"THE EXPLORATION OF BIM AND VISUAL DATA FOR OWNER BENEFITS"

by

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ABSTRACT

JESSE M. MALLARD. Exploration of how Building Information Modeling (BIM) and visual data is used within the Architectural Engineering and Construction (AEC) Industry currently to assist in closing the knowledge gaps between Owners and Design and Construction Teams. (Under the direction of DR. GLENDA MAYO)

Owners and their Facility Management (FM) teams face many challenges when handover is complete. The most significant challenges relate to ensuring the data provided can be adequately used for the facility to operate at its optimum performance. In recent decades technology has improved to provide solutions to some issues faced. However, the industry still lacks proper processes for storage and use of the data provided. Building Information Modeling (BIM) and other forms of visual data (i.e. 3D Laser Scanning and 360-degree photographs) have the potential to act as data libraries for the FM team to utilize during the Operations and Maintenance (O&M) phase, but the format to accommodate this project phase is lacking. The results of an in-depth literature review and a survey focusing on current uses, challenges, and requirements of BIM and visual data will be presented. Results of these analysis methods show that Owners and their FM teams need more knowledge on processes for successful adoption of BIM and visual data formats. The gap between Owners and Design and Construction teams must first be closed for the Owners to reap the potential benefits of BIM and visual data.

DEDICATION

First, I would like to dedicate this thesis to my parents. They have instilled in me a strong work ethic and determination that I used continuously throughout this research. I could not have made it this far in my academic career without them and their support. Words could never describe the appreciation I have for them, what they have done for me, who they have helped me become, and the values they instilled in me.

Next, I would like to dedicate this thesis to my partner, Brandi. She has helped support me through this incredible journey with continuous motivational words that helped me push through when I thought I got in over my head.

Last, I would like to dedicate this thesis to my mentor and professor Dr. Glenda Mayo. Dr. Mayo is the reason I even considered graduate school and taking on a thesis. She has helped me improve my writing and analytical skills required to complete this adventure, as well as my academic career. She pushed me to reach beyond what I thought were my limits and in turn allowed me to learn more about myself as a student and a person, all of which I will use the rest of my life. I appreciate all each have done for me.

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LIST OF ABBREVIATIONS AND TERMS USED

AEC – Architectural, Engineering and Construction

IFC – Industry Foundation Classes – Open data standard/specification allowing for FM data requirements to be collected in early project stages.

COBie – Construction Buildings Information Exchange – Open data standard/specification allowing for FM data requirements to be collected in early project stages.

CAD – Computer- Aided Design

RFI – Request for Information

CMMS – Computer Maintenance and Management System

AiM – Asset Information Model

AIR – Asset Information Requirements

IDM – Information Delivery Manual

OPR – Owners Project Requirements

BEPs – BIM Execution Plans

LOD – Level of Development

CAFM – Computer-Aided Facilities Management

O&M – Operations and Maintenance

ML – Machine Learning

Geometric Data – Data containing an elements geometry (i.e. construction drawings)

Non-Geometric Data – Data containing verbal descriptions (i.e. inspection and testing reports)

GIS – Geographic Information System

GPS – Global Positioning System

MR - Mixed Reality

VR - Virtual Reality

AR - Augmented Reality

IVE – Immersive Virtual Environment

GC – General Contractor

MEP – Mechanical, Electrical and Plumbing

IPD – Integrated Project Delivery

AiA – American Institute of Architects

IT – Information Technology

3D Point Cloud

IQA – Information Quality Assessment

CSF – Critical Success Factor

Scan-to-BIM – the conversion of point cloud data into an “as-built” BIM.

CHAPTER 1: INTRODUCTION

Owners struggle with the amount of data that is provided during handover. To review the importance of specific data and the uses of that data, the research is approached with a broad perspective (as an update to the industry state of practice) of BIM (Building Information Modeling) and visual data use for Facilities Management. BIM is an innovative, digital representation of a facility that contains functional characteristics for decision making during the lifecycle of the facility (Azhar et al., 2015; NBIMS, 2010). The goal is to explore, more specifically, the formats and uses of visual data (i.e. 3D laser scanning and 360-degree photography). The primary source of information for the state of practice was a survey distributed to Facility Managers/Owners. However, additional research included the focus on specifically the visual data. Visual data is often collected as part of the construction process, but very little research has been conducted to date to document not only its use but also its potential within FM.

Figure 1.2 below illustrates that research was approached from a broader perspective as an update to the state of practice of BIM and visual data use for FM. The orange box is the overall BIM umbrella which is where my research began. Then it works to more detail focusing on handover deliverables (blue boxes) to answer the overall methodology questions of why data is vital as well as how it is collected and used for FM purposes.

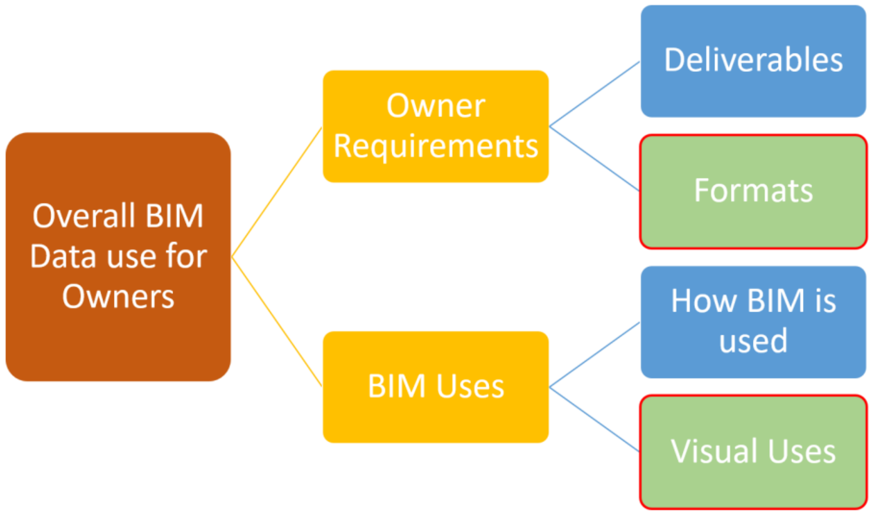

Figure 1.2 Research Plan – Formats and Uses

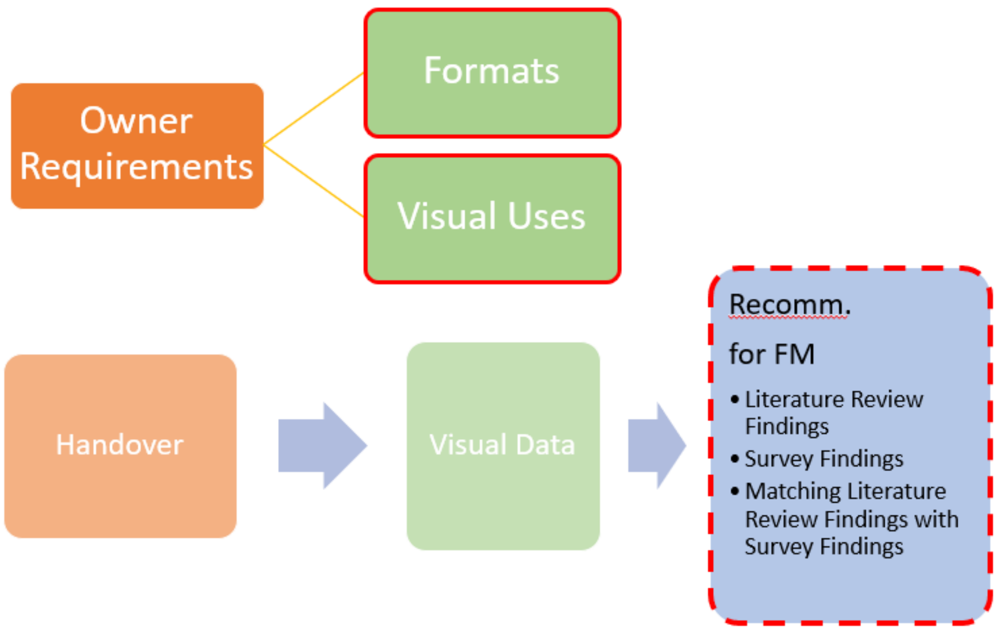

Figure 1.3 Plan - FM Recommendations

Recommendations for FM will be reported based on the literature review and survey results, along with a comparison of the two. The visual above (Figure 1.3) highlights that the portion of the research that focused on Owner requirements, specifically looking at formats and visual data uses.

CHAPTER 2: LITERATURE REVIEW

2.1: What documentation and data is needed for Facility Management (FM) tasks?

Facilities Management (FM) has been defined as a "multidisciplinary profession to ensure the functionality of the built environment by integrating people, place, process, and technology" (*International Facility Management*, 2013).The FM and Operations & Maintenance (O&M) phase of a building are terms that are of often interchanged. The FM stage of a building is the longest of the project stages and accounts for two-thirds of the building lifecycle costs (Chotipanich, 2004). The International Facility Management Association (IFMA) notes the importance of FM personnel as they make sure the places where people work, learn, live, and receive care are safe, comfortable, productive, and sustainable. Additionally, the FM team can contribute to the bottom line and the organizational strategy through the following; by ensuring the facility operates at optimum efficiency, managing risks to the facility and its occupants, promoting sustainable tactics for long-term cost management, and leveraging technological solutions (*International Facility Management*, 2013).

To best manage these facilities, personnel must ensure accurate documentation of the buildings and infrastructure. For centuries people have documented their thoughts and ideas on paper. Over the last several decades this has shifted to digital formats. Our society is becoming more and more immersed in the digital and virtual world. The Architecture Engineering and Construction (AEC) industry is gaining momentum to keep up with this shift. Traditionally, the FM sector has utilized data in visual formats. However, they have been limited to paper such as, 2D drawings, construction documents, equipment manuals, and warranty information. FM teams cannot adequately perform their jobs and responsibilities without the proper information and/or data. For instance, if a field technician receives a work order from a building occupant complaining of his/her office being hot, the technician will need information on the HVAC system. This information may take hours to track down due to how documents and information have been stored. However, with the assistance of new technologies this information can be stored and retrieved electronically allowing easy access for the technician. This is only one example of documentation and data needed for completing FM tasks. Getting the needed documentation into the hands of those that need it, and in a timely and efficient way is increasingly important but has not been well researched. This thesis will explore multiple ways that BIM and visual data are currently being used in the AEC industry and assist in closing knowledge gaps between Owners and the Design and Construction Teams. It will focus on the storage and use of handover data, looking at the best formats for ultimate use for maintenance personnel.

2.1.1: Handover Data

A study conducted by (Joroff & Project 2000, 1993) stated that there are four different roles in the O&M stage: strategy making (policy maker), controlling (controller), deal making (user), and task managing (technical manager), with data flowing continuously between all four – showcasing the difficulty in sharing information in a large FM organization. Most of the data needed for the O&M stage is created during the design and construction stages (Smith & Tardif, 2012) . Before this data can be used in the O&M stage it often has to be modified due to numerous factors (i.e. user interventions). Typical activities completed during O&M include portfolio management, asset management, property management, and service management (Schraven et al., 2011). Asset management focuses on the implementation of a building plan for the owner to realize the lifecycle value from the building assets (The Institute of Asset Management, 2011). The British Standards Institute, (2008) and (Schraven et al., 2011) research noted that asset management attempts to find the optimal balance between risks, costs, and performance to achieve high standards of reliability, availability, maintainability, and safety throughout the life cycle of the building.

The handover stage is crucial for owners as it is the stage, they are provided all needed and relevant building data for their structure (Cavka et al., 2017). This provided information will be used for the O&M stage and the lifecycle of the building. Caladas et al., (2005) notes that industry professionals deal with two types of data, structured and unstructured. Typically, unstructured data can be in paper or digital format, which owners and their FM teams often receive in an unorganized and incomplete manner. Unstructured data can also include warranty information, and equipment manuals, manufacturer information, which are only a few types of unstructured data. Structured data examples for the AEC industry include construction drawings, the project manual, and spreadsheets containing project information. Therefore, structured data is any type of organized data from the project. However, all of this data must typically be "unpacked" by the facility owner to make it accessible for use.

Experience and previous research have shown the data handed over is often incomplete, unorganized, and full of errors (i.e. unstructured) (Thabet & Lucas, 2017; Azhar et al., 2015; Cavka et al., 2017). Some Owners are aware if handover data received is the right data for adequately maintaining their facilities. However, others are unsure if they are provided the correct data, often due to their lack of technical knowledge of facilities and installed systems. Many owners are unaware if data they are provided is what they will need to adequately maintain their facility as they often lack technical knowledge of facilities and installed systems. Traditional handover procedures did not provide owners with the confidence and assurance they needed to ensure their building would operate at optimum performance. To resolve this issue the industry has begun using strategies and tools for handover data to ensure owners receive the data they need. These strategies and tools include utilizing open standards (i.e. IFC and Information Delivery Model (IDM), AIMs (Asset Information Models), Owners Project Requirements (OPR), and Building Information Modeling to name a few. Table 1 showcases the various terms used as well as the type and/or structure of the data and its format.

Table 1. Showcase of terms used and their type/structure/format

Term	Type	Definition
AIM (Asset Information Model)	Owner Requirement/Deliverable	Model with all data needed to operate an asset.
AIR (Asset Information Requirements)	Owner Requirement/Deliverable	Owner defined requirements for building lifecycle and often includes a maintenance strategy.
Asset Management	Process	The processes of measuring and fulfilling the value of all assets (i.e. equipment) and maximizing the return of investment of said assets through strategies like improving productivity and optimizing equipment reliability.
BOD (Basis of Design)	Process	Guides the design process to ensure owner requirements are achieved for the overall design.
COBie (Construction Buildings Information Exchange)	Collection Model/Schema	Open data standard/specification allowing for FM data requirements to be collected in early project stages.
IDM (Information Delivery Model)	Owner Requirement/Deliverable	Model detailing lifecycle processes of assets, including data requirements for all processes to be completed.
IFC (Industry Foundation Class)	Export Format	Open data standard/specification allowing for FM data requirements to be collected in early project stages.
OPR (Owner Project Requirements)	Owner Requirement/Deliverable	Provides guidance for project execution as well as forming a basis for measuring all activities and products during decision making throughout the facility's lifecycle addressing form, time, budget, and function.
Open Standards	Data Standard	Standards that are compatible and usable across a wide range of hardware and software platforms.

Construction projects generate large volumes of data, much of which is not relevant to the FM team. For example, the FM team will not need to be given a construction safety plan developed by the contractor or the steel erection notes in the structural plans. The FM team will however need construction drawings complete with any modifications to the design of the structure (i.e. geometric data) as well as non-geometric data (i.e. commissioning information, O&M manuals, test and inspection reports, schedules). To achieve these needs, the key is to ensure a project is a properly commissioned facility by beginning the project with an in-depth and complete OPR. This process starts with the owner defining what they perceive as a complete facility, which includes everything from space utilization to regulatory compliance (McFarlane, 2013). ASHRAE defines the OPR document as “a written document that details the functional requirements of a project and the expectations of how it will be used and operated.” McFarlane (2013) defines the OPR slightly different, as “a document that fully describes the requirements the owner considers important and which must be included in the project for it to be successful.” The OPR acts as the Basis of Design (BOD) document, or a “scorecard” to be used at project completion to determine if the project is successful. The BOD will guide the design process to ensure owner requirements are achieved for the overall design.

“Technical vs Process Commissioning: Owners Project Requirements” (McFarlane, 2013) provides a process for developing the OPR document. The first step is for the owner to develop a clearly defined and complete list of features, requirements, and expectations they feel are essential to the project being successful. Once the list is created it should be categorized in a manner that ensures the design team has a clear understanding of what the owner expects. The Owner will need to ensure the design team knows to whom and when data should be delivered as well as who is responsible for the data (Becerik-Gerber et al., 2012). Typically, the OPR has two major sections; an “Executive Summary” and “Negotiable and Non-Negotiable Requirements.” The “Executive Summary” is a broad overview describing project goals the owner sees as mandatory. Project goals that may be described in this section include but may not be limited to the following: providing occupants ease of access and security, be operable and maintainable within the owners budget and technical ability, achieve owners architectural appearance requirements, and comply with all applicable local, state, and federal regulations. The "Negotiable and Non-Negotiable Requirements" section details mandatory items (i.e. specific brand of HVAC equipment) and items that can be negotiated and/or substituted (i.e. flooring types) (McFarlane, 2013).

The body of the OPR should clearly define owner preferences for all elements of the project, including specifications, design elements, and other key aspects making up the overall design of the facility. Some of the core components in an effective OPR document include, but may not be limited to: detailed contact information for vendors, suppliers, and subcontractors, description of the project, space utilization table (i.e. number of spaces and type of space), special equipment standards, outdoor and indoor design considerations, sustainability requirements, utility baselines which will be used by the owner to evaluate building performance, the project delivery methods, and maintenance staff training (McFarlane, 2013).

Research by Patacas et al., (2015) proposed a framework for developing an Asset Information Model (AIM) using open standards (i.e. Industry Foundation Class (IFC). An AIM is a model that contains all the data required to maintain an asset in digital format which considers Asset Information Requirements (AIR). An AIR contains all defined requirements of the owner for the entire lifecycle of the building, including a maintenance strategy. In, "A framework for the development of Asset Information Models to support Asset Information Requirements throughout the lifecycle of buildings" a use case by (Patacas et al., 2015) demonstrated the proposed framework logic and its feasibility.

The industry is in dire need of a process that supports the definition and validation of owner requirements. The goal of Patacas et al., (2015) study framework is to give the functions and processes to support and check AIRs through a building lifecycle by developing AIMs. AIRs were defined after speaking with project team members. Input from team members identified what assets would be used and what the intended use of data handed over would be so it will meet owner requirements, which are created based on Organizational Information Requirements (OIRs). The AIMs and AIRs are created based on the OIRs and must include data to answer any questions arising from OIRs (Patacas et al., 2015; BSI 2014a). ISO 55000 suggests a set of data requirements for AIR based on PAS 55:2008-1 (Patacas et al., 2015; BAS 2008).

To ensure the specified processes are completed, the IDM methodology is used to define activity flows and to support the data and its requirements (i.e. how can the data be supported in data models). For certain tasks to be completed, data requirements must be specified, this is called an exchange requirement (Patacas et al., 2015; (*The BPEL Cookbook- BPEL with Reliable Processing*, n.d.). Once the specifications for these are known, services can be defined for supporting procedures stipulated in IDMs and to allow AIM exchanges to be verified. One example is a service inventory which can be used to define how data will be exchanged throughout the building's lifecycle. This strategy also gives support for altering requirements during the O&M phase. For this paper, AIR assisted in creating the AIM from the project information model utilizing a link between Bimserver and openMaint. AIR is supported by defining exchange requirements that state which IFC entities are to be imported into AIM via openMaint.

The framework offered by Patacas et al., (2015) proposed using Service Oriented Architecture in combination with IDM, IFC, and COBie standards for supporting the automation process of creating the AIM. COBie (Construction Buildings Information Exchange) is an open data standard/specification allowing for FM data requirements to be collected in early project stages, for data to be properly collected it is vital for the FM team to be involved in the early project stages. The use case verified and illustrated its ability to be used in multiple project contexts and support owners changing their requirements. The results can be used as a guide for adopting this framework as it shows how logic separation and process reusability is possible.

As the industry shifts from paper-based handover to BIM-based handover and O&M, research is being conducted to evaluate organizational practices to understand the possibilities and challenges of this shift. One specific study by Cavka et al., (2015.) examined current handover methods, data management and FM practices, as well as developing a framework to characterize the synchronization between organizational practices, data requirements, and technologies available. Within industry there is a gap between available and required data, procedures and technology, and the challenges owners face when considering BIM adoption.

The case study by Cavka et al., (2015) was conducted on the University of British Columbia (UBC) campus that operated and maintained its infrastructure using an in-house workforce. The case study focused only on the department responsible for O&M of educational buildings. The focus of this research was on asset management, maintenance management, records management, and facility information management. Multiple methods were used for collecting data, all of which assisted in a deep understanding of UBC’s existing FM practices from three specific views: organizational context, owner requirements, and project context. Existing FM practices were mapped to identify any limitations and examining how BIM could eliminate or improve them.

UBC Technical Guideline documents were examined to provide an understanding of owner requirements and how they differ from what may be given at handover. Requirements were identified by conducting twelve interviews with nine different members of the O&M staff. Interviews discussed practices, technology available to support them, and data requirements. FM activities were also shadowed to give a better understanding for research purposes. Project context was examined by completing and embedded case study over a several year time period on the CIRS (Center for Interactive Research and Sustainability) building to gain knowledge on handover data, O&M practices, and building data and records management at the project level (Cavka et al., 2015).

UBC, like many organizations face numerous challenges at handover. They lack, a method for checking accuracy and completeness of handover documents, defined standards for how handover data is formatted, and a process for generating an asset database in a reusable format, among others. Interviews were conducted on maintenance personnel, asset management personnel, and BMS (Building Monitoring System) personnel. These interviews identified data (non-geometric and geometric) requirements for each. All three stated they needed more detailed data, with visual representation being a common occurrence. Analysis was also conducted comparing the data included in both model and paper formatted handover documents, data tracked by owner asset databases, and data required by O&M personnel to accurately perform their duties (Cavka et al., 2015).

Results from this analysis showed consistencies between need for data requirements, organizational technology, and historical data. For example, the model lacked data pertaining to attributes defined and tracked by users, along with data the asset database needed. Since data was lacking on multiple levels, it posed a challenge to efficiently operate systems and equipment separately and as a whole. When the model, the research developed from the UBC documents provided, was compared to the as-built condition, it was discovered that they did not match, the model lacked numerous as-built elements and quantities. The same result was found when the design model was compared to the as-built model. (Cavka et al., 2015). This study highlights what many owners continue to struggle with in terms of managing data (what they ask for as well as what they receive).

Moving from paper-based handover to model-based handover requires changes in processes and data flows within the organization. To better understand how complex the change requirements can be, Cavka et al., (2015) research team created a framework to characterize the alignment between organizational practices, technology available, project documents, and owner requirements. The framework assisted in developing an understanding of how the numerous organizational pieces work together to achieve the organizational goals from the perspective of BIM-based data exchange and FM procedures. It is thought that the changes observed within the organization were influenced by other organizational changes in FM methods and IT advancements (Cavka et al., 2015).

Another potential reason of the organization's changes studied could have been the organizational efforts to internally align their processes, structures, and technology infrastructure to improve current methods through adopting technology. The developed framework showed the alignment between three main categories: project artifacts, technology available, and organizational structure. At the center of the framework was the owner requirements. Artifacts share building data, technology stores it and enables accessibility, and O&M staff use it to complete FM tasks through the defined processes. The framework also illustrated required alignments between the three categories. Organizational structure/processes and artifacts must be aligned to ensure the artifacts correctly represent the needed data. Artifacts and technology available must be aligned to ensure building data can be shared, stored, and accessed. Technology available and FM processes must be aligned to support the FM team in completing their tasks. It was discovered that a high level of compliance of processes, structure, technology infrastructure, and artifacts is vital at handover and FM functions to be completed efficiently (Cavka et al., 2015).

To demonstrate alignment issues observed between the three categories, the process of work requests was used. Work requests were assigned to buildings instead of the system/element and with a lack of available technology, the work completed was stored within the mind of the person doing the work instead of digitally for others to access. This alignment is still a challenge. Technology is available that doesn't comply with user requirements. Artifacts are also a challenge, as they do not align with technology or personnel requirements. UBC created a records retrieval system for storing handover data, however it lacks the interface O&M staff need. The O&M staff need one platform that stores and displays the data they require. Current UBC practices require O&M personnel to use numerous tools for data access, all of which must be managed separately (Cavka et al., 2015). The UBC FM team is not the only FM team facing the issue of needing multiple tools for data access, this is a challenge across the industry.

The misalignment example showed there is a lack of compliance to requirements. For BIM to be used the best way possible, organizations must align historical data, processes, and technology. Currently there is no formalized list of owner requirements pertaining to BIM for FM. For a list of requirements to be created, the data required for FM functions must be identified, as well as how the data will be used, and accessed, and stored. A document/guideline should also be generated to show how the model will make the data available, and processes and organizational technology should be reconfigured to accommodate the model and data within it. External changes also need modification to include how BIM will be used in handover and how project practices will be improved in terms of preparation and delivery of handover data to meet FM purposes (Cavka et al., 2015).

