can interact with the DPRBS in order to receive comprehensive safety information in an efficient manner. Consolidating and presenting the task specific safety information to the user in an efficient and user-friendly manner will likely improve a FM worker's willingness to interact with the system and aid in the mitigation of incidents. Future research will finalize the DPRBS interface and validate the data processing through interviews with experts. A pilot study, using existing facilities could be conducted with additional usability testing to the developed framework and interface.

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