The case study presented in (Cavka et al., 2015) showed how complex the process can be when moving from paper-based to BIM-based handover. This complexity helps to explain why BIM has not been implemented at a higher rate. The framework developed showed the significance of aligning the organization with the technology, historical data and requirements for owners considering BIM adoption. A key result found is that owners, especially large organizations, will need to change (both internally and externally) their structure, processes, and data management systems to adequately implement BIM.

No matter what method is used to ensure the owner receives the information needed to operate and maintain their facility, it all begins with the owner being involved in all project stages. However, as previously stated, many owners lack the technical knowledge of installed systems within their facilities resulting in the design team creating the document to meet their needs rather than the Owners requirements. This transfer of responsibility (i.e. Owner letting design team develop the documents without defining their requirements) often results in the requirements satisfying the designers agenda rather than the owners. The goal of the OPR, AIM, AIR, and IDM are ensuring the owner receives the data and information they require for the lifecycle of the building.

“BIM in the operations stage: bottlenecks and implications for owners” (Bosch et al., 2015) discusses how BIM can be used for data management during the O&M phase from an owner’s perspective, as well as determining the value of BIM within the AEC industry. This research team conducted a literature review, interviews and survey, and process modeling to explore BIM for O&M. Explorative interviews were used to collect data for this study (de Jong & van der Voordt, 2002). Survey results were analyzed using the software AtlastTI. Coding (open and axial) was used to index qualitative data and to examine meanings and correlations between identified issues (Bosch et al., 2015).

The findings of Bosch et al., (2015) study illustrated that data management in the O&M stage are dependent on a coherent framework made of three factors; people, systems, and processes. As the study was conducted on the AEC industry in the Netherlands the results are discussed in the context of the Netherlands. In the Netherlands a typical client, with the goal of managing their buildings to optimum efficiency, are organized into four business units; assets, administration, project’s and FM. Interviews found that Dutch clients are shifting from the traditional designer role to a director role, meaning they will coordinate with privately owned organizations to perform the work for them. Additionally, it was discovered that core business strategies are beginning to shift towards the maintaining of existing buildings instead of only developing new projects, meaning the users of the building are being recognized as having a vital role and creating a stronger demand for asset management data.

However, the users and government agencies that will receive the FM services have not become involved in the data management processes. This illustrates that there may be an imbalance between the supply and demand of data. Additionally, it suggests that the existing clients are not fully aware of their director role, which appears to be a key driver of conflicting interests between those involved in operating facilities. Interview results also identified seven categories of systems used in the O&M stage: document management systems (DMS), facility management systems (FMS), building management systems (BMS), energy management system, maintenance management system, asset management system, and geographic information system. Not all organizations will use all seven and some may use more than the seven listed, which could mean that some developed or bought their own systems to fit their individual needs.

Most of the systems operate as stand-alone systems as there was no discovered need to integrate or exchange data regularly and the structure for sharing and storing data is nonexistent. This was found to be a leading cause of organizations not having consistent, complete, useable, and accessible data. One interview participant of a large public organization stated; “The information about our assets is scattered across our organization […] it is totally fragmented and part of different processes.” This causes managers and their teams to conduct the laborious task of searching for data they need because it is not available. An interview participant of a private company said; “I think we still don’t know about 30% of the information concerning our assets.” The nonexistent data sharing process and lack of a coherent structure leads to difficult scenarios. One interview participant of a large client organization stated; “We have a system in which the condition of building element’s is described, but we don’t know where the elements can be found in the building.” Information flows from many different project team members throughout the project, which often results in data being lost or irrelevant data is handed over, and/or the wrong or incomplete data is shared (Bosch et al., 2015). This suggests that most issues of data management and exchange is due to the organization and its processes such as, inefficient data management processes.

Staying with the same research of Bosch et al., (2015), impacts on client organizations, specifically bottlenecks and inefficiencies for O&M data being incomplete and/or incorrect, were identified; users cannot find the data needed to create their own documents, information is filed in personal offline locations, data revisions are not recorded, processed, or updated in a timely manner, and data is incorrectly input. All of these can cause clients to incur high costs for checking the data they receive. Building Information Modeling (BIM) is thought to be a resolution for these issues and assist owners and their teams in operating and maintaining facilities at their optimum level.

Literature Summary for Handover

- Three main categories of organizational change; project artifacts, technology available, and organizational structure (Cavka et al., 2015)
- Bosch et al., 2015 lists people, systems, and processes as the components of….
- Almost all owners state that the problems are lack of data in the model, interoperability between software programs, lack of skilled staff, high initial investment, lack of industry standards, lack of successful adoption stories/examples within industry
- Literature outlines the misalignments of these categories.
- Critical Success Factors (CSF) for evaluating and managing BIM adoption as well as a baseline for evaluating future models (Won et al., 2013)
- CSFs are identified by asking four questions:

  1) "What are the CSFs for adopting BIM in a company?"

  2) "What are the CSFs for selecting projects to deploy BIM?"

  3) "What are the CSFs for selecting BIM services?"

  4) "What are the CSFs for selecting company-appropriate BIM software applications?"

2.1.2: Building Information Modeling (BIM) for FM

As previously stated, FM teams have traditionally relied on paper or digital formatted documents to perform their tasks for the O&M of their facility. However, an innovative technology and process is shifting the industry toward virtual data and information documentation and visualization. This technology is called Building Information Modeling (BIM). The National Building Information Modelling Standards (NBIMS) Committee defines BIM as “a digital representation and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder (Azhar et al., 2015; (*Welcome to the National BIM Standard - United States | National BIM Standard - United States*, n.d.). Previous studies have explored how BIM can be used for each project stage and the various technologies and strategies it can be paired with to benefit all project stakeholders. Figure 1 shows a visual representation of the concept. When owners and their FM teams have data in visual form they are able to better understand the problem at hand, increase productivity, make better informed decisions, and potentially verify the accuracy of the data they are given at handover (i.e. as-built models).

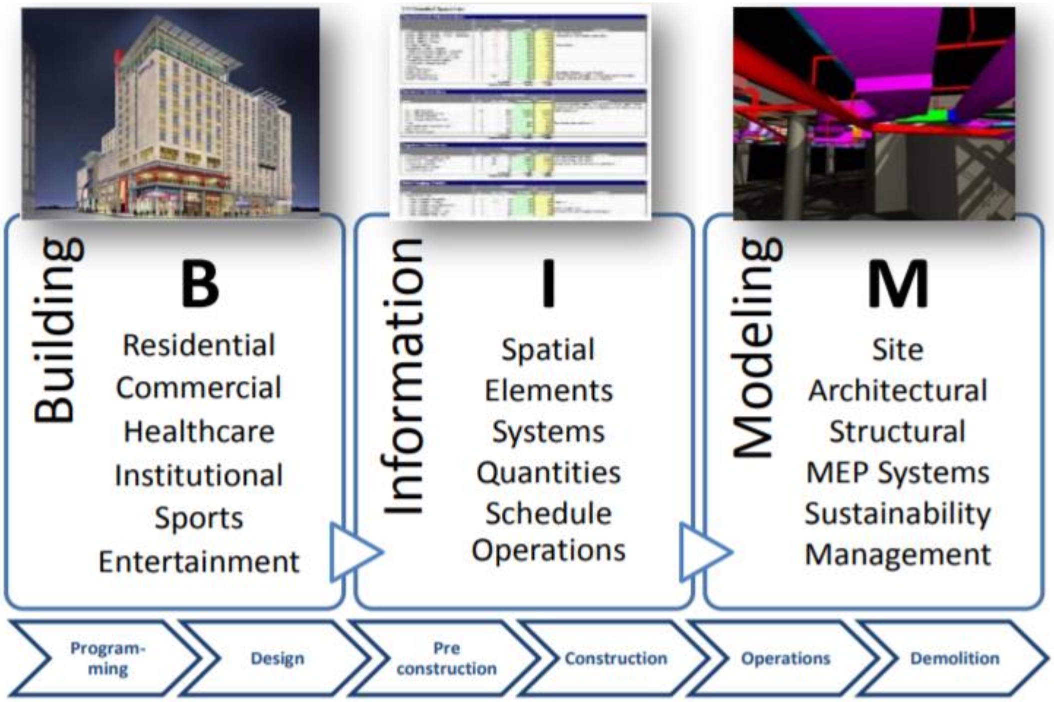

Figure 1. A visual representation of BIM concept (Azhar et al., 2015)

Khemlani in Eastman et al., (2011); Azhar et al., (2015) stated that BIM went from a buzzword to the focal point of the AEC industry. (*The Contractor's Guide to BIM - 2nd Edition*, n.d.)AGC, 2005 perceived BIM as the development and use of a computer model to simulate the construction and operation of a facility (*The Contractor's Guide to BIM - 2nd Edition*, 2005; Azhar et al., 2015). A BIM is a simulation of 3D models of elements installed in a facility having links to all required data for all project stages (Azhar et al., 2015 ; (Kymmell, 2008). Traditional visualization technology includes 3D CAD (Computer Aided Design), which differs from BIM in that the views (i.e. Plan, Section, Elevation) are not linked. If one view is modified the others must be updated as well, causing errors and poor documentation. Errors and poor documentation are major issues within the AEC industry. Additionally, data in CAD drawings are only graphical (i.e. lines, arcs), whereas BIM data is "smart" data allowing it to be defined in relation to elements and systems within the building.

Not all models fall under the BIM umbrella. Eastman et al., (2011) and Azhar et al., (2015) noted these in four categories; models with only 3D data (i.e. no object parameters), models with no support of behavior, models generated by compiling numerous 3D CAD reference files for defining the building, and models that only allow dimension modifications in one view but do not automatically reflect the modifications in other views. These four categories of models do not fall under the BIM umbrella as they are not processes. A process is defined as "a series of actions or operations directed toward a particular result" (Merriam-Webster Dictionary). BIM is a virtual parametric process of continuous updating and modifications from all project stakeholders, which ensures owner requirements will be met, all before construction even breaks ground (Azhar et al., 2015; *BIM*, n.d.). BIM is a parametric process because whenever on element if updated any adjacent element or assembly (i.e. a window installed in a wall) is automatically modified to maintain a previously established relationship (Azhar et al., 2015; Stine, 2011)).

Eastman et al (2011), (Reddy & Reddy, 2012) , and Azhar et al.,(2015) outlined multiple benefits available to owners. The first being early design assessment to ensure their requirements are achieved. By utilizing the walkthrough and simulation tools of BIM, owners can analyze how the building will perform and be maintained. From a cost perspective, the financial risk is reduced due to reliable estimates being created and change orders being decreased. Lastly, all required data will be in one location. BIM's ability to register and process large volumes of correlated data supports enhancements for data and project management, along with performance and resource monitoring (Bosch et al., 2015). BIM's capability to complete these tasks led to the development of an open standard COBie (Lee et al., 2013; William East et al., 2013; Anderson et al., 2012; Bosch et al., 2015). BIM adoption can be used throughout the lifecycle of the building which can lead to greater cost savings and benefits when an organization is willing to change its processes to obtain the best value of BIM (Love et al., 2013; Bosch et al., 2015).

Table 2 below shows how BIM can be used by all project stakeholders. Visualization and Building Performance Analysis are the two applications which can be used by all stakeholders. Although the literature did not specifically discuss Quantity Survey for FM use, it could be used for that in the event of a renovation and/or upfit to spaces. FM teams could refer to the Quantity Survey to determine exactly what is located in the space to plan the demolition or renovation of that space. BIM has applications for all areas of a construction project.

Table 2. Applications for Project Stakeholders (Azhar et al., 2015).

BIM APPLICATION	OWNERS	DESIGNERS	CONSTRUCTORS	FM's
Visualization	X	X	X	X
Options Analysis	X	X	X	
Sustainability Analysis	X	X		
Quantity Survey		X	X	
Cost Estimation	X	X	X	
Site Logistics	X		X	
Phasing & 4D Scheduling		X	X	
Constructability Analysis		X	X	
Building Performance Analysis	X	X	X	X
Building Management	X			X
Building Systems Analysis				X
Maintenance Scheduling				X
Asset Management				X
Space Management				X
Distaster Planning & Management				X

Benefits project designers experience when utilizing BIM include, producing better designs after completing extensive analysis, visual simulations and receiving owner input, ability to incorporate sustainable elements for predicting how the structure will impact the environment, better code compliance by using visual checks and analysis, identifying possible failures early in the project, and being able to produce shop/fabrication drawings quickly. Contractors experience benefits such as, improved construction planning, site safety plans, early discovery of design errors through clash detection, more accurate quantity take-off and estimates, ability to track construction progress, and value engineering and adoption of lean construction concepts. All the listed benefits lead to high profit, happier clients, cost and schedule compression, better quality, and more informed decision-making.

FM teams benefit by being given one electronic file containing all the data they need to operate the building efficiently, which saves them from having to sift through piles of owner and warranty manuals. Additionally, FM teams can use smart mobile devices (i.e. smart phones or iPads) along with augmented reality (AR) and/or mixed reality to obtain data by pointing the device in the direction of the element. (Joyce, 2012) and Azhar et al., (2015) reported an AR-based system, “Info Spot” developed by Georgia Technical Institute, which allows the team to early gather “on the spot” data via smart phones.

Additionally, BIM can support preventative maintenance and deferred maintenance. Preventative maintenance is maintenance completed regularly on pieces of equipment (while the equipment is working) to decrease the chance of failure and aid in the equipment achieving its expected life expectancy. Deferred maintenance is postponing maintenance activities of systems and elements as well as their replacement for extending the life of the facility. Deferred maintenance should be avoided as it can lead to increased overall O&M costs of the facility, increases the chance of emergency repairs, when equipment does fail it requires high capital expenditures, normal building operation can be disrupted and user productivity can be decreased, and it increases the risk of defaults on equipment warranties (Selzan et al., n.d.).

According to Eastman et al., (2011) and Bosch et al., (2015) BIM supports the collection, sharing, and management of data throughout the building lifecycle by acting as a single data sharing and collaboration platform for decision-making and its adjacent processes. Research by (Succar & Sher, 2014) presented three stages that must be adopted to establish BIM as this platform; object-based modeling, shared-model collaboration, and network-based integration, which integrates and manages all building data in one environment (Bosch et al., 2015). A key factor in establishing this single environment is interoperability, meaning that the same vocabulary should be used, data requirements should be defined, and no relevant data should be lost (Bosch et al., 2015). Multiple standards have been developed to increase interoperability, the International Framework for Dictionaries, the Information Delivery Model and the Industry Foundation Classes (IFC) (BuildingSmart 2012). According to (Grilo & Jardim-Goncalves, 2010) standards pertaining to communication, coordination, cooperation and collaboration should be developed for BIM to be fully utilized (Bosch et al., 2015).

The Cooperative Research Centre (CRC) stated that BIM requires input from six elements to function; strategy, use, process, information, infrastructure, and personnel (CRC for (Cooperative Research Centre for Construction, 2008; Bosch et al., 2015). The output of BIM is labelled as 3D, 4D, 5D, nD information (Jung & Joo, 2011; Bosch et al., 2015). In their research they stated, at the time Bosch et al., (2015) was published, BIM output is typically limited to 2D data as users cannot see, handle or deal with any other data format due to a lack of knowledge of data formats. Multiple previous studies emphasize that the strength and potential BIM offers are found in 4D, 5D and nD applications (Bosch et al., 2015). When BIM is implemented in the early project stages, energy analysis and simulations can be performed to help enhance an assets energy load, which can be used as a benchmark once the building reaches the O&M phase (Bryde et al., 2013); (Succar & Sher, 2014); Bosch et al., 2015). Specifically, in the Dutch AEC industry, a key concern is how BIM connects to existing systems (i.e. Building Management Systems (BMS)) (Smart Market 2012; Bosch et al., 2015).

Another study by (Won et al., 2013), "Where to Focus for Successful Adoption of Building Information Modeling within Organization," identified factors top management view as priorities for successful BIM adoption called Critical Success Factors (CSFs). To identify these CSFs the research team set out to answer four commonly asked questions of organizations in the first movement toward BIM adoption:

1) "What are the CSFs for adopting BIM in a company?"

2) "What are the CSFs for selecting projects to deploy BIM?"

3) "What are the CSFs for selecting BIM services?"

4) "What are the CSFs for selecting company-appropriate BIM software applications?"

It was suggested that the derived CSFs can be used as adequate metrics for evaluating and managing BIM implementation as well as a baseline for evaluating models in the future (Won et al., 2013). As noted previously, BIM adoption has been a much slower movement than expected when it first hit the market. Reasons for this slow adoption are technical (i.e. co and training) and organizational (i.e. professional liability and intellectual property). For a technology to be successfully adopted many factors must align such as, people's attitudes toward it, project characteristics, communication, and people's willingness to change (O'Brien, 2000); (Nitithamyong & M Skibniewski, 2007); (Won et al., 2013). Furthermore, ones attitude toward new technology implementation is shaped by involved risks of unknown means and methods, by the complexity of adopting new technology in specific settings, financial risks, and the view potential users have of said technology (Paulson and Fondhal 1980; Tatum 1989; Won et al., 2013).

The first wave of BIM adoptions in the mid to late 2000s occurred with the goal of overcoming low construction productivity and other challenges faced by the AEC industry (Egan 1998; Teicholz 2004; Won et al., 2013). One of the most significant studies reporting lessons learned of this first wave was the SmartMarket Report, a series of survey studies in the US, European, and Korean markets (Young et al., 2008, 2009; Bernstein et al., 2010; Lee et al., 2012; Won et al., 2013). This series of survey studies presented findings on the possible benefits, challenges and motivators for BIM adoption within an organization in the US, Europe and Korea. Later reports by SmartMarket identified additional obstacles to BIM adoption such as, training, senior management buy-in, cost of software, complexity of evaluating BIM, lack of functionality for user roles and responsibilities, and numerous others. Challenges involved with BIM adoption will be discussed in more detail in the following section.

Eastman's Building Description Systems (BDS) in the 1970s was the first to use the concept of BIM as it is known today (Eastman et al., 1974; Eastman 1976; Won et al., 2013) and the first to use the term BIM as it is known today was in van Nederveen's 1992 paper (van Nederveen and Tolman 1992; Won et al., 2013). It took a decade for commercial BIM tools to become available, enabling a slow adoption movement within the industry (Autodesk 2003; Bentley and Workman 2003; Cyon Research Corporation 2003; Laiserin 2003; Won et al., 2013). This area of adoption is often labeled as the "early stage of BIM adoption" or the "first wave of BIM adoption." During this time (mid to late 2000s) organizations had to work through technical and business strategy challenges and they did not know clearly where they were headed (Won et al., 2013). BIM adoption allows for a chance to change work processes (Curt 2005; AiA 2006) as well as adapting to the technology for suiting existing work processes (Hartmann 2008; Won et al., 2013). Allen et al., (2005) and Dossick and Neff (2010) studies suggested that as organizations navigate through modifying processes to account for legal risks associated with standards of practice, concerns over intellectual property, financial risks associated with capital investments in hardware and software, as well as the investment of training and maintaining a technology skilled staff that power struggles between the organizations personnel occur (Won et al., 2013).

Table 3 below lists the most common barriers faced by Owners and their FM teams when adopting BIM. Many of the barriers feed off each other. For example, “learning curve for BIM technology” and “lack of expertise” are similar. If one is resolved the other will be as well, the more one learns about BIM the smaller the learning curve becomes. Won et al., (2013) research utilized surveys and results of previous studies to identify barriers, limitations, and consideration factors (CFs) from previous research (Kim 1995; D’Agostino et al., 2007; Gilligan and Kunz 2007; Eastman et al., 2008; Yan and Damian 2008; Lee et al., 2009; Young et al., 2009; Dossick and Neff 2010; Gu and London 2010; Won et al., 2013).

Table 3. Barriers to BIM adoption (Won et al., 2013).

Barriers to BIM Adoption
Cost of Investment
Learning Curve for BIM Technology
Shift of Liability Among Project Participants
Poor Collaboration Among Project Participants
Poor Interoperability Among BIM Software
Reluctance to Openly Share Information
Management Problems with BIM Master Model
Lack of Collaboration Management Tools
Organizational Structure Doesn't Support BIM
Lack of Subcontractors Who Can Use BIM Technology
Security Risk
Lack of Expertise
Limitation of Current BIM Application
Lack of Industry Standards
Shortage of BIM Implementation Data in Construction Stage
Difficulties in Measuring Impacts of BIM

The second part of the survey for (Won et al., 2013)focused on CSFs pertaining to when an organization should deploy BIM. Critical success factors (CSFs) included items such as the project team's (excluding the owner) willingness to adopt BIM, BIM being requested by the client, project complexity. Success factors included items such as the subcontractor's interest and capability of adopting and using BIM, the project delivery method, purpose and size of the building, and site location. Results of part 2 aligned with previous studies stating that within the AEC industry, when discussing new information technology adoption, individual leadership is a vital factor for overcoming technical and non-technical issues (Dossick and Neff 2010). This is further validated as the interest and willingness of project managers scored higher than clients requesting BIM when deciding whether to deploy BIM on projects. Another interesting discovery was that complexity of building shapes and systems scored in the top three. This is due to the fact that buildings of complexity are difficult to construct with only 2D plans, meaning that buildings of complex shape and systems stand to benefit the most from successful BIM adoption.

BIM has many applications, both simple and complex. However, the cost of adopting and learning curves would be too high for an organization to implement BIM and utilize every application it offers. Part three of the survey was conducted to identify the CFs for determining the priority of BIM service applications. As was done by the first two parts of the survey, an initial list of CFs were identified from previous research (Khemlani 2007b; Gu and London 2010;) pertaining to the selection of BIM software uses (Won et al., 2013).

When an organization is selecting a set of BIM software applications it should consider how long the software can be used as converting from one system to another is very expensive. Many organizations select BIM software based on functionality, the software vendor's market shares and/or success stories (Won et al., 2013). Part four of the survey focused on the selection of CSFs for selecting appropriate BIM software applications. There are multiple previous studies on this topic. Khemlani (2007b) presented multiple factors to consider, such as, the possibility of the support for diverse working areas, libraries, usability, interoperability issues, automatic drawing generation, and market share of the software. Lee et al., (2009) grouped CFs into four categories; usability, functionality, business aspects, and experiences.

The research by Won et al., (2013) contributes to the body of knowledge as it derived CSFs for BIM adoption from four main aspects by condensing and prioritizing success factors identified in previous studies. The results of this research could be used as a baseline for the development of a quantifiable and effective management tool for analyzing successful BIM adoption within an organization. Additionally, the results of this research found that non-technical items should be ready before the technical utilization of BIM. Taylor and Levitt 2007 stated that successful BIM adoption depends more on how well an organization "aligns BIM technology with their work process and vice versa" instead of on technological readiness. The top CSFs identified were, from most critical to least critical, willingness to share information among the project team, standard work processes and data exchange processes, detailed BIM execution plans (Anumba et al., 2010) for multiple projects, and education to motivate senior management and project participants to help them get accustomed to BIM (Won et al., 2013). Kreider et al., 2010 research stated that 3D coordination and design review are seen as the most effective and relevant use of BIM today.

One of the most challenging barriers stakeholders face for BIM adoption is the lack of BIM standards for model integration and management between the project team. To integrate data, all stakeholders will need to access the model, which can cause new issues to arise if there are no protocols pertaining to formatting ensuring consistency. Due to the lack of standards, organizations must create their own, which can be problematic if the model is not routinely checked for issues (Azhar et al., 2015; Weygant 2011). A second issue which is well-known across the industry, is interoperability. Over the years there have been developments to assist with this issue (i.e. IFC, XML Schemas) but they have certain limitations that do not totally resolve the issue. These challenges have been described as "technology related risks" (Azhar et al., 2015).

A second category of risks and barriers discussed in previous research are process-related, including legal, contractual and organizational risks (Azhar et al., 2015). For example, lack of determining who owns the data within the model, as well as needed to protect it legally. Data ownership varies for every project. The main objective is to avoid inhibitions that deter stakeholders from seeing the full potential of the model (Azhar et al., 2015; Thompson 2011). Rosenburg (2007) stated the best way to eliminate disagreements of copyright issues is to state ownership and responsibilities within the contract documents (Azhar et al., 2015). Process-related risks also address who will be responsible for data input into the model and liable for inaccuracies (Azhar et al., 2015; Azhar S. et al 2012). Before BIM technologies are utilized it is vital to identify the responsible party, which will eliminate requests for quittance by those using BIM technologies and designers from offering disclaimers of liability. Utilizing BIM may potentially add costs to the project as someone will need to input and review/update data within the model, meaning cost must also be considered a risk.

Ku and Taiebat (2011) conducted a survey of 31 contracting firms and discovered the top barriers for BIM adoptions to be: 1) lack of skilled personnel, 2) high cost for adoption, 3) reluctance of other stakeholders (i.e. A/E), 4) lack of collaboration approaches and model standards, 5) interoperability, and 6) lack of legal/contractual agreements (Azhar et al., 2015). The noted barriers could be resolved with the advancements of BIM technology, owner requirements models, and the introduction of fresh graduates with BIM knowledge on the project team. BIM has also caused modular construction to reemerge as stated in the SmartMarket report of 2011 published by McGraw-Hill Construction (Azhar et al., 2015; SmartMarket 2011). BIM is assisting in the development in the development of fabrication processes of complex assemblies become more cost effective and technologically feasible (Azhar et al., 2015; Azhar S. et al 2012).

BIM will soon completely replace CAD systems. Technology advancements, such as having models accessible by smart devices will only push BIM adoption forward. Additionally, AR and VR technologies will assist owners and their FM teams to ensure the building reaches optimum performance. Azhar et al., 2012 categorized technological barriers into three groups; 1) need for well-defined standards to resolve interoperability issues, 2) requirements that digital design be computable, and 3) the necessity for a well-developed, practical approach to ensure successful data sharing and integration of model elements. Additionally, there is no defined process for implementing BIM, how to use it, or having a standard for BIM contract documents (Azhar et al., 2015; Associated General Contractors of America 2005, Post 2009).

Referring back to Azhar et al., (2015) study, identified issues were further research was conducted. For instance, Dossick and Neff (2010) identified organizational strategic issues such as, conflicts from roles and responsibilities to project scope (Won et al., 2013). Furthermore, Jung and Joo (2011) suggested that factors like property, standards, utilization, perspective, and construction business function be considered when developing a BIM framework (Azhar et al., 2015). Lee (2007) research classified BIM adoption into four stages by level of organization involved in a BIM project:

1) First Phase – Personal adoption – One person develops and maintains the model with others within the organization using the contained data, but no collaboration methods are used. An example of this would be one architect using a BIM tool to design and generate drawings without receiving data from others.

2) Second Phase – Adoption within a team of an organization – This is when several people within the company collaborate to develop the model using the same BIM tool. An example would be an architecture model is only developed and used by the architecture staff.

3) Third Phase – Adoption across various teams within an organization – This is when a company has several teams performing different roles. An example would be a model developed by one team can be sent to another within the same organization such as an estimator or scheduler.

4) Fourth Phase – This phase refers to more complex issues of coordination and collaboration such as coordination issues across different organizations (i.e. interoperability) with varying BIM capabilities (i.e. Mechanical, Electrical and Plumbing (MEP)) and interoperability challenges between BIM tools. For this phase an example would be that BIM adoption requires detailers to share their models for making one single model for things such as clash detection.

Literature review summary for BIM for FM:

- BIM is an innovative technology and process that is shifting the industry from paper-based documentation to virtual data and information documentation and visualization.
- BIM can benefit all stake holders, especially the Owner in the following ways:

  1) Deliver a better designed facility that will be maintainable within Owner budgets when the design team utilizes the walkthrough and simulation tools.

  2) Design errors can be identified and corrected before construction begins.

  3) BIM can assist the construction team in staying on schedule and within budget with decreased delays.

  4) Contractors can use BIM to develop site safety plans, construction planning strategies, provide more accurate quantity take-offs and estimates, and track construction progress.
- 5) FM teams benefit by being provided one electronic file with all the needed data to maintain the facility as well as ais in preventative maintenance strategies.
- Owners must make changes within their organization to achieve optimum BIM benefits and applications, which include changes to:

  1) Process changes

  2) Organizational structure

  3) Data management systems
- Critical Success Factors (CSF) for evaluating and managing BIM adoption as well as a baseline for evaluating future models (Won et al., 2013)

- CSFs are identified by asking four questions:

  1) "What are the CSFs for adopting BIM in a company?"

  2) "What are the CSFs for selecting projects to deploy BIM?"

  3) "What are the CSFs for selecting BIM services?"

  4) "What are the CSFs for selecting company-appropriate BIM software applications?"

- Common barriers identified by previous research in terms of BIM adoption (Azhar et al., 2015):

  1) Lack of standards for model integration and management between the project team

  2) Lack of skilled personnel

  3) High cost of adoption

  4) Interoperability between software programs

  5) Reluctance of stakeholders (other than the Owner and their FM team)

- Barriers could be eliminated with the following:

  1) Advancements in BIM technology

  2) Owner requirement models

  3) Introduction of fresh college graduates with BIM knowledge

2.1.3: BIM for Owner Benefits by Project Phases

In, "Building Information Modeling (BIM): Now and Beyond" it is noted that during the design phase the project team can examine space and its complexity (i.e. land regulations), enabling them to spend time on more valuable tasks (Azhar et al., 2015; CICRP, 2009). Over the last decade, the integration of GIS with BIM has been examined. Some of the discovered "GIS-

BIM" benefits were found to relate to site analysis, such as assistance in determining if the site meets project requirements (i.e. financial factors), reducing costs of utility demands and demolition, and minimizing possible hazard encounters on site (Azhar et al., 2015 ;CICRP, 2009). A model created during these stages can significantly differ from the as-built building and as built-model. The differences may occur for numerous reasons. For instance, undocumented design changes or errors during construction. It is vital for the owner to be given models that contain all changes and modifications to ensure they have accurate and complete data within the model. One way to generate an "as-built" model is to use a laser scanner to collect 3D point sets (point cloud) that can be converted into a BIM (Y. Furukawa, B. Curless, S.M. Seitz, R. Szeliski 2009; Xiong et al., 2013). This will be discussed in more detail further down in this section.

The design phase of a construction project typically includes three main stages, schematic design (SD), detailed design (DD), and construction detailing (CD). BIM can be advantageous for each (Azhar et al., 2015; Azhar, S et al., 2012). During SD, BIM can be used to compare multiple design options or to incorporate photographs of existing conditions into the model. When the owner has multiple design options to view and choose from, they can ensure their investment will provide optimum results and meet their requirements. BIM applications for DD include 3D models of the exterior/interior, walking through the structure, analysis of the design and structural elements, and conducting performance analysis. The last of the three, CD, consists of 4D scheduling, clash detections, and shop/fabrication drawings. For the last, CD, owners will mainly benefit from clash detections and 4D scheduling ensuring the project stays on track and no "out of the blue" changes must be made increasing their budget. "BIM: Now and Beyond" also discusses a case study utilizing BIM during the design phase. For the project, three different

BIMs were developed for comparison to identify the most cost efficient, each having BIM-based cost estimates for three different cost levels (budgeted, mid-range, and high range). Once all three models were completed the owner walked through each to determine the most cost-efficient option that met their requirements, which saved them just under $2M.

"BIM for Facility Management: Version 2.1" (*BIM-FM-Consortium-BIM-Guide-V2_1.Pdf*, n.d.) published by IFMA stated that the BIM design model will be developed by the design team. This model will be created to the level needed to relay the intent of the design, create documents, and provide details needed for construction. Additionally, it will only have general descriptions, dimensions, and performance requirements of equipment and/or systems that will be installed. The Owner will be able to use this model to conduct energy analysis, visualize the design of their facility, ensure the design meets their requirements, and provide it to possible contractors who wish to bid on the project. Changing the design drastically increases costs after the design stage is completed, meaning that project costs and owner satisfaction grow at a significant rate in later project stages (Heydarian et al., 2015).

BIM is a very versatile visualization software and has many applications allowing it to be paired with various technologies. The AEC industry has recently began pairing BIM with Immersive Virtual Environments (IVEs), which promotes the inclusion of the Owner in the design stage through the integration of mock-ups and BIMs to analyze design options (Heydarian et al., 2015; Gopinath and Messner, 2014; R.M. Leicht et al., 2010). IVEs could be used to collect data on owner and user preferences during the design stage, which could result in a better and more cost-effective decision making in all project stages. The most common of these technologies are 3D laser scanning and photographs. In the last several years panoramic or 360-degree images are gaining popularity. However, the storage and retrieval methods for these images are sometimes difficult as they may require additional viewing software. As 3D laser scanning and photographs have been utilized by the industry for ten years or more there are many previous studies discussing their uses.

Laser scanning can be used to generate point clouds that can be used later in the project to compare an as-built model with the as-designed model. Hajian & Becerik-Gerber (2009) research suggested that BIM standardization methods would be vital when project teams are considering using laser scanning technologies, as scans can be used to update models with accurate data. When a project team decides to use laser scanning, they should adopt a lifecycle approach which moves data collection and sharing to the forefront of the project. When BIM and laser scanning are used together the design team can make better informed decisions using the accurate and structured data they have collected.

Literature Review Summary for BIM for Owner Benefits by project phases: Design Phase:

- Design Stages BIM can be used in (Azhar et al, 2015; Azhar et al., 2012):

  1) Schematic Design for comparing design options as well as incorporating photographs of existing conditions into the model.

  2) Detailed Design for analysis the design (i.e. analyzing structural elements) and walkthroughs to analyze the flow and appearance of the design.

  3) Construction Detailing for completing clash detections to identify design errors, developing fabrication/shop drawings, creating 4D schedules.

- BIM can also be paired with technologies like IVEs, which can be used to motivate the Owner to be more involved in the design stage.

BIM can be used for the pre-construction phase in three major areas, estimating, site coordination, and constructability analysis. Stanford University Center for Integrated Facilities

Engineering (CIFE) discovered that BIM-based estimates were within 3% with up to 80% decrease in time for creating the estimate (based on 32 major projects) (Azhar et al., 2015; CRC Construction Innovation, 2007). Site coordination uses 3D or 4D models, which enables contractors to plan for possible hazards on site, create traffic plans, and develop a site layout plan. Additionally, models can be used to analyze constructability for developing a sequence of operations. The case study discussed in Azhar et al., (2015) for this portion of the project lifecycle was conducted on the Auburn University campus to demonstrate how BIM can be used for safety and planning management. The project team created the model during the design phase and used it to coordinate operations on site. After identifying all potential hazards through team meetings mitigation plans were created. The mitigation plans (4D simulations of hazards) were also used to illustrate the construction operations of the day during toolbox meetings (Azhar et al., 2015; Azhar S. et al., 2012).

Sticking with research from (Azhar et al., 2015 , the team also discussed uses of BIM during construction.; monitoring progress via 4D phasing plans, coordination of meetings between trades, and incorporating RFIs (Request for Information), change orders, and punch list items into the model. It should be noted that the model requires continuous monitoring and updating to ensure it contains all needed data to be used during the O&M stage. Mobile technologies allowing the project team to access the models while on site were also noted. They include, BIMX, Bentley Navigator, and BuzzSaw. AutoDesk 360 (cloud-based service) allows BIM models to be exchanged in a web environment, as well as complete various tasks on site (i.e. prepare digital RFIs, clash detection, and walk throughs) (Azhar et al., 2015; Rubenstone 2012).

BIM allows the project team to examine and interact with data visually, which is extremely beneficial as most people are visual learners. Kuo et al., (2011) research study presents a framework containing four data views, four interactive functions, along with two display layouts (matrix hardware and flexible hardware). The adopted prototype system for Kuo et al., (2011) research was called “Construction Dashboard,” which can display multiple building networks. The project team can analyze construction data via direct manipulation and receive immediate feedback as the framework has dynamic interrelation of data (Kuo et al., 2011). The four data views are as follows: temporal information view, spatial information view, hierarchical information view, and relational information view. The temporal view displayed data that must be continually monitored, controlled, and managed by the project team. For this study it was displayed in a Gantt Chart. The spatial view displayed geometric data of systems as well as the systems locations. Spatial data is used by the project team to check system distribution, circuits, ducts, and other components of MEP systems to resolve clash issues. Current methods for representing spatial data consists of 3D modeling and rendering. The hierarchical view systematically displays building system information. This is useful for assisting the construction team in understanding the scope of the project, their responsibilities, and the organization of work activities. Tree diagrams were utilized for this view as they are easy to interpret and effectively represent the data and its relationships. The last view, relational was represented as a network chart with nodes and edges to convey system relationships.

The next element of the proposed framework were the interactive functions, visual information exploration, cross-highlighting, use of a time controller, and information extraction. Visual information exploration (i.e. zooming, panning, rotating) ensured users could easily navigate and analyze data used in the case study. Cross-highlighting is a method that represents data relationships, which assists users in describing, explaining, and comparing data. This function is beneficial as it enhances a team’s understanding of the multi-dimensional model in a limited visualization area, which results in an improved decision-making process (Liston et al., 2000; Kuo et al., 2011). Time controllers were used to manipulate temporary data for a better understanding of the various data types. Additionally, this research study utilized different colors for representing operation activities and project status. The last function, information extraction, refers to the filtering, emphasizing, and searching of data. Filtering enables unnecessary data to be hidden. Emphasizing allows users to display specific information. Searching displayed data associated with keyword commands of the user. It was suggested this function would enhance usability of limited user platforms (Azhar et al., 2015).

The "Construction Dashboard" was developed as a three-layer structure (user interface, data-processing, and data-storage layer), with each layer having major functions. The user interface layer provided user functions for manipulation and interaction with elements on each view and displayed results visually. The data-processing layer extracts information from the database and produced a view table required for creating user needed elements. The data-storage layer stored construction data. Users were able to manipulate views and components directly on the views as well as gather visual feedback immediately (Azhar et al., 2015).

A case study was conducted to test the effectiveness of the framework using an example virtual project involving four systems (power, air conditioning, water, and computer). The project was a multi-system computer room with 154 elements in the 3D model and a project duration of 100 days. The case study was used to determine how using the "Construction Dashboard" can assist the project team in exploring and understanding project data. Users were asked to identify problematic work areas using the "Construction Dashboard." Each participant was asked to perform three levels of tasks; an equipment task, functional task, and space task in both the "Construction Dashboard" and a traditional BIM model with the project schedule).

Additionally, participants were asked to answer three levels of questions; coordination (i.e. were the work items completed?), management (i.e. when will the uncompleted tasks be completed?), and project-wise (i.e. project progress in terms of percent complete).

The case study was analyzed to determine how quickly and accurately participants completed each task using the “Construction Dashboard.” Completion times were analyzed using a statistical approach, mean value and standard deviation. Results showed when using the “Construction Dashboard” tasks were completed significantly faster compared to using the conventional method. Success rates were analyzed using statistics, the t-Test, and the chi-square test to determine variations between using the developed dashboard and conventional method. Three tasks achieved statistical significance, equipment coordination, equipment project-wise, and functional project-wise. The case study verified the “Construction Dashboard” to be an effective and efficient tool for displaying interactive data. Participant feedback concluded that the flexible software layout for the developed dashboard was convenient to work in. User comments also showed agreement that the presentation of the data was better than traditional methods. The matrix hardware layout for the dashboard was said to be useful for data comparison simultaneously and decreased how much data had to be retained.

Another case study conducted by Azhar et al., (2015) consisted of a GC converting 2D structural and MEP system drawings into 3D models. The GC was able to save close to $300,000.00 using clash detections and the integration of all “single” BIM models.

Research by Rebolj et al., (2017) discussed the use of scan-vs-BIM to monitor construction progress. Scan-vs-BIM is a method when an as-built point cloud model is compared to the as-designed model. The point cloud was generated using 3D laser scanning. This strategy produced two sub-sets of elements in the model, elements classified as existing and elements classified as missing in the as-built model. Scan-vs-BIM can assist in fixing schedule delays and errors as well as helping the owner know what they are paying for when the contractor requests payment. Elements were classified by size for this study, large (i.e. slab), medium (i.e. column), small (i.e. finishing work), and very small (i.e. detailed finishing work) (Rebolj et al., 2017). This classification will also help the owner to understand the progress of the project and be used later during the O&M phase to know details behind walls to better manage and maintain the building.

With the advancement of technology contractors are beginning to see the benefit of using 360-degree cameras. 360-degree images are producing using a 360-degree camera with two or more lenses. The camera captures one image simultaneously using the lenses and stitches the images together into a single 360-degree image. This technology is extremely beneficial for the project stakeholders as it fills in gaps that are often produced from taking still images and provides a complete capture of the environment. 360-degree cameras are lightweight, easy to use, and capture images quickly. Additionally, the images are stored on the cloud enabling anyone access from any location. Since one 360-degree image takes the place of 10 still images there are also less photographs to store and organize (Hedmond, 2017, p. 360).

Many 360-degree cameras have the capability to create virtual "job walks" allowing for the project team, especially the Owner, to easily orient themselves on the site to understand how the project is moving forward. Applications like Holobuilder TimeTravel saves images from different times and people and stores the images virtually on a sheet allowing for the Owner to obtain images during construction to be used later during the O&M stage (Hedmond, 2017, p. 360). Another benefit of this technology is creating virtual punch lists, record damage, and develop and close change order requests. This can provide the Owner with confidence that their building is being constructed properly and will meet their requirements at handover. When the Owner decides to request 360-degree images it is important for a team member to be responsible for reviewing the images for proper location and quality. This process will ensure the photograph is stored in the correct location and with the proper name. Images are also more likely to be provided while construction is in progress than requesting updated models in short time intervals.

Owners requiring 360-degree images can also utilize a software called StructionSite, which is "automated site documentation that translates daily project updates into actionable insights" (*StructionSite - Construction Documentation & Project Tracking*, n.d.). StructionSite offers multiple products the Owner can benefit from. 360-degree Video Site Documentation can be used when walking a job site and recording a video that automatically marks the path on the floorplan file. The team can then view any spot-on site as if a 360-degree image was captured there. The videowalk also increases transparency, reduces risks, and keeps the entire project team informed on how the project is progressing. A NavisWorks Plug In is also available, which allows BIM information to be matched to the related 360-degree image. This plug in can compare the model and video content side by side to track progress. StructionSite features include the following; applications for both desktop computers and mobile smart devices, exported request, an analytics dashboard, and x-ray mode. (*StructionSite - Construction Documentation & Project Tracking*, n.d.). All of these features can assist the Owner in maintaining their facility to its optimum performance, especially the x-ray mode, which lets FM teams see through walls to located MEP elements for completing FM tasks.

BIM can also be paired with 360-degree images. For example, 360-degree renderings can be produced from the model (i.e. AutoDesk Revit and Navisworks) which can be developed into a handover package. Before the project is complete, the 360-degree renderings can assist the design team with changes, site conditions, and other project models early in the project when the cost of modifications is lower. The Owner will appreciate this as it ensures they only pay for what they have at the time of payment (i.e. progress matches the Work in Progress reports). Perhaps one of the best features of 360-degree photography is the ability to look in all directions, up, down, and side to side. The field of view is not limited to only where the camera is pointed like in still photographs, 360-degree photographs offer full flexibility. Skanska in New York is utilizing 360-degree photography on job sites. Skanska regional director, virtual design, and construction, Albert Zulps stated, "these photographs are game-changing. You can capture that space and then later you can actually look at versions of those photographs, go back in time, peel back the sheetrock and go into the wall." Zulps further notes that 360-degree technology can be paired with models generated from 3D laser scans, VR headsets, and technology for mixed reality environments (Zeiba, 2019).

Literature Review Summary of BIM for Owner Benefits by Project Phases: Pre-Construction and Construction Phase:

- BIM use for Pre-Construction Phase: estimating, site coordination, and constructability analysis
- BIM use for Construction Phase: monitoring progress via 4D phasing plan, coordination of meetings between trades, incorporating RFIs (Request for Information), change orders, and punch list items in the model.
- BIM allows the project team to examine and interact with data visually
- BIM can be used to convert 2D drawings into 3D models
- BIM can be paired with the following technology:

1) 360-degree photographs for: virtual job walks, cloud based storage for accessibility from any location, automated site documentation, NavisWorks plug in to compare as-built model with as-built photographs, and increasing transparency by allowing FM teams to see within walls for O&M tasks (Hedmond, 2017 p.360; *StructionSite - Construction Documentation & Project Tracking*, n.d.; Azhar et al., 2015; Rebolj et al., 2017)

In the "Facility Management Handbook," authors David G. Cotts, Kathy O. Roper, and Richard P. Payant stated that owners and building developers can decrease operational costs by maximizing the use of BIM data for FM (*Access To BIM Data Improves Facility Management Operations*, n.d.). Examples of BIM data for FM use were noted to be; asset inventories and registries, space management applications, building systems analysis, environmental analysis, regulatory compliance management, and accurate as-built data for renovations. IMAGINiT Technologies survey from 2017 showed that the percentage of owners integrating BIM into their FM system's rose from 6.1% (2016) to 15% (2017). Additionally, the survey found that the biggest issue owners face with using BIM data in FM systems is the integration of the data into the FM platform and maintaining the data once they receive it. Data loss was also noted as an issue as the models from the design and construction stages can be missing data needed to complete O&M tasks. For example, if the model has HVAC service zones but has no details about the system components to import into the maintenance management system or if the data is not formatted in ways that are compatible with FM systems. Both of these issues prevent a streamline data integration between BIM and FM systems (*Access To BIM Data Improves Facility Management Operations*, n.d.).

"Improving Facility Management Through BIM Data" (*Access To BIM Data Improves Facility Management Operations*, n.d.) provided three tips for overcoming challenges encountered pertaining to integration of BIM to FM systems, as well as ways to enhance building management and automation by having access to BIM data. The tips are as follows:

1) Complete a review of FM BIM requirements. The data needs to be identified at the start of the project. It would also be beneficial to include the FM team to help manage the model for bridging the gap between owners and other project team members by sharing known goals.

2) Develop a BIM guideline. Defining the model requirements for each discipline will help guarantee a smooth model development process. Owners should ask themselves; what data is needed, how it will be collected, and how will it be kept up to date?

3) Data should be added over time, it is not a "one and done" scenario. Data can be input for present situations and modified for future situations. For example, at first the location and unique ID numbers of assets can be input, then later more details for the assets can be added.

As previously stated, BIM can be paired with 3D laser scanning and photography, both still images and 360-degree images. When these technologies are paired with BIM the modeling process can be enhanced. These two technologies can also be used as stand-alone technologies without the creation of a model. In "Integrating 3D laser scanning and photogrammetry for progress management of construction work" illustrates a study was conducted on an active job site in Montreal (El-Omari & Moselhi, 2008). Both technologies have limitations but when used together most of them are eliminated. The methodology used in this study aimed at automating the data collections process through integrating multiple data collection tools. The focus of the paper was on the use of laser scanning and a digital camera to show how time can be saved versus the large amount of time required when using only a laser scanner. The results were generated through laboratory experiments and on site of a building being constructed. When this technique is utilized by FM team's data can be collected multiple ways. Laser scans can be used to verify as-built models with as-designed models. Photographs can be used as a quick data access tool if a technician should need to go into the field to complete a work order. When both technologies are used together scan time can be decreased by up to 75% as cameras are able to reach areas the laser scanner cannot.

The goal of the study was to model both types of images captured to estimate how much work was completed at the end of each day, which the Owner can monitor to make payments for Work In Progress reports they receive. Scanning was only performed on one side of the site due to accessibility limitation. The scan used horizontal and vertical angles, 200 ° and 59 ° respectively, with both resolutions set to 0.2 ° as determined from laboratory experiments. The range varied from 1m to 50m (average of 30m). For the 30m range, the distance between two adjacent points within the point cloud was 10cm. Although this is low accuracy, time limitations for scanning did not permit resolution angles to be adjusted. Photographs were taken separately from the scans so the angles and distances could be adjusted for gathering more data of the objects. It also decreased the number of scans required.

Korman et al., (2006) noted a major challenge for FM teams is not having a model of the as-built environment for an O&M tool (Randall, 2011). This issue could be resolved if laser scanning was completed throughout the entire lifecycle of the project starting with construction breaking ground. When an as-built model and point cloud receives validation, they can be integrated into building automation systems (BAS) for improving the O&M phase. Models have the ability to create O&M plans, promote safety and security plans, as well as act as an as-built data library.

Once construction is complete the main objective is to transfer all data into the O&M stage to ensure the building operates at its highest level of performance. The FM team can use the developed model for completing maintenance tasks in a timely manner. For example, a technician responding to a work order can extract data for the element in the work order (i.e. location, operation manual). Additionally, the model can be used to manage spaces, conduct inspections, and manage emergency requests. Going back to (Bosch et al., 2015) research, all but three of the interview participants (21 interviews total) stated they had adopted BIM for the design and construction stages for a significant period of time. They reported that BIM helps them collaborate with other members of the project team in a more efficient manner. However, the models used in the design and construction stages hold only a piece of data needed for the O&M stage. Respondents of the interviews identified multiple barriers they experience when using BIM for new construction. The most significant include concerns about the development of IFC, growing number of standards, BIM being limited to model-based collaboration, and an as-built model isn't as verifiable as as-built in real life. Theoretically, BIM can assist in the asset management process for O&M as it manages data without being dependent on time and people. This ability of BIM enhances the quality, consistency, and reliability of data. Additionally, BIM enables more efficient integration of building documentation and can support the asset management through the monitoring and benchmarking of data (Bosch et al., 2015).

A BIM for FM purposes should be created from the as-built BIM, which means certain modifications will need to be completed as the as-built BIM contains data the FM team will not use (i.e. fabrication data or construction means and methods. The following modifications will need to be performed: (IFMA "BIM for Facility Management: Version 2.1")

- Irrelevant data should be removed (i.e. construction details)

- When models are linked to represent different elements (i.e. building envelope, building core) they should be merged into one model.
- Models containing architectural, structural, and MEP can also be merged into one model if practical (i.e. if project is small enough if project is large and complex they may be more navigable separate).
- Room numbers are derived from construction room numbers and building signage.
- Work spaces/stations and offices are defined and numbered with occupancy numbering system. The team should also try and match office occupants to desks, spaces, and offices to support adequate work order management.
- Equipment is numbered with unique asset identification numbers/names.
- FM model is linked to FM system that tracks work orders, maintenance operations, occupancy information, equipment and material replacement costs, as well as other operational data.

The guidelines and results of the study show that the client will need to think in terms of the buildings life cycle, meaning the owner should have a central role in the process. The research team of Bosch et al., (2015) suggested and presented a revamped organizational chart, which accounted for the owner having a central role and a contract-management team (CMT) that the owner controls. The CMT is responsible for ensuring adequate and timely delivery of the various services of the project disciplines (i.e. Architect, Design, Contractor responsibilities). To ensure data is consistent and complete the person responsible for the data should have minimum contact points and one reliable data source. This approach decreases the chance of losing data and allows for the matching of supply and demand of data, removing the imbalance that is often present.

At the time Bosch et al., (2015) was published the value of BIM in the O&M stage was minimal, which is the result of an imbalance between people, processes, and systems, specifically in a manner that aligns with the basic principles of BIM. Results of the 21 interviews found that the owner works inefficiently and ineffectively due to knowledge silos of the project team and the lack of attention paid to the O&M stage. Additionally, it was stated that BIM processes can be enhanced if owner processes (specifically those involving people) were modified. This research presented multiple starting points for owners to consider when trying to improve data management processes. One suggestion was to create an owner-based framework with defined data flows and data structure that aligns the supply and demand independently of time, people, and systems to support successful BIM adoption for the O&M stage. The limitations identified related to the immaturity of BIM for the O&M stage, as well as the small research sample. Using a small sample could create biases pertaining to the challenges and barriers in the O&M stage. The authors also noted that more attention could've been given to the strengths of existing data management processes and systems (Bosch et al., 2015).

The as-built model should be created to a high level to allow for analysis and model manipulation at the element level (i.e. doors or windows) rather than the level of individual points (Xiong et al., 2013). Scan-to-BIM is the conversion of point cloud data into an "as-built" BIM. Geometric surfaces are fitted to the point cloud (i.e. scan data) to model elements of interest (i.e. walls, ceilings, etc.) (Xiong et al., 2013). These elements are then labeled for identification and metadata (i.e. surface material), spatial and function relationships of close by components and spaces are created. This method is time consuming, prone to errors and can produce different results from different people (Anil et al., 2011 ;Xiong et al., 2013). The research team of “Automatic creation of semantically rick 3D building models from laser scan data” discuss the creation of a tool to move in the direction of an automated process using methods from computer vision and machine learning (Xiong & Huber, 2010; Xiong & Huber, 2010 ; Adán & Huber, n.d.; Anil et al., 2011; Xiong et al., 2013).

The process used in this study used a registered 3D point cloud collected from laser scans and automatically identifies and models surface planes of walls, floors, ceilings, doors, and windows. Once applied to all the rooms, a compact, semantically rich 3D model will be automatically created. The model will not be a BIM in its traditional definition but will have the geometric and identity data that makes up a BIM. Labeling elements and converting the model from surface representation to volumetric representation were still being researched at the time this study was published. A key barrier for automating the “as-built” BIM generation process is the issue of occlusions (Xiong et al., 2013). Typical building algorithms are tested in areas with nothing obscuring the scanning surface, which isn’t practical for real-world cases. To resolve this issue, algorithms must function in natural, unmodified environments. The algorithms used in (Xiong et al., 2013) addressed the clutter and occlusion issues by clear rationalization of each throughout the entire process.

A case study was conducted on a two-story, forty room schoolhouse to test the presented method. The experiments were completed by floor. The first floor (23 rooms) was for training and verification, the second (13 rooms) were used for testing. The building was modeled manually by the company who performed the laser scanning. The experiment sets were completed for the detailed wall modeling. The first analysis used surfaces created from the stand-alone wall detection algorithm (Adan & Huber, 2011; Xiong et al., 2013). The second used surfaces generated by the context-based modeling algorithm. The first evaluation focused on large and simple rectangular shaped rooms. The focus of the analysis was on understanding how well the algorithm identified openings and steps of modeling.

The performance analysis used has two aspects, how reliable it is for detecting openings and how accurate are openings modeled after detection. The first aspect was measured by comparing the detected openings with openings in the manually created model. Results showed the algorithm correctly detected 93.3% of openings with 10 cm voxels and 91.8% of openings with 5 cm voxels. Non-detected openings were mainly in areas with severe occlusions and in closets with closed doors during scanning. The second aspect was evaluated based on the accuracy of reconstructed openings through the comparison of the manually created model openings with positions the algorithm estimated. The average absolute error was found to be 5.39 cm with a standard deviation of 5.70 cm and an average relative error of 2.56% (Xiong et al., 2013).

The second experiment set was analyzed with all 13 second floor rooms. Results found the percent of recognitions to be 88% and the average error in opening size to be 4.35 cm. These results are slightly worse pertaining to the percent of recognition, but this could be due to the inclusion of stairwells and hallways in analysis. Although data was missing in the openings and the levels of occlusion were high, the detailed wall modeling algorithm worked well. One area that could be improved is the accuracy of the opening’s boundary. It was suggested that if the entire point cloud was used the level of accuracy would be higher. The reconstructed model was also tested on floor and ceiling reconstruction and found no openings, showing it to be successful for simple areas of focus (Xiong et al., 2013).

The authors of (Xiong et al., 2013) stated they will be focusing future research on improving their algorithms for automatic building models. Their first step is developing a scan-to-BIM pipeline. BIM is typically a volumetric model, while the researcher's models were surface based. They were in the process of developing an algorithm for automatically converting the surface-based model into a volumetric model and exporting it in the standard file format for BIM representation (IFC format). A possible advance could be to use room relationships. For example, if a surface in one room is a wall, then a close parallel surface beside it is most likely the other side of the wall. This would help identify and model surfaces with high clutter or occlusions, such as materials being stored on a job site ready to be installed. This would benefit owners and their FM teams greatly if this approach could be used for mechanical rooms as they often are small and cluttered.

As previously stated, the AEC has begun pairing IVEs with BIM. For the O&M stage these two technologies can be paired to allow FM teams to interact and visualize real-time data (Heydarian et al., 2015; E. Hailemariam et al., 2010; Malkawi and Srinivasan 2005). For example, these tools can be used to identify malfunctions of systems (Heydarian et al., 2015; Frazier et al., 2013; Hou et al., 2014). Heydarian et al., (2015) research set out to examine how people's performance differs in both a virtual and physical environment. The participant's performance was measured using three parameters; how daily tasks are completed, how participants perceive colors and objects for identification, and how participants feel when immersed in a virtual environment. Participants were asked to complete two tasks, reading a provided handout, which they were questioned about afterwards to determine how much they retained, and identifying as many books covers of a specific color in 30 seconds, with the number recorded for analysis.

Before the experiment was conducted, participants were taught how to maneuver in the virtual environment. All participants completed both tasks and were provided a questionnaire for feedback of their experience. The questionnaire was broken into categories; focus, gaming, immersion and involvement, control factors, distraction factors, and IVE interaction. The experiment was analyzed based on the hypothesis that people's performance varies greatly between dark and bright lighting conditions in both an IVE and physical environment. The results were evaluated in three categories; comprehension (ratio of correctly answered questions), reading speed (ratio of speed and number of words counted per second), and object identification (deviance from identifying the correct book color). Results showed a significant variance between mean values in the dark IVE and bright scenario IVE, as well as confirming the hypothesis that performance varies between the physical environments (i.e. bright and dark). After calculating variations for each of the three parameters, no significant variations were found between the two environments for all parameters. Additionally, the results showed that participant performance in both environments were very similar (Heydarian et al., 2015). Participants noted that the IVE was very realistic and similar to the physical environment. However, a limitation was found to be the movement within the IVE.

As mentioned previously, StructionSite has many features the FM team can benefit from, such as x-ray mode that enables the FM team to see what is installed in the wall. This feature lets FM personnel to view project photos with real-time conditions. For example, if a field technician was asked to verify if a system failure alarm was real or a fluke the technician could go to the location of the alarm and look behind the drywall and inspect wiring or piping. At project completion the FM team would be provided with the handover package containing digital drawings, when the technician reaches the location of the alarm they would open the drawing for that area on a mobile device. Then the image captured during construction could be viewed and x-ray mode selected on the viewfinder to overlay the existing condition and construction image (*StructionSite - Construction Documentation & Project Tracking*, n.d.).

If the technician was asked to respond to a work order or another less severe task it would be possible to view the 360-degree image captured at various project stages. This would allow for the technician to view what equipment they may be working on, tools needed to complete the task, and previous maintenance data to assist in completing the task before going into the field. Visualization platforms have been proven to assist FM teams in completing work orders in a more efficient and productive manner. "Design and Evaluation of an Integrated Visualization Platform to Support Corrective Maintenance of HVAC Problem-Related Work Orders" (Yang & Ergan, 2016) implemented a user-controlled method to design and adopt a visual interface for issue resolution. The interface was tested with a case study and proved that visualization can be successfully adopted for FM tasks, as well as being a valuable consideration for CAFM vendors when designing HVAC task user-interfaces.

Previous research by Yang et al., (2013) showed that HVAC technicians can waste up to two hours trying to obtain data they need to resolve a work order. It has also been discovered that work efficiency varies with different visualization methods showing the required data (Yang & Ergan, 2014; Yang & Ergan, 2016). When a work order is submitted an HVAC technician will need performance, spatial and historic data to resolve the issue (Yang and Ergan (2014b)). Traditional data visualization for HVAC technicians has been schematic diagrams showing the relationships between elements. The interface used "low-fidelity prototypes" and "high-fidelity prototypes." Low-fidelity are quickly assembled at low cost early in the project. High-fidelity are created using IFC input files and are designed based on feedback received from low-fidelity prototypes, making it more costly and time-consuming to develop (*Prototyping for Tiny Fingers*, n.d.); Yang & Ergan, 2016). To ensure the interface was not overloaded with data, elements were visualized based on priority (i.e. HVAC systems, non-geometric data, historical data) and all other elements were displayed using in text format (*Information Overload*, n.d.) ; Yang & Ergan, 2016).

To test both prototypes, HVAC mechanics were given three "real-world" scenarios, with all three having the same data, but in different visualization methods. The goal of all test scenarios was to find the appropriate resolution for the work order. The visualization types used were, documents only, prototype minus visualization, and data given using the developed prototypes with visualization. A virtual environment was used to simulate the scenarios given, allowing the technicians to inspect the systems and zones until the failure was found (Yang & Ergan, 2016).

Analysis of each scenario found the quickest time (5 minutes 12 seconds) for determining the cause of failure using the prototype with visualization. Having to sift through documents to find the required data took the most time, 12.5 minutes. The prototype with visualization improved productivity rates for two reasons. First, having the data displayed visually required less mental effort to understand what was shown. Second, visually displaying the system allowed for the element to be identified faster. Another benefit discovered was having the schematic diagram and 3D view connected making interpretation of the system and its components easier and faster. Interviews conducted after the test scenarios found benefits to be the ability of determining patterns in performance and conduct cross-system analysis since historical data was displayed for individual elements. This ability allowed innovative maintenance practices instead of only corrective maintenance. The presented prototypes also visually display any and all potential causes of failure (Yang & Ergan, 2016).

The results found that the visual interface should use a floor plan with rooms identified and a model with boundary boxes showing element locations, as well as having elements highlighted on schematic diagrams with 3D model displaying control relationships, schematic diagrams with text overlays, color coding, and systems. Additionally, the interface contained a model with color coding and symbols showing performance and historical data about the elements, which allow the users to modify it to fit their preferences. Total time troubleshooting failures was found to be 58% more efficient, 35% due to the integrated interface, and 23% because the interface contained visualization. The last noted benefit was the ability of the interface to display possible causes of failure automatically, along with visually displaying related data that may be required to complete the work order (Yang & Ergan, 2016).

Literature Review Summary of BIM for Owner benefits by project phases: O&M Phase:

- BIM use during O&M phase: asset inventories, space management, building systems analysis, environmental analysis, regulatory compliance management, and accurate as-built data.
- 3 tips for overcoming challenges for BIM integration into FM systems ((*Access To BIM Data Improves Facility Management Operations*, n.d.):

  1) Complete a review of FM BIM requirements

  2) Develop a BIM for FM guideline

  3) Add data to the model overtime

- Korman and Tatum (2016) research noted that FM teams often lack a model with as-built data for use as an O&M tool. This issue could be eliminated if 3D laser scanning was utilized during the building's lifecycle.
- FM teams typically have to adjust as-built models they are provided (i.e. link individual models into a single model, number equipment with unique ID numbers, label workspaces, and link the model to the FM system)
- BIM can also enhance the quality, consistency, and reliability of the data being used
- BIM can be paired with the following technologies:
  1) IVEs for allowing interaction and visualization of real-time data (Heydarian et al., (2015); Hailemariam et al., (2010); Malkawi and Srinivasan 2005; (Heydarian et al., 2015).
  2) 3D laser scanning for generating as-built models (Xiong et al., 2013)
  3) 360-degree photographs for allowing the FM team to see within walls for completing FM tasks (Yang & Ergan, 2016 ; *StructionSite - Construction Documentation & Project Tracking*, n.d.).

2.2: Survey Addresses

The survey has 34 questions and was divided into six sections; BIM Personnel, BIM Requirements, Construction Deliverables, Facility Management, Visualization & Asset Management, and Demographics. The purpose of the survey was to gain further insight on how BIM and visual data is used currently in industry and to assist in closing knowledge gaps between Owners and Design and Construction teams. The survey was developed using a survey distributed by Dr. Mayo and a colleague in 2012 and from the results of the literature review. The survey was developed on Qualtrics and distributed to Owners and Facility Management personnel. It opened June 16, 2020 and will be closed at the end of August 2020 to provide the researcher three months to analyze the results. Analysis will be completed using Qualtrics analysis tools and will later also be reviewed using SPSS analytics. The ultimate goal of the survey is to connect results to the literature review conducted to establish recommendations for FM teams on the use and storage of visual data to enable FM functions to be completed easier and in a timelier manner.

Each survey section began with a description of the section. The first section; BIM Personnel asked questions related to the types of leadership roles (internal and external) required for BIM-assisted projects and how many people within the organization have dedicated BIM roles. The goal of BIM Personnel was to determine how organizations take a leadership role when using BIM on projects (i.e. a BIM project manager to assist in construction administration for your organization), as well as determining how many organizations have established specific BIM related positions. The second section, BIM Requirements asked what percentage of projects is BIM used, provisions made within the organization to assist in BIM adoption, obstacles faced causing slow or no BIM adoption, and BIM requirements created within the organization. The purpose of this section was to narrow down specific organizational changes (i.e. revised contractual agreements addressing BIM processes) made to adopt BIM or obstacles faced when starting to adopt BIM.

Construction Deliverables contained questions pertaining to when asset data is collected and/or checked, formats of requested handover deliverables, and types of BIM deliverables mandated by the organization. For example, the answer choices for the question asking when data is collected and/or checked, the participant could select COBie schema, BIM model, paper, electronic, visual, or multiple others. The goal of this section was to determine what Owners request or are given during handover. The Facilities Management section was the largest of the six, and asked questions to gain a further understanding of when models are reviewed, QA/QC procedures to assess the accuracy and completeness of model-based deliverables, the most used format by FM teams for referencing data needs, how floor plans are used, how the final BIM deliverable is used, most common reasons why building documentation is not collected, time spent after handover organizing BIM data so it is useable, and the importance of BIM for the O&M stage. The goal of this section was to determine how models and their data are used for FM tasks and issues faced for not being given building documentation/data.

Visualization and Asset Management contained questions related to which visual formats are useful for O&M teams, how assets are named, where they are named, and who provides the visual data. This section was more centered on gaining further insight on the use and storage of visual data such as 360-degree photographs or 3D laser scans. The last section, Demographics contained questions to determine the type of organization participating in the survey and the participants role within the organization. Additionally, this section allowed for participant feedback/comments to be given, as well as the participant being able to request results of the survey. The survey will be provided in appendix “X” at the end of the research.

Summary for 2.2: Survey Addresses:

- Survey contains 23 questions and was divided into 6 questions
- Section 1: BIM Personnel – asked about leadership roles required for BIM-assisted projects and how many people within the organization have dedicated BIM roles
- Section 2: BIM Requirements – asked about the percentage of projects BIM is used, provisions made within the organization to assist in BIM adoption, obstacles faced causing slow or no BIM adoption, and BIM requirements created by the organization.

- Section 3: Construction Deliverables – asked about when asset data is collected and/or checked, formats of requested handover deliverables, and types of BIM deliverables mandated by the organization.
- Section 4: Facility Management – asked about when models are reviewed, QA/QC procedures for model-based deliverables, the most used format by FM teams for referencing data needs, floor plan use, time spent on final BIM deliverable to make it useable, most common reasons why building documentation is not collected, and the importance of BIM for the O&M stage.
- Section 5: Visualization & Asset Management – asked about visual formats useful for O&M tasks, how and where assets are named, and who provides the data.
- Section 6: Demographics – asked the participants what type of organization they work for and their roles within the organization.

2.3: Big Picture Discussion

Lucas & Addagalla, (2017) research discusses the current status of integrating BIM and CMMS for FM on university campuses in the U.S. The research team notes that their research can provide other institutions a baseline for considering BIM for FM. A questionnaire was devloped and distributed to the top 100 U.S. university campuses to identify the level of BIM for FM use. Universities view their buildings as capital investments, with the majority of the lifecycle cost being the O&M of said facilities. The goal of any construction project is to handover a "high quality project of value to the owner." However, if the O&M of the completed facility is complex any cost savings from earlier project stages will be lost. Fuller (2010) research stated that over a 30 year building lifecycle 2% of the total cost associated with the building cover design and construction while over 6% goes to the O&M of the building (*Life-*

Cycle Cost Analysis (LCCA) | WBDG - Whole Building Design Guide, n.d.). Fuller (2010) further added that the rest of the associated cost are salaries of the personnel using the structure. A well-maintained and easily maintained building can decrease some of the administrative costs as well as improve the performance of the users by providing an optimum work and business environment (Alsyouf, 2007).

Adequate O&M is only achieved when the FM team has the correct data. Typically, owners organize this data in one of three ways:

1) Direct reference of original project documents.
2) Paper-based or electronic spreadsheets requiring manual reference and updating.
3) Technology-based solution (i.e. CAFM, CMMS, or IWMS). It should be noted that many of these technology-based solutions are heavily dependent on manual input (Di Iorio, 2013; Teicholz, 2013).

If properly planned, BIM can act as a data library. For FM specifically, BIM can be used to locate asset locations within a building, provide real-time data access, check maintainability, management assets and space, among many other tasks (Becerik-Gerber et al., 2012). Previous research has suggested that many owners and FM teams see BIM as another responsibility requiring already limited resources to maintain (Lewis and Whittaker, 2012). If an owner decides to utlize BIM for FM they must clearly define their data requirements, standard processes, and deliverables needed to properly operate and maintain the building (Kiviniemi & Codinhoto, 2014); Teicholz, 2013). Owners typically use a BIM Management Plan or BIM for FM guidelines to define their BIM and data requirements (Teicholz, 2013).

Lucas & Addagalla, (2017) developed a survey based on results of a literature review and research methods were not discussed. Industry professionals tested the survey before it was distributed to universities to verify its reliability of responses. The survey consisted on three sections:

1) Demographics of respondents and the universities they represented.

2) Questions to narrow down the extent of systems and technologies used for O&M.

3) Follow up questions for respondents to clarify their answers and include barriers related to the intitial question. (A skip-logic was used to identify appropriate follow up questions based on responses to the types of systems they use).

Questions were both multipe choice and open-response. The multiple choice identified the types of systems used and the BIM-FM or FM system requirements. Open response questions provided better insight to barriers and benefits identified by each participant. The Clemson University Institutional Review Board (IRB) reviewed and approved the survey and process before it was distributed. The team targeted directors, presidents, vice-presidents and senior management of FM departments of universities in the Top 100 U.S. National Universities List in the 2015 US News and World Report. The survey was distributed to one hundred individuals and twenty-six completed the survey. Participant responses were considered valid if they had knowledge and experience in FM and held a management position for a minimum of five years in facilities operation, building support, or capital projects at their university. Additionally, participants needed an understanding of technologies used for FM. They survey contained questions that verified all criteria was met.

Responses were obtained from across the country but half (53%) were on the east coast. Survey responses were also analyzed based on the gross square footage (GSF) of building’s on campuses and number of employees. From the analysis it can be seen that the average university personnel that participated in the survey represented a university with 10-20 million GSF and

500-1000 employees, which is a large university. Additionally, responses were analyzed on the investment amount for renovations and new construction. The majority of responses showed the investment for new construction to be in the range of $100 million and $1 billion and $500 million for renovations. The renovation investment could be a result of there being little research on documenting existing buildings using BIM (Lucas & Addagalla, 2017).

The survey focused on identifying issues faced in new construction and renovations of existing buildings pertaining to the collection and use of O&M data at the end of construction. Since the response rate was low (26%), the margin of error and confidence interval were calculated using the Adjusted Wald Method, with a confidence level of 95% (Lucas & Addagalla, 2017); (Bonett & Price, 2012). The authors stated: "The confidence in these calculations represent the range of a larger population that would likely have the same reponse to the identified issue." Table 4 below lists identified issues and the percentage rate of response. From the table it can be concluded that O&M procedures for assets are a challenge for many project teams in both new construction and renovations of existing buildings.

Table 4. Respondent identified issues for collection of O&M information (Lucas & Addagalla 2017).

Issues in New Construction	**Response (%)**
O&M procedures for assets	88%
Collecting equipment specifications and warranties	77%
Identifying location of equipment on drawings	54%
Identifying proper replacement part information	54%
Identifying information for energy performance analysis	50%
Linking parent/child assets (i.e. fans in AHU)	46%
Issues in Renovation of Existing Buildings	
O&M procedures for assets	85%
Collecting equipment specifications and warranties	85%
Identifying location of equipment on drawings	58%
Identifying proper replacement part information	58%
Identifying existing equipment conditions	58%
Performance of efficiency of existing assets	58%
Linking parent/child assets (i.e. fans in AHU)	50%
Identifying information for energy performance analysis	42%

The survey had a section allowing participants to identify additional challenges faced in new building construction; proper as-builts, tracking post-warranty information, incomplete punch list issues, and incomplete commissioning reports. Table 5 below lists the additional challenges identified in Lucas & Addagalla, 2017 research study.

Table 5. Respondent status for requiring the use of BIM (Lucas & Addagalla 2017).

Status	Response (%)
BIM as a formal requirement for new construction and renovation	24%
BIM as a formal requirement for new construction only and actively considering it for existing building in the next 5 years	8%
BIM as a formal requirement for new construction and not considering for existing	8%
BIM as a formal requirement for existing buildings and actively considering for new construction	4%
Total Requiring BIM in some way	**44%**
No formal BIM requirement and none being considered	11%
Actively considering for the next 5 years for renovation projects only	4%
Actively considering for the next 5 years for new construction only	11%
Actively considering for the next 5 years both new construction and renovation	30%
Total Not Currently Requiring BIM	**56%**

The survey also identified reasons for BIM being required or its use being actively explored, asset management, caputring and integrating with FM systems, space planning, energy analysis, maintenance scheduling, and emergency planning. Reasons found for those not considering formal requirements for BIM are; lack of skill, cost of system implementation, and lack of knowledge. When analyzing the status of those using computerized systems for facility O&M, the research team found that 85% use FM systems and 15% do not. Of the 85% only 15% are integrating BIM with the FM system and 55% were planning to intgrate BIM into FM systems within the next 5 years. Respondents noted that they integrate of are planning to integrate BIM into FM systems soon due to; visualization of the facility, improved operations, O&M procedures, and scheduling maintenance activities. When asked how the data was transferred into the FM systems 90% stated they use spreadsheet formats (i.e. .cvs or .xml) and 10% use COBie or a proprietary integration method. Additionally, the top three benefits of using the FM systems of choice were found to be; work order management, asset management, and configurable ability to support specific needs. These benefits were consistent among all respondents.

Lucas & Addagalla, (2017) research identified lack of knowledge, lack of skill, and cost to be three reasons why some owners are not adopting BIM for FM. It was stated that the design and construction team should work with owners at the start of the project to promote the use of BIM and explain how BIM can be used for O&M. Owners successfully using BIM for FM should share their experiences so other owners can see the value BIM can provide. It may also be useful for software companies to devlop training methods to help increase owners knowledge of BIM which could make them more aware of what their data requirements should be and also assist them in the handover process.

"Introducing Building Information Modeling for Campuses" dicussed how in 2014, the Franklin W. Olin College of Engineering set out to improve data analysis for its O&M tasks. Their objective was to "use technology to collect, integrate, maintain, and use visual modeling to improve planning, space utilization, energy optimization and delivery of daily operating services." Generally speaking the FM department needed a technology to correctly gather, verify, and store space and equipment information along with being able to store documents for operating, managing risks and support strategic planning. Their goals were based on three desired outcomes:

1) Enhance user services by decreasing traditional, inefficient methods of responding to service requests.
2) Collect and maintain building and service data for informed decision making.

3) To operate within the established budget by decreasing energy consumption, space density issues, and outstanding emergency and corrective work orders.

Olin knew having all data in a single location would enabled advanced insight into the operations of the campus as well as increase their risk minimization efforts. Before BIM, Olin maintained data in numerous locations and formats such as, drawings, hard copy manuals, and spreadsheets. They had no way to bring it all together or access and analyze it in real time. This issue was resolved when Olin adopted BIM, using smart cloud technology and integrating data with its current CMMS. The combination enabled the FM team to gather, model, verify, access, and report performance data in real time. As a result, Olin has improved their decision making process, operational efficiency, cost management, and risk exposure. Additionally, they have enhanced building operations, cleaning services, energy consumption, strategic planning, and budget management.

For example, on many campuses, a call for service starts with a lengthy and time consuming process of correction. The person placing the request for service often has limited information resulting in the field technician having to physically locate the source of the problem and identify the mode of resolution. To resolve the issue the field technician may have to disrupt a class or order a replacement part, both of which are time and energy consuming. At Olin, the FM team can immediately acccess floor plans, documents and/or operation manuals using desktop computers or hand held devices. For instance, they can virtually open floor plans and identify the area containing the issue. If the technician clicks on the space, the data for equipment within that space is accessible, as well as notes from previous maintenance and supplies used. This has resulted in a reduction of corrective action time by an average of 20%. Technology can also reduce risk in a event of an emergency. For example, if a flood occureed and a pipe burst, the pipe can be identified and shut off remotely which can save costly damage and insurance claims and/or future increases in insurance premiums.

The visualization features allow the FM team to enhance planning, space utilization, shcedule personnel, budget for maintenance and establish “what if” scenarios on possible building modifications. Olin has also integrated BIM into its curriculm enabling engineering students to learn how to use BIM and its many analysis features.

Olin is only one of the many higher education institutes shifting toward BIM for FM. *The New England Journal of Higher Education* stated that campuses must find new ways for addressing the rising costs of FM. Many institutes are selecting BIM as it provides the power for better decision making and realize goals such as:

1) Creating achievable deferred maintenance strategies
2) Maintaining existing systems and installing new equipment
3) Balancing investments in new vs. existing building space
4) Determining where to renovate, repurpose or replace buildings

BIM benefits for FM are the same as the benefits when used during design and construction. The functions and abilities of visualizing structures and systems in 3D allows FM teams to view geometry, spatial connections, geographic data and property information. Additionally, analysis can be performed on building elements, cost estimates, material inventories, project schedules and multipe others during the buildings lifecycle. FM teams typically rely on the construction team to provide them with correctly measured maintainable space data as it is time consuming and laborous to collect. For example, contractors give cost estimates for replacement flooring (i.e. carpet, vinyl, etc) or painting according to their measurements. When the model contains quantities for these elements by type and walls by color the FM team can devlop more accurate maintenance plans and budgets. A report by McGraw Hill Construction (*Business-Value-of-Bim-for-Owners-Smr-2014.Pdf*, n.d.) found that almost 55% of building owners in the U.K. have already implemented BIM. The U.K. took the lead on BIM implementation for FM as in 2016 BIM use was required on all national public projects. However, in the U.S. only 14% of building owners have implemented BIM. By 2019, 92% of U.K. owners expect to be using BIM for FM, while in the U.S. this expectation is only 49%.(*Business-Value-of-Bim-for-Owners-Smr-2014.Pdf*, n.d.).

(Judge, 2014)also stated five reasons BIM will expand to be used more on U.S. campuses. The reasons are as follows:

1) Streamlined Maintenance – Immediate access to needed data on one platform (i.e. pre-mapped campus viewpoints, O&M manuals, drawings, and system schematics). Data can be accessed on hand-held devices. Additionally, mechanical and operational equipment can send alerts to FM teams (i.e. if maintenance is required).

2) Improved Space Management – Spaces can be managed better as FM teams have access to data such as, how the space is being used. Additonally, maintenance can be improved and renovation costs decreased. Higher education institutes require large volumes of data that is often dispersed across multiple departments. However, the naming and coding of the space is typically very different based on the department with the information. Systems such as CMMS, building automation systems and fire control systems operate with correct floor plans and space identification data. If spaces are named differently in different systems (i.e. as-built drawings and fire control systems) it can create risk. Similarly, if there are differences in event planning systems and BAS service, response times can be increased and disruptions could occur during an event. Using BIM and

industry standard coding systems enables colleges and universities to better manage and coordinate campus space.

3) Efficient Energy Use – Models can contain basic data to in depth data such as statistics for individual pieces of equipment (i.e power consumption, room temperatures, mechanical system pressures). When the process is seamess, elements can be maintained at the optimum level as well as avoid waste related to inefficient operations.

4) Economical Retrofits and Renovations – FM teams can use models to strategically plan renovations and retrofits by simplifying the process and potentially decreasing the costs if inaccurate data was used.

5) Ehanced Lifecycle Management – BIM has the ability to enhance the planning process. Some designers have stated inputting life expectancy data and replacement costs into the model can help owners better understand their investment of materials and systems. Additionally, BIM can track depreciate of elements to allow the owner to fully realize financial and tax benefits.

"Xavier University Realizes the Benefits of BIM from Planning to Operations," an article published by AutoDesk discusses how BIM was used for design, construction, and operations while Xavier added four buildings to its campus. For this project, Messer Construction chose to implement BIM to ensure the buildings being constructed remained on schedule and within the set budget. BIM enabled the design team to fully explore the design before construction began. Once Xavier saw how BIM benefited the design and construction stages they decided to use it for FM. BIM was paired with FM: Systems, Inc. with support from BIM solutions from AutoDesk throughout the building lifecycle, which allowed Messer Construction and Xavier to:

1) Save thousands of hours of data entry for FM

2) Make better informed budgeting decisions for FM
3) Stay ahead of tight construction schedules
4) Reduce RFIs with more precise building coordination

Messer Construction had used BIM on many previous projects and they saw the value it could add to the Xavier project. Messer Construction had found that BIM could prevent issues that increased costs and cause delays. They also discovered that without a BIM process construction is more difficult. Messer Construction conducted an in-house study comparing similar projects and found that BIM reduced RFIs by 72%, change orders by 42%, and punch list items by 56%. Andrew Burg said, “When you’ve seen what BIM can do, it’s hard to go back to the 2D world. We were faced with some very aggressive schedules, especially for a new residence hall that was started after the first three buildings. Delays and cost increases were not an option, so we turned to our proven BIM process” (*Xavier University Realizes the Benefits of BIM | Autodesk*, n.d.).

For three of the four buildings the design teams used AutoDesk BIM Solutions (i.e. RevitArchitecture Software) to develop 3D architecture and structural models which they shared with Messer Construction. Messer Construction enhanced these models with details needed for construction. The design of the first building used traditional 2D design tools. Messer Construction shifted to a BIM process, as stated by Andrew Burg, “The design team on one of the buildings, the new Central Utility Plant, was not up to speed on BIM when the design was done. We wound up taking the 2D designs and shifting to BIM software to create a 3D model of the building. You cuold view that as duplicate work, but we didn’t. We saw it as an investment. The returns take the form of smoother project execution, fewer RFIs, and a better quality building.”

Messer Construction stated that when BIM is used for design by all designers and contract documents are created from the design models, they see a decrease in RFIs by up to 52% when compared to projects that created models from the contract documents. This decrease is from the designers collaborating while designing the building and identifying issues (i.e. minor interferences) and correcting them immediately. Design reviews are also improved as the client is able to clearly visualize the design and provide feedback before construction breaks ground. Messer Construction further noted that BIM has been the “biggest game changer” pertaining to coordination. Messer Construction uses Navisworks Managing Software to combine the individual Revit and contractor fabrication models. The software enables Messer to identify clashes as construction is planned as well as create 4D schedules that link construction tasks to the 3D model (*Xavier University Realizes the Benefits of BIM | Autodesk*, n.d.).

Burg (Executive of Operations Technology for Messer Construction) said, “By coordinating using a BIM process, we have more confidence in the accuracy of the design, it’s not just that you address the concerns that can cuase RFIs sooner. You can also do more off-site fabrication of things like mechanical systems because you know you won’t have to redo it on-site. BIM helps to prevent problems to help maintain project schedules.” Burg further stated that, pertaining to the residence hall that 4D scheduling was especially valuable, “On this building, we had an extremely aggressive schedule. Being able to tie the model to the schedule made a big difference. For concrete, we could pour a slab at 4:00 a.m. and then pour the columns on top of it at 6:00 p.m. the same day. Everyone could see how we were sequencing that in the model, and everyone knew what they needed to do and when.”

Messer made sure to include the Xavier FM department during construction planning and execution, in which the model was referenced and the FM department saw its potential for O&M

right away. Greg Meyer, Assistant Director for Facilities Assessment at Xavier stated, "I went to a building coordination meeting and saw the model. It included just about everything we need from a data perspective to manage our facilities. Upon further exploration, we realized that the model had the potential to be integrated into the FM:Interact System we use in our facilities management process." FM Interact is a cloud based IWMS. Messer assisted Meyer in preparing the construction model for use in FM:Interact by removing irrelevant data and adding FM data pertaining to handover (i.e. space classification codes). Then Messer worked with FM:Systems to connect model data to FM:Interact. This was the first bidirectional integration with a model and space management software, which allowed FM personnel to access accurate building data on mobile devices and desktop computers (*Xavier University Realizes the Benefits of BIM | Autodesk*, n.d.).

Meyer said, "The timesavings we've experienced by taking advantage of BIM has been staggering. Preparing and entering the data using traditional methods might have taken as long as a year. The process would have been more error-prone too. Instead, we had instant access to building information flowing directly from the design and construction model into Interact. Maintenance people have access to the information they need to help keep our building operating efficiently." Meyer further stated, "Decision makers can make more informed budgeting and space management decisions. BIM data helped me to prepare a comprehensive, 10-year capital plan for Xavier. The data demonstrated that additional funding for maintenance and renovations was needed to support the school's mission. As a result, Xavier's administration raised the facilities budget from US $750,000 per year to US $12 million per year."

Messer first started using BIM applications in 2006 and has since seen a continuous improvement in its construction processes. Messer is especially proud of how BIM has had a positive impact on the entire lifecycle of the four buildings constructed on the Xavier campus. Burg stated, "from the start of the design to completion, the residence hall took only about 18 months. BIM helps make these kinds of accelerated project schedules not just possible, but practical. Even though building management is not our core business, we could see that BIM had the potential to transform that process. It was amazing to see the whole vision come together at Xavier University. Sharing the building model with Xavier University knowing that it's going to help people get more from those buildings for decades is very satisfying" (*Xavier University Realizes the Benefits of BIM | Autodesk*, n.d.).

Literature Review Summary for the Big Picture that the Survey Does Not Address:

- Typically, Owners organize data in one of three ways: direct reference of original project documents, and paper-based or electronic spreadsheets requiring manual references and updating.
- BIM can be used to: locate assets within a building, provide real-time data access, check maintainability, management of assets and space (Becerik-Gerber et al., 2012).
- Lucas & Addagalla, 2017 research distributed a survey to determine issues for the collection of O&M data for both new construction and existing buildings: O&M procedures for assets, colleccting equipment specifications and warranties, identifying location of equipment on drawings, identifying proper replacement part information, identifying information for energy performance analysis, linking parent/child assets (i.e. fans in AHU), and performance of efficiency of existing buildings.
- The New England Journal of Higher Education stated that campuses are selecting BIM as it provides the power for better decision making and realize goals such as: creating achievable deferred maintenance strategies, maintaining existing systems and installing

new equipment, balancing investments in new vs. existing building space, and determining where to renovate, repurpose or replace buildings.

- Judge n.d. research noted the following reasons why BIM will be used more on U.S. campuses: streamlined maintenance, improved space management, efficient energy use, economical retrofits and renovations, and enhanced lifecycle management.

CHAPTER 3: METHODOLOGY

To evaluate how BIM and visual data is used within industry currently and to assist in closing knowledge gaps between Owners and Design and Construction teams, an in-depth literature review was conducted, and a survey was developed to be distributed to Owners and Facility Managers. Due to the limited amount of previous research on the optimum storage and use of visual data for maintenance personnel, there was a heavy reliance on participation of the survey to gain further insight on industry professionals state of practice. Additionally, the researcher collected 360-degree and still photographs on the UNCC campus to explore how to best name and store them for UNCC FM use.

The survey was developed on Qualtrics to be distributed to Owners and Facilities Management personnel. It has 23 questions and was divided into six sections; “BIM personnel,” “BIM requirements,” “Construction deliverables,” “FM,” “Visualization and Asset Management,” and “Demographics.” The researcher distributed the survey through emails using contact lists and LinkedIn posts. It opened June 16, 2020 and closed on September 30, 2020 at 12:00 p.m. Analysis will be completed using Qualtrics analysis tools. Due to the need to significantly modify the response database, the research will later include IBM’s Statistical Product and Service Solutions (SPSS) for a subsequent publication. The survey was first analyzed by each survey question with the assistance of graphs to illustrate the responses. Then the survey was compared to the literature review (see section 3.1 for an in-depth analysis). Lastly, analysis of the overall survey was conducted.

The ultimate goal of the survey and literature review is to establish recommendations for FM teams on the use and storage of visual data to enable FM functions to be completed easier and in a timelier manner. The literature review discovered how BIM and visual data is currently used within industry, as well as how data is collected, stored, organized and used in industry currently. Owners and their FM teams are often handed over incomplete and inaccurate data. BIM and visual data (i.e. 3D laser scans and 360-degree photography) have been viewed as a resolution to this issue and have the potential to provide a more organized and structured handover process if used adequately.

Table 6 below lists the six sections of the survey, number of questions per section, and a description of each section. Based on the focus of the research, “Facilities Management,” and “Visualization & Asset Management” sections contained the most questions centered around FM tasks and data to allow further insight to be gained for the comparison of survey and literature review results. The survey was distributed via email using a list from attendees of a webinar Dr. Jake Smithwick (A Committee Member) was involved with, various industry organizations Dr. Glenda Mayo (Committee Chair) participates in, and various employees at universities of the North Carolina University System. Of the 284 emails send from the webinar attendees list only 15 participants finished the survey and 27 started the survey.

The list of various employees of NC universities was composed with to solicit their participation to assist in FM recommendations to the UNC-Charlotte FM Department. Table 7 below details the universities and job titles of the email recipients. A total of 49 emails were sent to university employees from table 7, 2 started the survey but only 1 finished the survey. The search of university websites served to locate those with responsibilities and jobs pertaining to facility operations and services, maintenance, utilities, financial planning, project managers, construction services, BAS, and facility planning. The goal for distributing the survey to these employees was identified in the literature review findings, which are detailed in tables in section 3.1.

Table 6. Owners Distribution Survey Overview

SECTION	NUMBER OF QUESTIONS	DESCRIPTION OF SECTION
BIM Personnel	2	Types of leadership roles (internal and external) required for BIM-assisted projects.
		Dedicated BIM roles within organization
BIM Requirements	4	What percentage of projects BIM is used
		Provisions made within organization to assist in BIM implementation
		Obstacles faced causing BIM to be slowed or not adopted at all
		BIM requirements created within organization
Construction Deliverables	3	Data collection and verification methods during construction
		Requested format of handover deliverables
		Types of BIM deliverables mandated by organization
Facilities Management	8	Time intervals for reviewing models for coordination and QA/QC from designer
		QC procedures used to access the accuracy and completeness of model-based deliverables
		Most used format used by maintenance and FM staff for referencing building data needs
		Use of floor plans, post-construction
		How is final BIM deliverable used post-construction
		Most common reasons why building documentation is not collected
		Time spent after handover organizing BIM data to make it useable for organization
		Importance of BIM uses in O&M stage
Visualization & Asset Management	4	Useful visual data for O&M staff
		Types of visual data requested and by whom are they provided from
		Organization's nomenclature for assets
		Where are assets named
Demographics	2	Type of organization
		Role of survey participant within their organization

Table 7. Description of NC universities and job title of survey distribution

University of Employment	**Job Title**
APP State	Director of Facilities Operations
	Mechanical, Preventative Maintenance & Zone Maintenance
CPCC	Director of Facilities Operations
Elizabeth City State University	Director of Facilities Management
Elon	Director of Utilities
Fayetteville State University	Director of Facilities Operations
	Facilities Supervisor
	Building Environmental Services Supervisor
	Director of Planning & Construction
	Building Environment Supervisor
NC A&T	Facility Maintenance Supervisor
	Facility Maintenance Supervisor
	Facility Maintenance Supervisor
	Facility Maintenance Technology
	Director of Facilities Operations
NC Central University	FM Supervisor/HVAC Shop
	Director of Facilities Services
	Building Environmental Services Supervisor
	Asst. Director of Utilities & Facilities Operations
NC State	Building Services Manager
	Construction Services - Asst. Director of Contracted Construction
	Facilities Services Admin - Senior Director
	Grounds & Building Services - Director
UNC Asheville	Project Manager FM Engineer, BAS Administrator
	Building Operations & Maintenance Manager

Table 7. Description of NC Universities and Job Title of Survey Distribution (Continued)

UNC Chapel Hill	Operations Management
UNC Greensboro	Asst. Director for Facility Services
UNC Pembroke	Director of O&M
UNC Wilmington	Director of Physical Plant
Wake Forest University	Asst. Director Maintenance Services
	Financial Planning & Systems
	Director of Planning & Construction
	Manager of Utilities Operations
Western Carolina University	Building & Environmental Services Supervisor
	Building & Environmental Services Supervisor
	Building & Environmental Services Supervisor
	Building & Environmental Services Supervisor
	Facility Maintenance Supervisor
	Facility Maintenance Supervisor
	Facility Maintenance Supervisor
	Facility Maintenance Supervisor
	Director of O&M
Winston-Salem University	Building Envir Services Manager
	Facility Planner
	Building & Envir Manager
	Facilities Maintenance Supervisor
	Utilities Plant Operation Supervisor
	FM Supervisor
	Director of Facilities Operations

The distributed emails received feedback from several recepients pertaining to the survey. Multiple email recepients noted they did not use BIM, were not an "Owner," stated they were not suitable to take the survey, or that it was not their area of work making them inapplicable to take the survey. One email recepient replied saying, "We are a CAFM, IWMS software provider, we integrate CAD and BIM with Archibus for our customers, thanks for asking." This recepient did not provide any further detail on whether or not he completed the survey or passed it to clients to complete the survey. However, one respondent working with a university in North Carolina provided excellent detail of his organization and offered feedback on the survey. This recepient stated that "none of the above" would have been a good answer choice for multiple questions. Further explanation was provided:

- "Your survey assumes my firm (university in this case) is at least conversant with BIM/GIS to the point where we have some rules and regulations for using it. We aren't there yet, but we are interested in it because we know it represents the future. We just haven't put a foot down in the future yet. Leadership is divided about when and how, not whether to or not."
- The survey asks about how records are kept within the organization, what kinds of records, and what is or is not required in BIM models, these could not be answered without explaining the organization's position in its complete context.
- It was stated the organization does "try to follow SCO and NC Archives minimum rules for records---that means permanent records (paper, mylars) for construction with different shelf lives prescribed in NC statutes."

- The feedback further stated that they ask for. dwgs, pdfs, and scans for their own convenience. Different departments within the organization use the files differently depending on their job responsibilities.
- The recipient also stated that they know their database is not "well consolidated and exists in many formats" as their PMs operate independently throughout the project lifecycle pertaining to tracking and reporting.
- Assetworks/AiM was implemented several years ago but they have only recently successfully utilized it for internal accounting, which also applies to the FM side of Campus Operations.
- Pertaining to GIS and BIM, they receive models at handover but have no way to update them or distribute them as they have no dedicated staff or proficiency for this task. Furthermore, it was stated that the design and construction teams extract the construction documents and conduct analysis throughout the project and the organization archives the "derivative materials."

One organization within the Charlotte area contacted the research team to further discuss the research project. During the meeting they shared multiple issues they have experienced within the industry. One issue shared was issues during the deliverable phase such as, the Charlotte area has robust BIM requirements, but deliverables do not meet these requirements. Additionally, it was stated that the organization would like to know what is being doing by the industry as a whole pertaining to BIM and handover deliverables, but research is lacking in this area. The organization involved in this meeting noted that they bid on projects to get more involved in the Charlotte area but they have experienced when they bid the project specifications and it cost this amount, a plumbing contractor told them they are two times higher than another

BIM provider. They discovered that the price difference is from the other BIM provider not providing every specification requirement but that is how things are typically done in the Charlotte area. The organization described this as a "hardship" they have experienced. The organization has witnessed Owners desiring standards for project data and the best ways to apply the standards, as well as the fastest way to receive the data they need, but research is lacking in this area as well.

To address the feedback received and gain further insight on the current industry state-of-practice the survey will be analyzed using Qualtrics Analytics and SPSS with the following analysis types:

- Count-Mode
- Count – Mean/Mode
- Data scales – nominal & interval

Analysis will also be conducted to determine:

- A review of QC procedures vs. how it's used
- If the organizations have established procedures pertaining to Facility Management and Visualization & Asset Management
- How prevalent the use of visual data is

When the in-depth data analysis was attempted it was discovered that the set of up questions would require significant rework of the results to enable a detailed statistical analysis.

3.1 A comparison between the literature summaries and the survey responses will be reported.

The literature review discovered many factors impacting BIM implementation for Owners and FM teams. Results of the literature review were compared to the survey questions to potentially identify connections between the two.

Table 8. Literature Review organizational identified factors for BIM adoption

FACTORS IDENTIFIED BY LITERATURE REVIEW FOR BIM ADOPTION	SURVEY QUESTIONS
Organizational structure to support BIM	Q2, Q3, Q5, Q6, Q7, Q8, Q10, Q11, Q12, Q16, Q17, Q19, Q21, Q22,
Information-sharing & interoperability protocols	Q5, Q8, Q10, Q11, Q12, Q15, Q16, Q17, Q19, Q21, Q22
Standardized work procedures for BIM	Q2, Q3, Q5, Q6, Q8, Q10, Q11, Q12, Q15, Q16, Q17, Q19, Q21, Q22
Client satisfaction level & metrics for evaluating effectiveness on BIM projects	Q2, Q3, Q5, Q8, Q11, Q12, Q16, Q17, Q18, Q19, Q21, Q22

Table 9. Literature Review identified factors for BIM adoption

FACTORS IDENTIFIED BY LITERATURE REVIEW FOR BIM ADOPTION	SURVEY QUESTIONS
Expected economic impact by adopting BIM services (return on investment)	Q2, Q3, Q6, Q7, Q8, Q20, Q21
Whether service is required by company's business strategy	Q5, Q6, Q7, Q8, Q12
Whether service is required by client or specific project	Q5, Q6, Q7, Q8, Q11, Q12, Q15, Q16, Q19, Q20
How well current employees can use BIM services	Q2, Q3, Q6, Q7, Q8, Q20, Q21
Learning curve (required time to adopt services)	Q2, Q3, Q5, Q7, Q8, Q20, Q21
Whether service can be adopted without conflicts with traditional work process	Q2, Q6, Q7, Q8, Q10, Q11, Q15, Q16, Q17, Q18, Q19, Q20, Q21, Q22
Initial investment costs including hardware and software costs and training fees	Q6, Q7, Q8, Q15, Q16, Q17, Q18, Q20, Q22, Q28

Table 10. Literature Review software factors identified for BIM adoption

FACTORS IDENTIFIED BY LITERATURE REVIEW FOR BIM ADOPTION	SURVEY QUESTIONS
How well a software application currently supports services of interest	Q8, Q10, Q20, Q21
How interoperable a software application is with other applications	Q8, Q10, Q20, Q21
Whether major subcontractors or business partners are currently using the software application	Q7, Q8, Q12, Q17, Q21
How well current employees use the software application	Q2, Q3, Q6
Whether software application is already in use in other departments	Q2, Q3, Q6, Q8
How good content libraries are	Q8, Q10, Q11, Q12, Q17, Q19

Table 11. Literature Review factors identified for BIM adoption

FACTORS IDENTIFIED BY LITERATURE REVIEW FOR BIM ADOPTION	SURVEY QUESTIONS
Request from client on BIM	Q5, Q8, Q17, Q19, Q21
Project complexity (in terms of building shape or systems)	Q5, Q7, Q8, Q17, Q21, Q22
Project Stakeholder (except Owner & FM team) use, willingness and interest in adopting BIM	Q7, Q8, Q12, Q17, Q21
Total project construction cost	Q7, Q8, Q12, Q17, Q20

3.2 Analysis of individual survey questions

Analysis was conducted on each individual survey question. The frequency for each question was examined, as well as how each question and answer selection related to results found in the literature review. Analysis of individual survey questions, along with more in-depth analysis results will be used to develop a report for recommendations on BIM implementation to be provided to the UNC-Charlotte FM Department. The individual survey questions were exported from Qualtrics as a “Default Report.” The responses for each question were then entered into Excel and a graph for each question was created. The question is at the top of each graphic. The x-axis contains answer choices and the y-axis has the frequency for each.

CHAPTER 4: ANALYSIS

In an attempt to provide further analysis on the data (as listed in Ch.3 Methodology), it was determined that the set-up of questions would require significant rework of the results to enable a detailed statistical analysis. However, there was not enough time to perform the rework, so analysis was completed on individual survey questions for all participants. Additionally, analysis of survey questions was conducted on those selecting only college and university as the organizational type. The most significant discoveries were:

- The top 2 leadership roles required on BIM-assisted projects were, a project BIM manager to assist in construction administration and a team member focusing on managing assets.
- 15 of the 16 have 1-3 dedicated BIM personnel
- 3 participants with a dedicated BIM role also have at least 2 other roles within the organization.
- BIM/VDC requirements, asset lists, and trained staff member dedicated within the organization to manage BIM procedures are the most adopted provisions.
- 63% have adopted a minimum of 3 BIM requirements and 44% adopted 6 or more requirements.
- 81% request BIM for handover deliverable formats
- 50% have 2 or more mandated BIM deliverables required at construction handover.
- 56% designated a team member to QA/QC procedures.
- 63% find 2 or more formats useful to O&M staff for referencing building data needs; 75% request CAD drawings, 38% request Revit.

- 56% use the models' data to track asset management, space management or have integrated the model into the IWMS/CMMS.
- 72% rated the uses of BIM in the O&M stage as extremely important, very important or somewhat important; 53% rated extremely and very important.
- 75% find photographs useful for O&M staff, 56% find 360-degree photographs useful for O&M staff, 50% find both photographs & 360-degree photographs useful.
- Participants request visual data from the construction team the most followed by collecting the visual data internally. Photographs are requested the most from both sources, followed by laser scans, then 360-degree photographs.
- 69% of participants utilize a similar nomenclature to "bldg._Plbg_Pump_01_02" name assets
- 69% name assets or assign nomenclature in IWMS/CAFM, 19% name assets or assign nomenclature in the BIM file and IWMS/CAFM.
- 6 of the 16 participants have 2 or more roles.

4.1: Individual Question Analysis

This section discusses the analysis of individual survey questions. The goal is to report recommendations can be provided to UNC-Charlotte FM Department to assist in successfully implementing BIM but to also provide a benchmarking document for all owners regarding the state of practice for BIM use. Some organizations have successfully adopted BIM for FM purposes (aka BIM "success story"), which will be included in the created report to handover to the UNC-Charlotte FM Department. A BIM "success story" is when an organization is able to implement BIM and receive the many benefits it has to offer. Successful BIM adoption occurs when all impacting factors align. Factors examined in literature (Won et al., 2013; Xiong et al., 2013; Azhar et al., 2015; Bosche et al., 2015):

- People's attitudes toward BIM
- Project characteristics
- Communication
- People's willingness to change
- Organizational culture and/or structure
- Organizational processes
- Collaboration between the project team
- Project team member knowledge on BIM and its processes and capabilities
- Work processes
- Data exchange processes
- Senior management involvement

In another words, successful BIM adoption depends on how well an organization "aligns BIM technology with their work processes and vice versa (Anumba et al., 2010)." Lucas & Addagalla (2017) suggested that Owners successfully adopting BIM for FM should share their experiences with other Owners so they can see the value BIM can provide. The literature review identified multiple research case studies resulting in successful BIM adoption for FM, as well as a success story of Xavier University implementing BIM. Yang and Ergan (2016) study illustrated that total time troubleshooting failures was 58% more efficient, 35% due to the integrated interface, and 23% because the interface contained visualization. The developed interface contained non-geometric (i.e. work order history, HVAC system information) and geometric data (i.e. schematic diagram of HVAC equipment, 3D view of equipment, 3D model of facility). Technicians completed test scenarios being provided only documents, protype interface minus visualization, and data given using the developed prototypes with visualization.

Xavier University Realizes the Benefits of BIM from Planning to Operations discusses how BIM was used for design, construction, and operations while Xavier added four buildings to its campus. Messer Construction chose to implement BIM to ensure the buildings being constructed remained on schedule and within the set budget. BIM enabled the design team to fully explore the design before construction began. Xavier decided to implement BIM for FM once BIM benefits for design and construction were discovered. Xavier experienced the following results from BIM adoption:

- Saved thousands of hours of data entry for FM
- Made better informed budgeting decisions
- Stayed ahead of tight schedules
- Reduced RFIs with more precise building coordination

Andrew Burg of Messer Construction stated, “When you’ve seen what BIM can do, it’s hard to go back to the 2D world. Delays and cost increases were not an option, so we turned to our proven BIM process.” The Xavier FM department was involved during construction planning and execution. Greg Meyer, Assistant Director for Facilities Assessment at Xavier, stated, “I went to a building coordination meeting and saw the model. It included just about everything we need from a data perspective to manage our facilities. Upon further exploration, we realized that the model had the potential to be integrated into the FM:Interact System we use in our facilities management process.” Messer assisted Meyer in preparing the construction model for use in FM:Interact by removing irrelevant data and adding FM data pertaining to handover (i.e. space classification codes). FM Interact is a cloud based IWMS. Then Messer worked with FM:Systems to connect model data to FM:Interact. This was the first bidirectional integration with a model and space management software, which allowed FM personnel to access accurate building data on mobile devices and desktop computers.

Meyer said, “The timesavings we’ve experienced by taking advantage of BIM has been staggering. Preparing and entering the data using traditional methods might have taken as long as a year. The process would have been more error-prone too. Instead, we had instant access to building information flowing directly from the design and construction model into FM:Interact. Maintenance people have access to the information they need to help keep our building operating efficiently.” Meyer further stated, “Decision makers can make more informed budgeting and space management decisions. BIM data helped me to prepare a comprehensive, 10-year capital plan for Xavier. The data demonstrated that additional funding for maintenance and renovations was needed to support the school’s mission. As a result, Xavier’s administration raised the facilities budget from US $750,000 per year to US $12 million per year.”

Messer first started using BIM applications in 2006 and has since seen a continuous improvement in its construction processes. Messer is especially proud of how BIM has had a positive impact on the entire lifecycle of the four buildings constructed on the Xavier campus. Burg stated, “from the start of the design to completion, the residence hall took only about 18 months. BIM helps make these kinds of accelerated project schedules not just possible, but practical. Even though building management is not our core business, we could see that BIM had the potential to transform that process. It was amazing to see the whole vision come together at Xavier University. Sharing the building model with Xavier University knowing that it’s going to help people get more from those buildings for decades is very satisfying" (*Xavier University Realizes the Benefits of BIM | Autodesk*, n.d.)

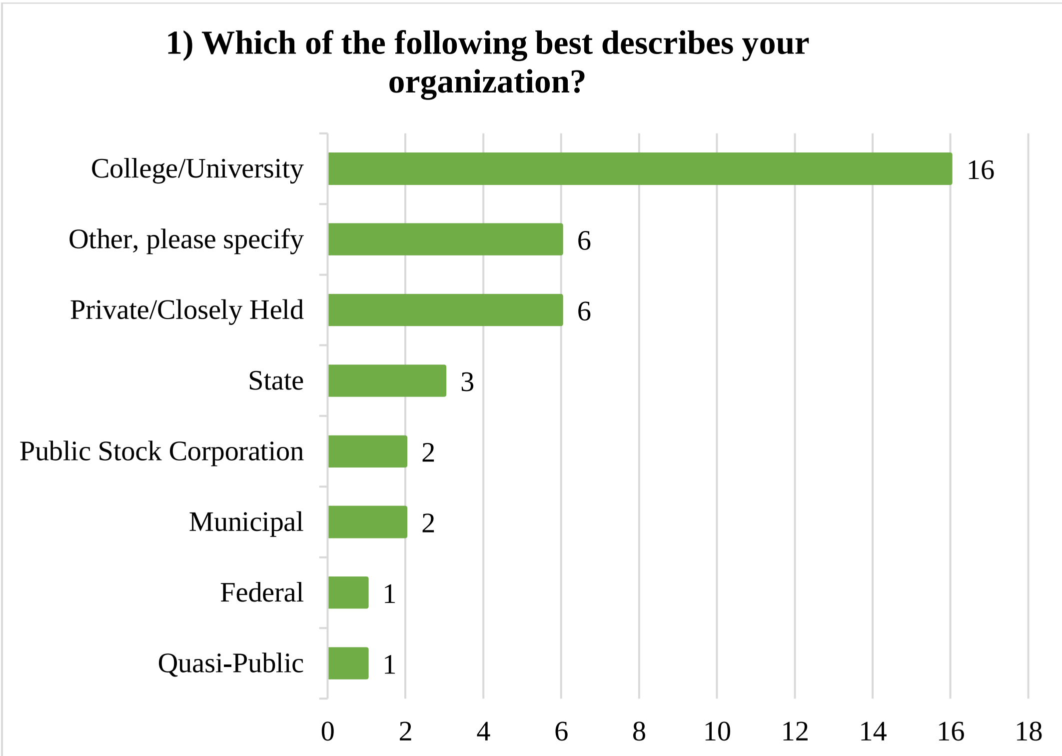

Figure 2. Question 1 of survey

Participants were asked to best describe their organization. As stated above there were 59 surveys recorded. This question had a frequency of 37. Of the 59 surveys recorded, 22 participants felt this question did not apply to them or did not wish to provide the information. Of the 37 participants that responded to this question, the category receiving the highest count,16 represented a College/University. This is significant in that the researcher hopes to provide the UNC-Charlotte FM department with recommendations to better utilize BIM. The categories with the second highest counts represent, Private/Closely Held and Other, please specify. For the latter, respondents input the following: "Healthcare System," "Not for Profit," "Independent," "Manufacturing," "Private and Owner Consultant," and "Architecture Firm." Federal was the category the least represented with only 3 respondents. This could be significant in the fact that certain countries, such as, Canada and England have adopted BIM mandates and requirements for publicly funded projects.

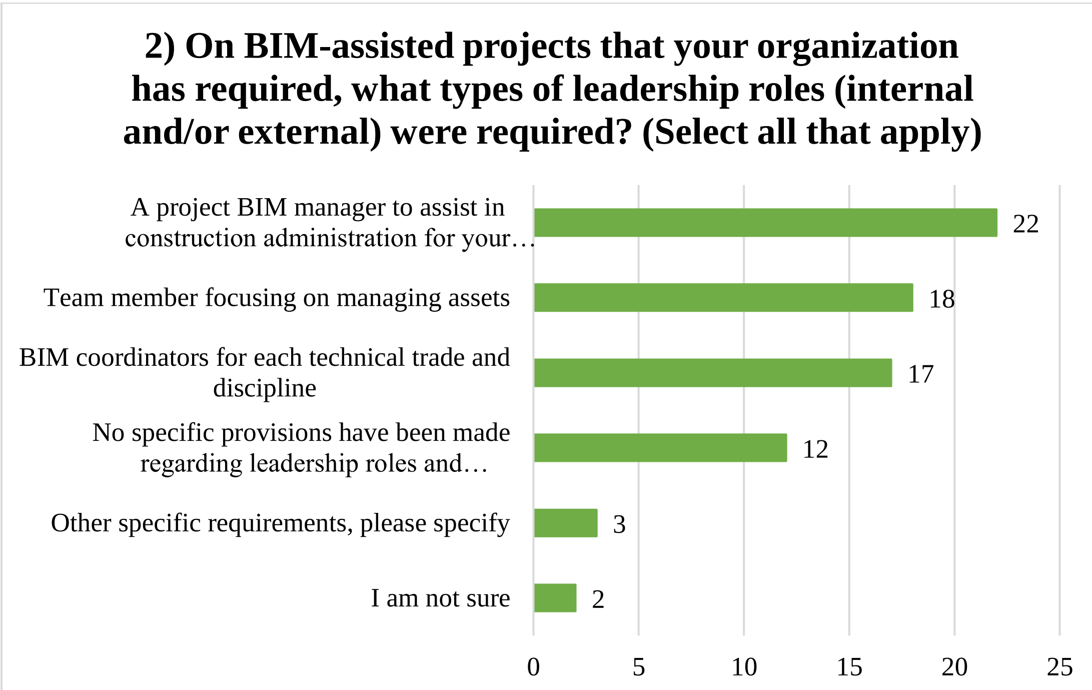

Figure 3. Question 2 of survey

The graphic for this question, pertaining to leadership roles required for implementing BIM, found "a project BIM manager to assist in construction administration" to be most vital. The literature review identified factors for adopting BIM. Specifically, related to this question it found "organizational structure to support BIM," "standardized work procedures for BIM," "whether service can be adopted without conflicts with traditional work process," "how well current employees use the software application," and "whether software application is already in use in other departments" to be a vital component to successful BIM adoption. Research by Won et al., (2013) discovered that key barriers to BIM adoption are "organizational structure doesn't support BIM" and "lack of expertise." Based on the answer choices available, when the 22 respondents selected "a project BIM manager to assist in construction administration," 8 participants selected only that answer choice. However, 9 selected "a project BIM manager to assist in construction administration," "BIM coordinators for each technical trade and discipline," and "team member focusing on managing assets." All 3 choices are the highest ranked categories illustrating the importance of each for successful BIM adoption. As stated previously, 59 surveys were recorded (34 being 100% complete, 25 being less than 100% complete). This question had a frequency of 74 and was completed 100%, which signifies some participants selected more than one answer for this question. This confirms the literature review findings of successful BIM implementation must be part of the organizational culture and structure. Additionally, participants were able to provide responses if the choices provided were not suitable to their organization. For this question three participants chose to input their responses:

- "We have provisions to receive BIM models, but did not have internal people or processes to take advantage of those deliverables until 8 months ago. We now have a BIM Project Manager (me) to define project protocols, receive and process models, and to develop strategies for using BIM moving forward."
- "BIM not yet used"
- "Facilities record coordinator, keeps existing conditions and past renovations, to pass on to new project teams."

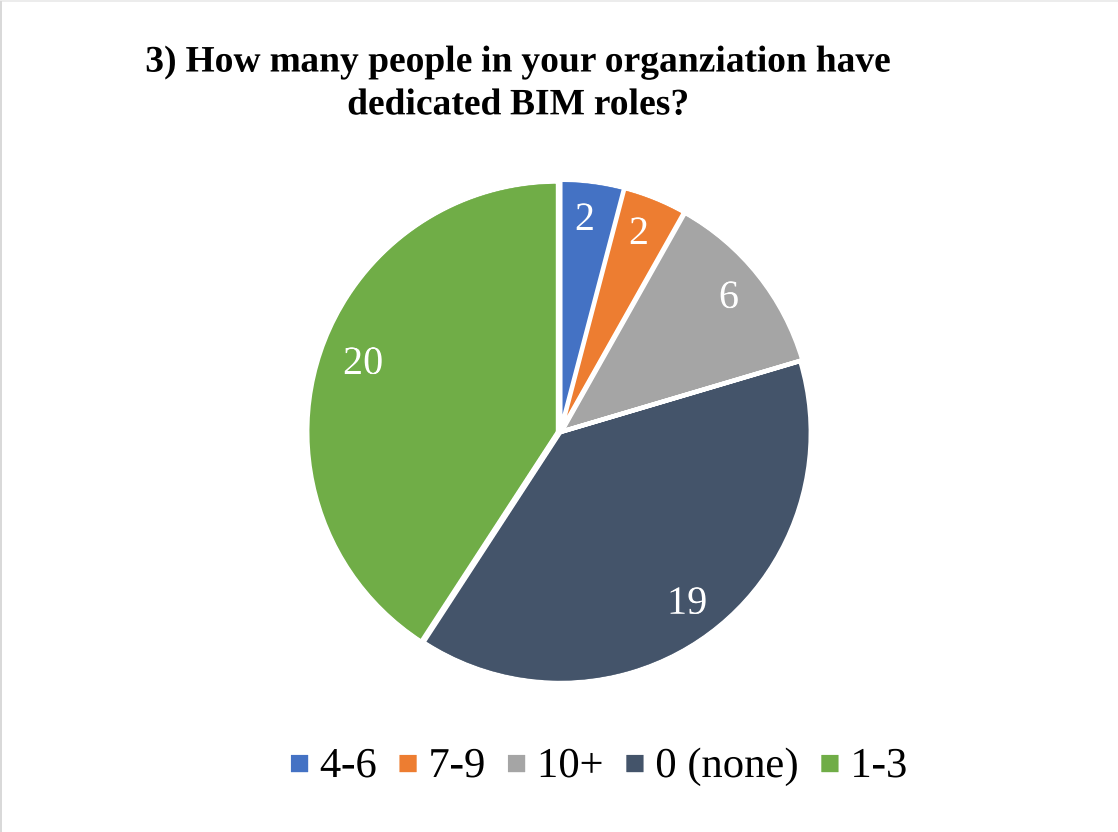

Figure 4. Question 3 of survey

This question asked the participant how many people within their organization have dedicated BIM roles. The highest scoring category (1-3) had 20 responses with the next highest scoring category being the “none” category with 19 responses. Like the first question, not all participants answered this question. BIM has high upfront costs including the software and hardware as well as training for employees to efficiently use it. The goal of this question was to determine how many of the organizations currently have people in dedicated BIM roles. When comparing the responses of this question to question 2 (“On BIM-assisted projects that your organization has required, what types of leadership roles (internal and/or external) were required?”) the frequency could be interpreted in a way suggesting that the leadership roles are mainly external. If the organization had in-house BIM personnel, the frequency for the lowest selected categories would have been higher. External roles could be more cost-efficient for

Owners as they would not have to pay for training employees or make drastic changes to their organizational structure.

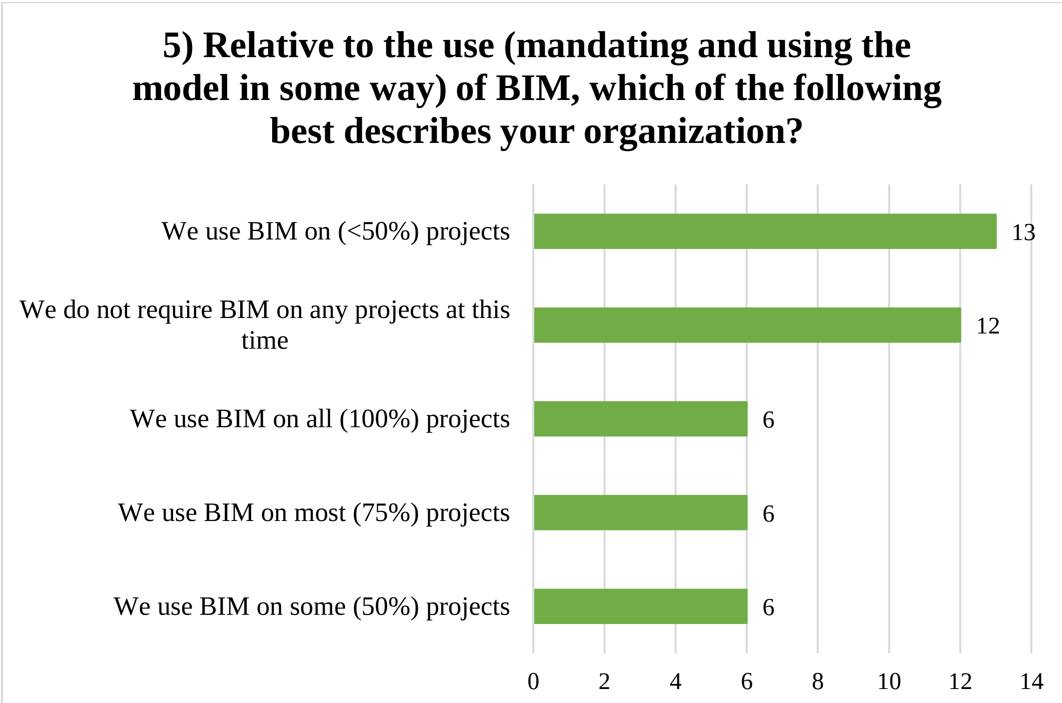

Figure 5. Question 5 of survey

This question asked the participant on the percentage of projects within the organization using BIM. Based on the illustration, a majority of the participants use BIM on less than 50% of projects or not at all. The remaining 18 responses were evenly split between using BIM on all (100%) of projects, on most (75%) of projects, or on some (50%) or projects. The literature review discovered the following applications of BIM during the FM stage; visualization, building performance analysis, building management, building systems analysis, maintenance scheduling, asset management, space management, and disaster planning & management (Azhar et al., 2015). There were 59 surveys recorded. However, this question only counted 43 responses so not every participant answered this question. The literature review found that many Owners are not using or requiring BIM due to various issues or concerns such as, cost of investment, poor collaboration among project participants, organizational structure not supporting BIM use, lack of expertise, lack of industry standards, and the shortage of BIM implementation data in the construction stage. It is expected this question could receive more responses for the use of BIM on 50% or more of projects as research has and is being done on the transition of paper-based handover to BIM-based handover and O&M. Specifically, research done by Cavka et al., (2015) identified a gap within the industry between the available and required data, procedures, technology, and challenges owners face when considering BIM adoption.

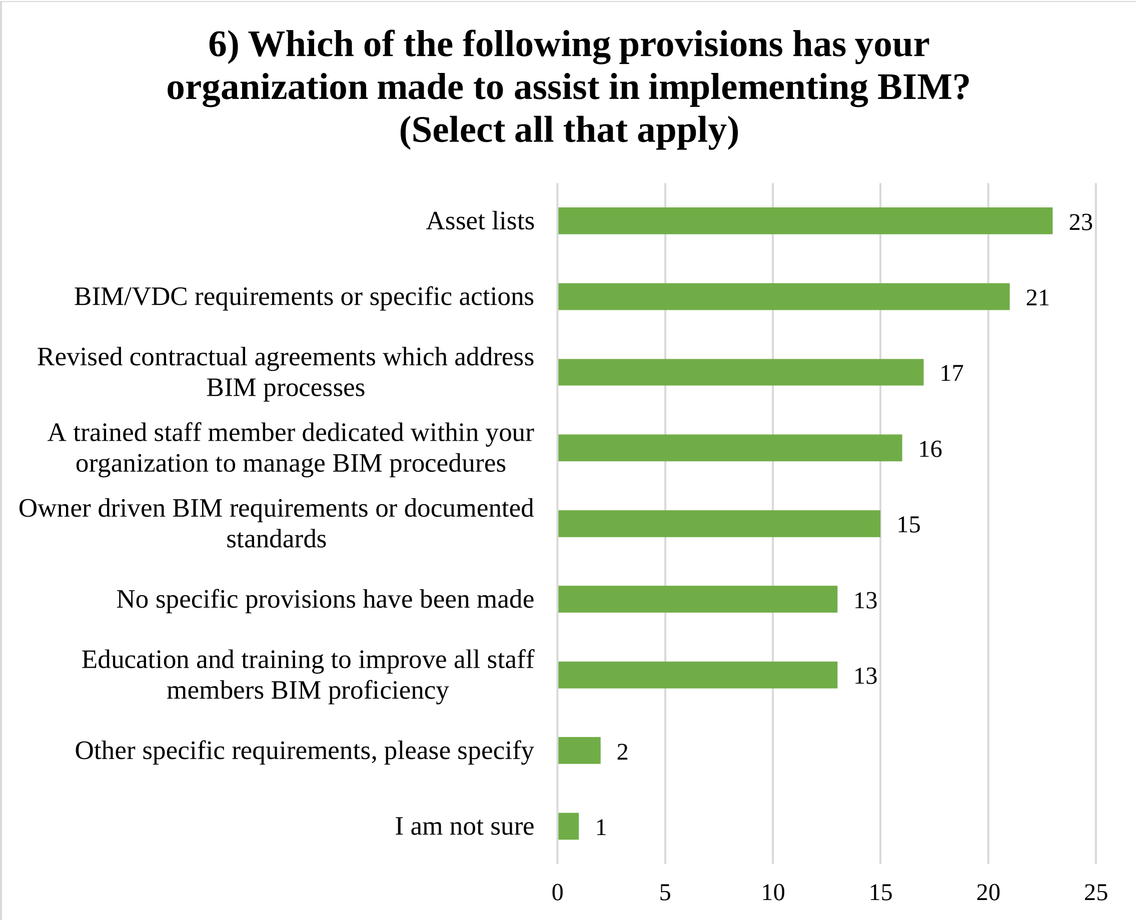

Figure 6. Question 6 of survey

The frequency for this question was twice as many as the number of surveys recorded (59). It is assumed that some participants selected more than one answer choice for this question. As the literature review discovered BIM implementation requires organizational provisions and changes. This question asked the participants what types of provisions their organizations have made in supporting BIM implementation. The frequency for each answer choice were in a close range to one another. For example, the highest scoring category (frequency of 23) was Asset lists. Assets are a main component in a facility and asset management is a key responsibility of the FM team who strive to achieve optimal performance of the facility (Van Driel, 2010). BIM/VDC requirements or specific actions were a close second with a frequency of 21. Improving Facility Management Through BIM Data noted that conducting a complete review of BIM requirements at the start of the project is vital for BIM to be successfully used for O&M. To assist in this success also includes involving the FM team to help bridge the gap between other project team members (*Access To BIM Data Improves Facility Management Operations*, n.d.). The remaining answer choices were scored as follows (from highest to lowest count):

- Revised contractual agreements which address BIM processes (frequency of 17)
- A trained staff member dedicated within your organization to manage BIM procedures (frequency of 16)
- Owner driven BIM requirements or documented standards (frequency of 15)
- Education and training to improve all staff members BIM proficiency (frequency of 13)
- No specific provisions have been made (frequency of 13)
- Other specific requirements, please specify (frequency of 2)
    - “Revit templates”
    - “We use BIM only in that our staff uses Revit”
- I am not sure (frequency of 1)

The second response to Other specific requirements, please specify stating that “We use BIM only in that our staff uses Revit” signifies that many people do not fully understand what BIM is.

Revit is a software tool that is used to leverage BIM. BIM is a virtual parametric process of continuous updating and modifications from all project stakeholders, which ensures owner requirements will be met (Azhar et al., 2015; *BIM*, n.d.).

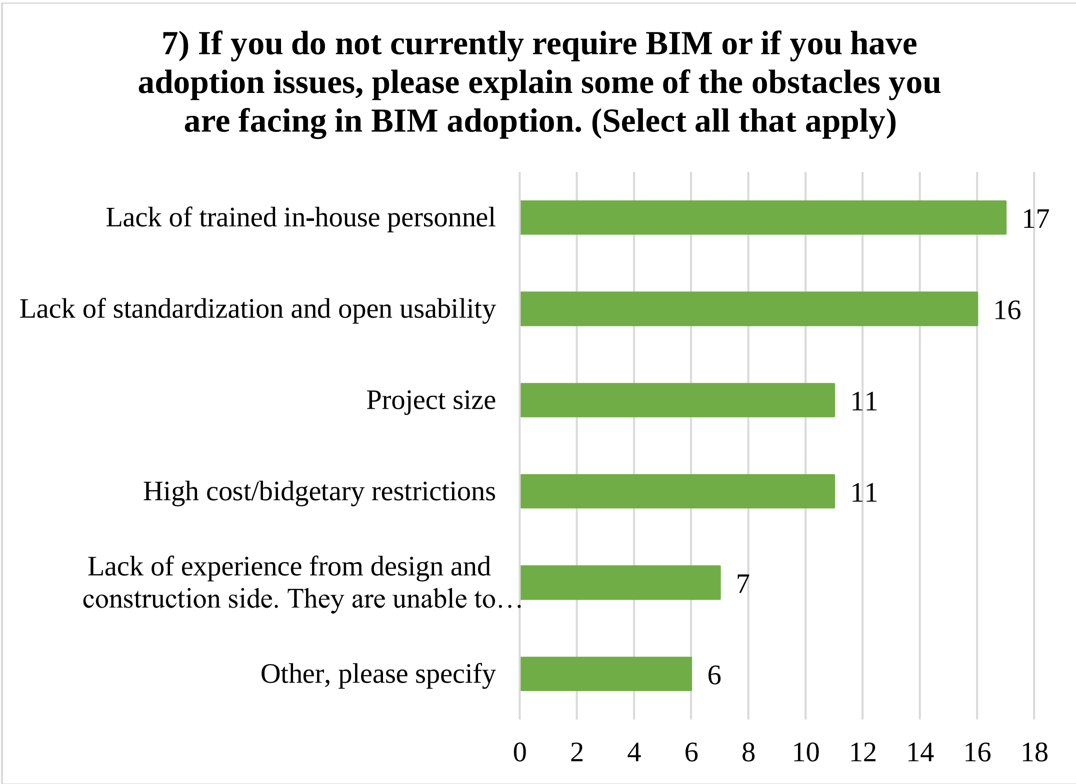

Figure 7. Question 7 of survey

This question asked the participants to identify any adoption issues or obstacles facing that have inhibited BIM adoption. As with previous questions, the frequency was higher than surveys recorded (59) illustrating that organizations may face multiple issues. The two highest scoring answer choices were, Lack of trained in-house personnel having a frequency of and Lack of standardization and open usability which had a frequency of 16. These two issues/obstacles were noted as major factors inhibiting BIM adoption in a majority of the research articles used for this thesis. In fact, all of the answer choices for this question were confirmed as current issues faced by Owners and their teams after the literature review was conducted. Examining the individual answer choices and their frequencies it is also discovered that only 10% of the participants selected “Lack of experience from design and construction side. They are unable to provide BIM deliverable at this time,” which could be interpreted to mean that the Owners are more hesitant to implement BIM. Possibly due to “high cost/budgetary restrictions,” “lack of standardization and open usability,” and/or “lack of trained in-house personnel.”

Bosche et al., (2015) research consisted of interviewing industry professionals to determine how BIM can be used for data management during the O&M phase from the Owners perspective. One interview participant stated; “We have a system in which the condition of building element’s is described, but we don’t know where the elements can be found in the building.” Information flows from numerous team members while the project is in motion, which often results in data being lost or irrelevant data being handed over, and/or the wrong or incomplete data is shared. Boshe et al., (2015) study further suggested that most issues of data management and exchange is due to the organization and its processes, such as, inefficient data management procedures. During the project the model will be accessed by multiple disciplines and stakeholders as they will need to import their data. It is vital for owners and their teams to have the proper processes and procedures in place, especially for data requirements and formatting. Azhar et al., (2015) research stated that the lack of standards causes organizations to create their own, which can be problematic if the model is not routinely checked for issues.

“Lack of standardization and open usability” is another major issue for industry professionals pertaining to BIM. Over the years there have been developments to assist with this issue (i.e. IFC, XML Schemas) but they have certain limitations that do not totally resolve the issue. Previous research has discovered that interoperability can be enhanced when the same vocabulary is used, data requirements are defined, and no relevant data is lost (Bosche et al., 2015). Grilo & Jardim-Gonclaves (2010) research further recommended that standards pertaining to communication, coordination, cooperation, and collaboration should be developed for BIM to be fully utilized. This recommendation is parallel with owners promoting collaboration between their projects stakeholders and sharing information.

“High cost/budgetary restrictions” has been identified by numerous studies. However, if used correctly, BIM can actually reduce costs. From a cost perspective, financial risks are reduced as BIM can be used to create more reliable cost estimates as well as decrease change orders. Cost savings start when the project begins. The designer can utilize BIM for enhancing and producing a better design, visual simulations and receiving owner input, as well as the ability to incorporate sustainable elements and predict how the structure will impact the environment. Contractors can also benefit by improving construction planning, early discover of design errors through clash detection, more accurate quantity take-offs and estimates, value engineering, and the adoption of lean construction concepts. All of these benefits lead to high profit, happier clients, cost and schedule compression, better quality, and more informed decision-making.

As with other questions, participants could input their own answer if desired. Those input responses are as follows:

- “Divided opinion as to BIMs actual utility and priority among other needs”
- “lack of education on the full value of BIM by owners and design teams to assist in the design process”
- “Use/need not identified”
- “N/A”
- “Schedule does not allow proactive BIM”
- “Staff size and cost restrictions”

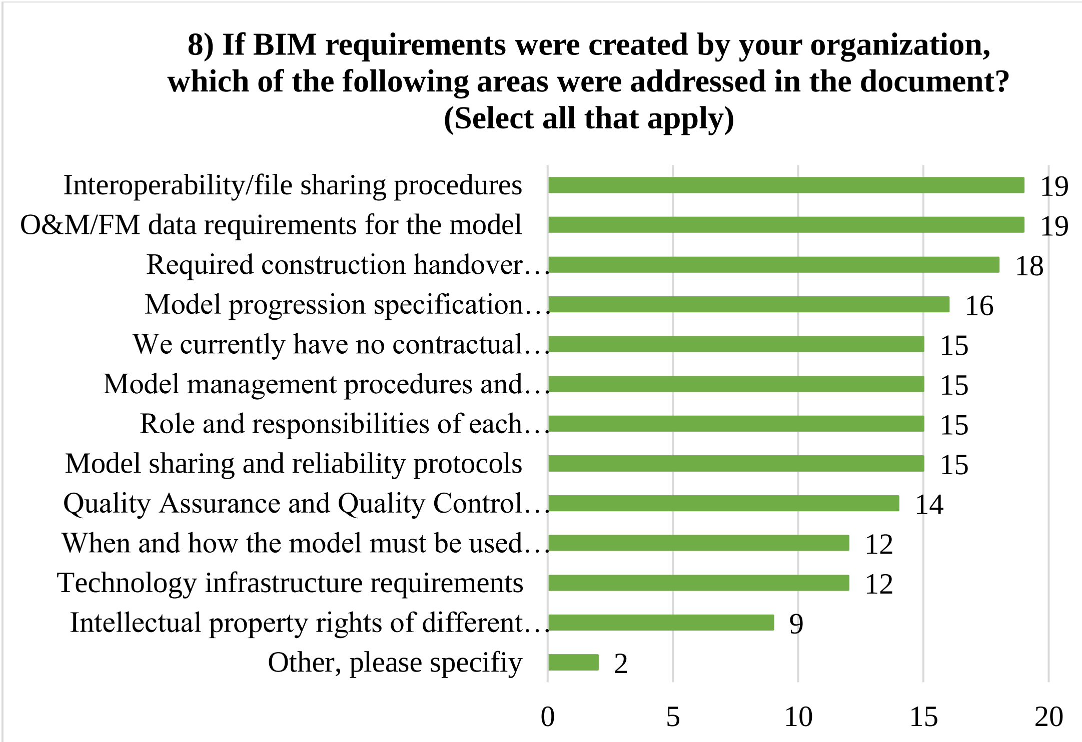

Figure 8. Question 8 of survey

This question asked participants what BIM requirements their organization created. The frequency for this question was the highest at 181. With having only 59 surveys recorded, this confirms what the literature review found in that organizations must make multiple changes to successfully implement BIM. One of these changes pertains to “interoperability/file sharing procedures,” which is one of the two highest scoring categories. Multiple standards have been developed to assist in the “interoperability/file sharing” issue such as, Industry Foundation Classes (IFC) and the Information Delivery Model (IDM) (Bosche et al., 2015). BIM implementation has occurred slower than first predicted. O’Brien (2000) noted the reasons to be, technical (i.e. interoperability and training) and organizational (i.e. professional liability and intellectual property). Both of these reasons were provided as answer choices in this question and all were chosen. For example, “Intellectual property rights of different authored aspects of the model” was chosen 9 times and “Roles and responsibilities or each stakeholder regarding BIM processes" was chosen 15 times. The literature review identified requirements for successfully implementing BIM and the survey illustrates that some Owners have acknowledged them and are shifting towards BIM adoption.

All of the categories were scored in a close range with each other and the same counts occurred for multiple answer choices. For instance, four answer choices received a frequency of 15. One of these answer choices was "We currently have no contractual agreements or requires/guides regarding BIM," this answer may have been chosen less had the answer choice not included "contractual agreements." Participants taking the survey may not be aware of contractual agreements or changes to contractual agreements could be in the works within the organization. One participant verified this by inputting, "the above are currently in development" by selecting the "Other, please specify" option. It is reassuring for the top 7 answer choices being selected. Specifically, the third highest scored choice being "Required construction handover deliverables," which one organization that reached out to the research team wanted to know what the industry was doing as a whole pertaining to BIM and handover deliverables. The literature review found multiple areas in which BIM can be used in the construction stage and it begins by including the FM team early on in the project as well as the Owner defining their requirements (i.e. data requirements and who is responsible for what data and when).

Azhar et al., (2015) research identified risks and barriers as process-related (i.e. legal, contractual) and organizational risks. For example, not identifying who owns the data within the model or needing to protect it legally. Data ownership varies for every project. The main objective is to avoid inhibitions that deter stakeholders from seeing the full potential of the model (Azhar et al., 2015; Thompson 2011). Rosenburg (2007) research stated the best way to avoid disagreements of copyright concerns is to state ownership and responsibilities within the contract documents. “We currently have no contractual agreements or requirements/guides regarding BIM” had a frequency of 15. After conducting the literature review

Another significant find from the literature review was that the model must constantly be managed, checked, and its contents verified. The survey reiterated this importance with the answer choice, “Model management procedures and protocols” as well as “Quality Assurance and Control (QA/QC) procedures to check deliverables” scoring where they did. The second input response of “Other, please specify” also provided insight into how BIM is being used. This participant stated, “At this time, we are backing into BIM by experimenting with GIS. That databased is managed by a GIS contractor to our University. If you think of it as “macro”, we imagine facilities BIM integration will be “micro” databasing that we will back into (eventually). Large new project designers use BIM and share it, but we do not have facilities to tap the models nor the expertise to manage them---yet.” Again, another identified issue from the literature review is confirmed, lack of trained in-house personnel.

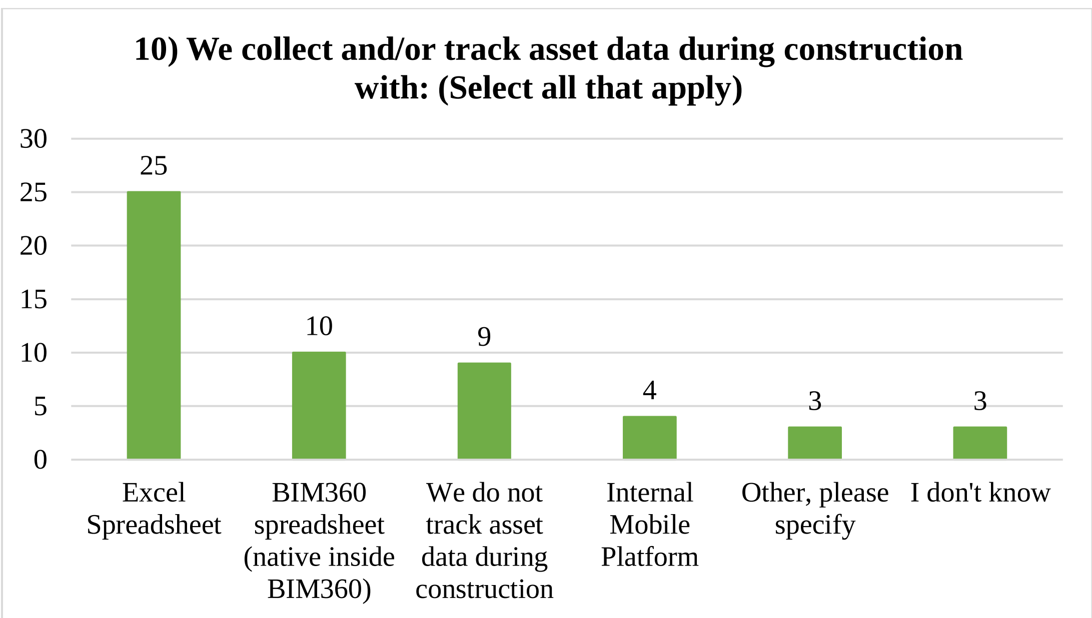

Figure 9. Question 10 of survey

Participants were asked how they collected and/or checked asset data during construction in this question. As with other questions, the number of surveys recorded, and frequency do not match. For this question the frequency is lower than the number of recorded surveys (59). The difference in the two could mean that some participants are unsure if and how asset data is collected or checked during construction. The answer choice with the highest frequency was "Excel Spreadsheet." The next highest frequency was for "BIM360 spreadsheet (native inside BIM360)," with a frequency of 10 whereas "Excel Spreadsheet" had just over double that amount with a frequency of 25. Research completed by Lucas & Addagalla (2017) identified that the transference of data into FM systems, almost all use spreadsheet formats (i.e. .cvs or .xml). However, in "Introducing Building Information Modeling for Campuses" recounted how the Franklin W. Olin College of Engineering wanted to improve their data analysis for its O&M tasks. As stated in the article, their objective was to "use technology to collect, integrate, maintain, and use visual modeling to improve planning, space utilization, energy optimization and delivery of daily operating services." Before Olin successfully implemented BIM to achieve their objective, they maintained data in many locations and formats (i.e. drawings, hard copy manuals, and spreadsheets). Olin used BIM and integrated it with their current CMMS. The end result exceeded their expectations, they reduced their corrective action time by 20% by allowing the FM technicians to have quick access to floor plans and data, reduce risk in emergency events by developing "what if" scenarios, and integrated BIM into their curriculum for their students.

The literature review noted the importance of having accurate and complete data as a key requirement for efficient O&M. The chance of FM teams having that data begins at the start of the project and is at its greatest significance during construction. Construction data provides as-built data, something many Owners and their FM teams lack at handover. Or if they are provided it at handover it is in unstructured, unorganized format requiring them to sift and sort through what is provided to them and make it usable. This is confirmed with 9 participants selecting “we do not track asset data during construction,” which was a close third to “BIM360 spreadsheet (native inside BIM360).” To truly optimize BIM and its many tools Owners need evidence of BIM being used for FM needs during construction. This was also suggested by numerous research articles as a recommendation for future studies. Evidence of previous BIM success stories (as described previously) for FM was a goal of this research to be able to provide the FM department of UNCC with recommendations to advance their implementation of BIM. If requirements are properly and clearly defined early in the project, BIM can act as a data repository during all stages of the project, especially during O&M.

Three participants chose to input their own response rather than select one of the four options available. These responses are as follows:

- “Assetworks (AiM)”
- “We currently provide low level data check as part of our services. The asset data checks are not specifically part of our requested scope.”
- “Whatever is used by the design team, dRofus (Revit Plugin) or others”

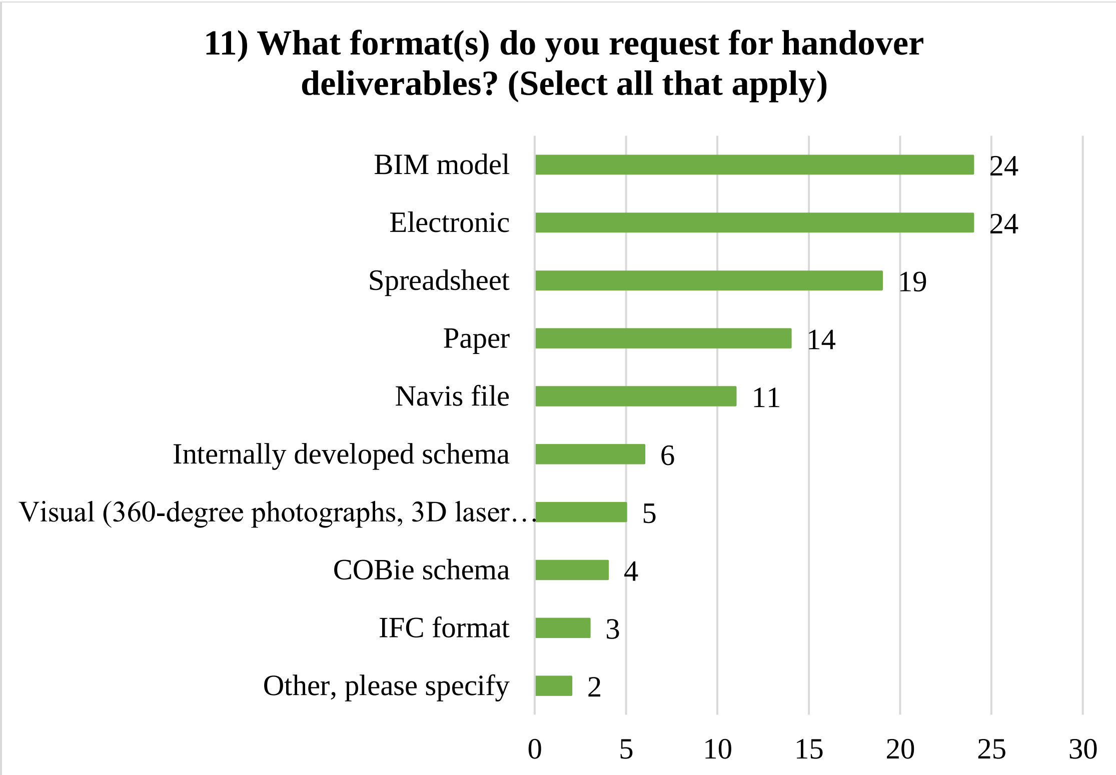

Figure 10. Question 11 of survey

This question asked participants what format(s) are requested for handover deliverables. This question also allowed participants to input their own responses or select multiple options, which led to the frequency being more than double the number of recorded surveys (59). The illustration shows the count of the responses, with “BIM model” and “Electronic” both receiving 24 counts. “Electronic” could mean a number of things, such as paper formatted documents and information handed over on a jump drive. For this answer choice, perhaps a better option would have been to allow the participant to have an “input text option” as having “Electronic” is such a broad choice. Comparing the frequency for “Spreadsheets” of 19 for this question to question 10 which had “Excel Spreadsheet” receiving 25 counts could be interpreted multiple ways. For example, those selecting “Excel Spreadsheet” for question 10 may not use and/or request them for handover deliverables but may create them on their own.

After examining the survey data more closely, all but one participant requesting BIM for handover deliverables, use BIM on some percentage of projects (per question 5). The one participant that selected the option of not requiring BIM on any project at the time they took the survey, selected not only “BIM model” for this question but also selected, “Internally developed schema” and “Spreadsheet.” Of the 24 frequency for “BIM model,” only 4 selected only “BIM model,” the other 20 counts selected two or more answer choices. The participants selecting two or more answers for this question, selected the following choices in addition to “BIM model:”

- Electronic (frequency of 12)
- Navis Files (frequency of 11)
- Spreadsheet (frequency of 8)
- Paper (frequency of 6)
- Visual (360-degree photographs, 3D laser scans, etc) (frequency of 5)
- Internally developed schema (frequency of 4)
- COBie schema (frequency of 3)
- IFC format (frequency of 3)

Results from the literature review identified COBie and IFC as open standards that were developed to assist project teams with interoperability issues, which could signify their small frequencies. However, they have limitations that do not totally resolve the interoperability issues. Involving FM teams early in the project can improve the use of COBie and IFC. As noted by Bosch et al., (2015) BIM’s capability of registering and processing large volumes of correlated data resulted in the development of IFC and COBie. Research by Patacas et al., (2015) presented a Service Oriented Architecture that used IFC and COBie with an Information Delivery Model (IDM). The use case confirmed the ability to use IFC and COBie for supporting Owner’s in achieving their requirements. “Paper” receiving a frequency of 6 signifies that some project stakeholders still prefer paper formatted documents for some information. The traditional method for managing projects are paper formatted documents, some team members may be reluctant to step away from this comfort. However, there is a positive, when the participants selected “Paper” they also chose “BIM model” and other answer choices. Only two participants selected only “Paper” as their requested format for handover deliverables.

There were two participants who elected to input their own response, they are as follows:

- “For everything: mylars and dwgs. Approved shop drawings: paper or digital. Our trade shops have been using Assetworks only for about 3-4 years to any practical effect.”
- “require only RVT or DWG, plus the data in whatever format, but, if they’re got scans and photos, we accept them”

The participant who input the first response also input that their organization uses Assetworks (AiM) to check and collect asset data during construction and that they have “Divided opinion as to BIMs actual utility and priority among other needs.” This organization could possibly benefit from evidence of successful BIM implementation. However, one item found when researching BIM for FM for the literature review discovered that many members of the project team do not often share their BIM experiences whether they be positive or negative. If project team members were more open to sharing their experiences the industry could benefit as it would know what does work and what does not work. A key aspect of BIM success if collaboration and sharing information, so why not apply this to experiences of BIM as well?

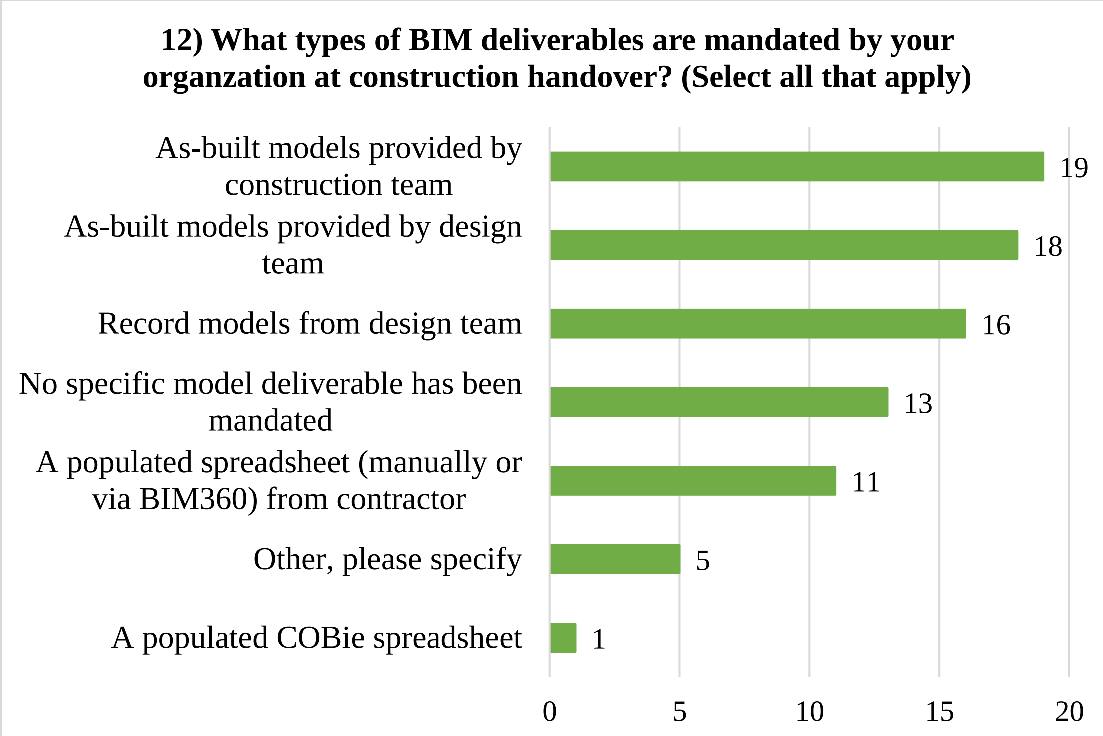

Figure 11. Question 12 of survey

This question asked participants what types of BIM deliverables their organization mandates at construction handover. The two highest counted answer choices were "As-built models provided by construction team" with 19 counts and "As-built models provided by design team" with 18 counts. One research article used in the literature review found that as-built models and as-designed models do not always match. Cavka et al., (2015) research team developed an as-built model using documents the University of British Columbia (UBC) were provided and found that it did not match the as-designed model. For example, the as-built model was missing multiple as-built elements and their quantities. This study is significant in that it highlights the struggle of Owners not receiving what they ask for. Accurate as-built models can allow Owners and their FM teams to better understand the facility and its assets, make better informed decisions, and possible verify the accuracy of handover data. People often better understand things better in visual format and having an accurate as-built model will help the Owners and their FM teams be successful in the O&M of the building.

Additionally, models can be paired with 3D laser scanning allowing the Owners and their teams to verify the as-built and as-designed models. 3D laser scanning can also be used during construction for the Owners to collect data on their own. This process is called Scan-vs-BIM, it uses an as-built point cloud from laser scanning that can be compared to the as-designed model (Rebolj et al., 2017). Rebolj et al., (2017) study produced two sub-sets of elements in the model, existing and missing in the as-built model. When the project team knows what is installed in the facility and what is missing they are able to update quantities, provide confidence to the Owner that their payments are being applied to completed installations, and ensure the elements that were missing are in fact installed at closeout.

Five participants selected, "Other, please specify" and input their responses. They are as follows:

- "BIM NOT USED"
- "I think these answers are correct, but I am not the BIM manager do not 100%"
- "Data upload to BIM360 Ops"
- "Record documents are required, the PM leadership fails at not placing responsibility into the contract, as to who is responsible for update and turnover."
- "depends on the ILM plan for that project"

The participant who provided the third response reiterates an important find from the literature review. Some Owners lack the technical knowledge of installed systems within their facilities which results in the design or project management team creating documents that meet their needs rather than the Owners requirements. This transfer of responsibility often results in the requirements satisfying other project team members agenda rather than the Owners. A study conducted by Bosche et al., (2015) presented a revamped organizational chart to account for the Owner having a central role and a contract-management team (CMT) that the Owner oversees. One task the CMT is responsible for is ensuring adequate and timely delivery of the various services of the project disciplines (i.e. Architect, Contractor, and Project Management responsibilities). To ensure Owners and their FM teams are provided with accurate and complete data by the appropriate responsible party it is vital for the contract to note who is responsible for what data and when, as well as the desired format for the data. Additional research has validated this suggestion. For example, multiple studies noted that if Owners decide to utilize BIM for FM they must clearly define their data requirements, standard processes, and deliverables needed to properly operate and maintain the building (Kiviniemi & Codinhoto, 2014; Teicholz, 2013).

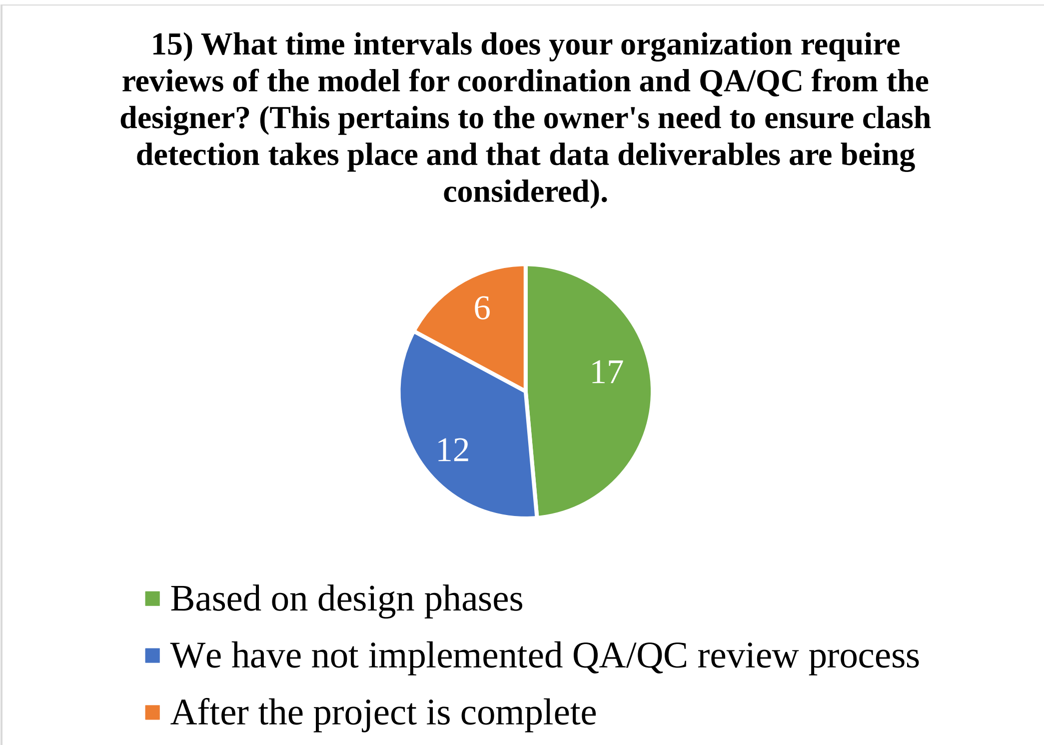

Figure 12. Question 15 of survey

This question asked participants when their organization requires model reviews, specifically pertaining to the Owner ensuring clash detection takes place and that the project team considers data deliverables. Results of this question illustrate that just under half of the respondents review models in line with design phases. The frequency of this question compared to the 59 recorded surveys that not all participants answered this question. Of the 35 total responses obtained for this question, 34% noted they have not implemented QA/QC review processes. Research conducted by Kreider et al., (2010) stated that 3D coordination and design review are seen as the most effective and relevant use of BIM. It is common for FM teams to spend time and monetary resources to input, review and/or update data within the model. If QA/QC processes were in place during the earlier stages of the project these resources could be put toward more important tasks.

Owners stand to gain benefits through all project phases when BIM is incorporated. Azhar et al., (2015) research presented Owners can achieve benefits during the design phase through:

- Schematic Design to compare design options as well as the inclusion of photographs of existing conditions into the model.
- Detailed Design for analyzing the design and conducting walk-throughs to analyze the flow and appearance of the design.
- Construction Detailing to complete clash detections for identifying any design errors, developing fabrication/shop drawings, and completing 4D schedules.

BIM enables the project team to visually examine and interact with the data. Additionally, it can be used to convert 2D drawings into 3D models. Pertaining to the Pre-Construction and Construction stages, BIM can be implemented for the following:

- Pre-Construction: estimating, site coordination, and constructability analysis.
- Construction: monitor progress, coordination of meetings between trades, inclusion of RFIs (Request for Information), change orders, and punch list items into the model.

BIM benefits for the O&M phase included the following: asset inventories, space management, building systems analysis, environmental analysis, compliance management, and accurate as-built data. IMAGINiT Technologies survey from 2017 showed that the percentage of Owners integrating BIM into their FM system's rose from 6.1% (2016) to 15% (2017). However, data loss was noted as an issues as the models from the design and construction stages can be missing data needed to complete O&M tasks. For example, if the model

A technology that is rising in popularity, is 360-degree photographs. 360-degree cameras are relatively inexpensive, require no formal training for use, and are easily transported from location to location. This technology uses cloud-based storage and viewing, allowing for the project team accessibility from any location. StructionSite, a 360-degree software has the capability to automate site documentation and link locations of the photographs with the plans. NavisWorks has a plug-in for comparing as-built models with as-built photographs, and increases transparency by enabling the FM team to see within walls for O&M tasks (Hedmond, 2017 p.360; *StructionSite-Construction Documentation & Project Tracking, n.d.*; Azhar et al., 2015; Rebolj et al., 2017).

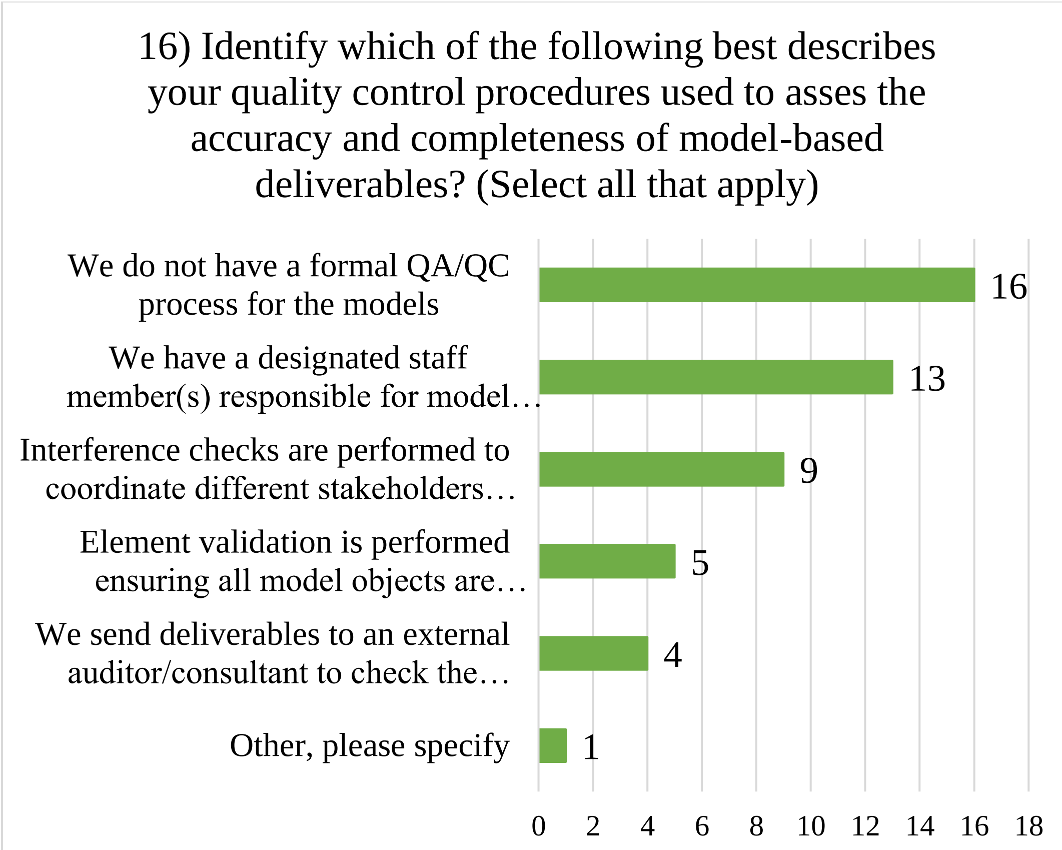

Figure 13. Question 16 of survey

This question asked participants to identify the organizations best quality control procedures for assessing the accuracy and completeness of model-based deliverables. As with other questions, the frequency is less than the 59 surveys recorded. The answer choice with the highest frequency was found to be "We do not have a formal QA/QC process for the models." However, "We have designated staff member(s) responsible for model management and QA/QC," which is promising. Based on the available answer choices and the frequencies of each, 64.5% of the answers chosen describe quality control procedures being completed. Models must be continuously updated, especially models from the design and construction stages, which hold only a piece of the data needed for O&M tasks. Research by Cavka et al., (2015) created a framework to characterize the alignment between organizational practices, available technology, project documents, and owner requirements. The framework aided in gaining a further understanding of how the many organizational pieces come together to achieve organizational goals from the perspective of BIM-based data exchange and FM procedures. Cavka et al., (2015) suggested that changes observed within the organization were influenced by other organizational changes in FM methods and IT advancements.

For BIM to be implemented for FM these changes begin with involving the FM team at the start of the project as well as clearly defining O&M data requirements. The industry has started using strategies and tools for assisting in handover data to ensure Owners receive the data they need. These tools and strategies include utilizing open standards (i.e. IFC and Information Delivery Models (IDM)), AiMS (Asset Information Models), Owners Project Requirements (OPR), and BIM. Additionally, these tools and strategies can act as a guide for Owners in quality control procedures. For example, based on their OPR they can check the models and verify they contain the data defined in the OPR. If requested by the Owner or used by the design and construction teams, 360-degree photographs will need to be verified for quality as well. This includes verifying the images contain assets that will later be tracked and maintained as well as the images being clear and of a quality that is useable. Bosche et al., (2015) research discovered that BIM enables more efficient integration of building documentation and can support asset management through the monitoring and benchmarking of data, an aspect of quality control.

As with other questions this one allowed participant to select "Other, please specify" and input a response. For this question an input response was: "The 3rd party commissioning authority is involved in the QA/QC. Also, we require the construction team BIM coordinator to use the Model Checker as part of the QA/QC process." This is significant as adequate commissioning procedures will assist the Owner and FM team in efficiently managing and operating the facility. Additionally, the FM team will need commissioning information, testing and inspection reports, O&M manuals (i.e. non-geometric data) and construction drawings (i.e. geometric data). McFarlane (2013) research suggests utilizing an OPR at the start of the project, which begins with the Owner defining what they perceive as a complete facility (i.e. space utilization to regulatory compliance). McFarlane (2013) study outlines the steps for developing an OPR. Research conducted by Lucas & Addagalla (2017) identified incomplete commissioning reports as one of the many barriers industry professionals face.

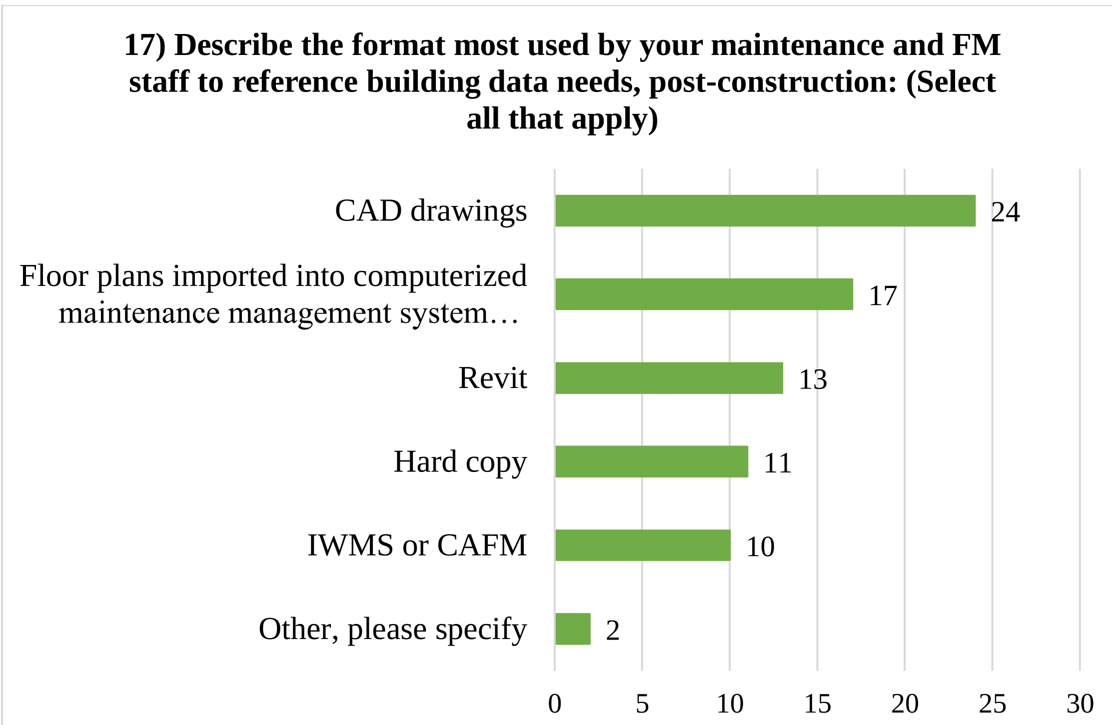

Figure 14. Question 17 of survey

This question asked participants the format most used by maintenance and FM staff for referencing building data needs, post-construction. The frequency for this question illustrates that many organizations utilize more than one format. “CAD drawings” had the highest frequency at 24, “Floor plans imported into CMMS” was second with 17, “Revit” was third with 13, “Hard copy” was next with 11, “IWMS or CAFM” was fifth with 10, and 2 participants selected “Other, please specify.” CAD is a traditional visualization technology, which differs from BIM in that the views (i.e. Plan, Section, Elevation) are not linked. Another differentiation from BIM is that CAD contains only graphical data (i.e. lines, arcs), whereas BIM has “smart” data enabling it to be defined in relation to elements and systems within the building. Previous research has stated that BIM will soon completely replace CAD systems. Azhar et al., (2012) research categorized technological barriers into three groups; 1) need for well-defined standards to resolve interoperability issues, 2) requirements that digital design be computable, and 3) the necessity for a well-developed, practical approach to ensure successful data sharing and integration of model elements. As CAD does not contain “smart” data like BIM it is not capable of resolving these technology issues arising from technology advancements. However, 3D CAD reference files can be combined as reference files for defining the building. The model that would be developed using combined 3D CAD reference files would not be as useful as BIM since it is not a process like BIM is. Additionally, CAD systems have not been successfully paired with Augmented and/or Virtual Reality systems.

Lucas & Addagalla (2017) research discussed the current status of integrating BIM and CMMS for FM purposes on university campuses in the U.S. The research team noted that their research can provide other institutions a baseline for considering BIM for FM. Previous studies have identified three ways that Owners typically use to organize O&M data. They are as follows:

- Direct reference of original project documentation
- Paper-based or electronic spreadsheets requiring manual reference and updating
- Technology-based solutions (i.e. CAFM, CMMS, or IWMS). It should be noted that many of these technology-based solutions are heavily dependent on manual input (Di Iorio, 2013; Teicholz, 2013).

The Franklin W. Olin College of Engineering successfully adopted BIM, using smart cloud technology and integrating data with its current CMMS. The combination enabled the FM team to gather, model, verify, access, and report performance data in real time. As a result, Olin has improved their decision-making process, operational efficiency, cost management, and risk exposure. Additionally, Olin has enhanced building operations, cleaning services, energy consumption, strategic planning, and budget management (Judge, 2014). Judge (2014) provided five reasons why BIM will expand on more U.S. campuses. The reasons are as follows:

- Streamlined Maintenance – immediate data access on one platform (i.e. drawings).
- Improved Space Management – FM teams have access to data such as how a space is being used to allow better space management. CMMS can have floor plans and space identification codes integrated into them which can assist FM teams in quicker response times along with better managed and coordinated campus spaces.
- Efficient Energy Use – models contain basic and in-depth data allowing for statistical analysis to be conducted.
- Economical Retrofits and Renovations – models can be used as a strategic planning tool for renovations and retrofits.
- Enhanced Lifecycle Management – BIM can improve the planning process and track depreciation of elements to assist Owners in receiving their optimum financial and tax benefits.

One email recipient on a survey distribution list replied to the email instead of taking the survey. The respondent simply stated, “We are a CAFM, IWMS software provider, we integrate CAD and BIM with Archibus for our customers, thanks for asking.” This response illustrates that organizations could use multiple options, such as CAD, CAFM and/or IWMS, BIM, and CMMS, three of the possible answer choices provided. The literature review confirmed that vendors are integrating BIM with software systems. Yang & Ergan (2016) study developed and successfully implemented a user-controlled method to design and adopt a visual interface for issues resolution. This interface was tested via a case study and proved that visualization can be successfully adopted for FM tasks, as well as being a valuable consideration for CAFM vendors when designing HVAC task user-interfaces.

Two survey participants selected “Other, please specify” for this question. The input answers are as follows:

- “We are FM Consultants, this question does not apply to our workflow.”
- “PDF scans”

It could have been helpful if the participant inputting the first response had noted if providing any of the above choices were requested by the clients served. However, that did not happen. It could be assumed that as FM consultants they recommend Owners require CAD drawings, or floor plans in a format that can be integrated into a CMMS, Hard copy of documentation, and/or Revit files.

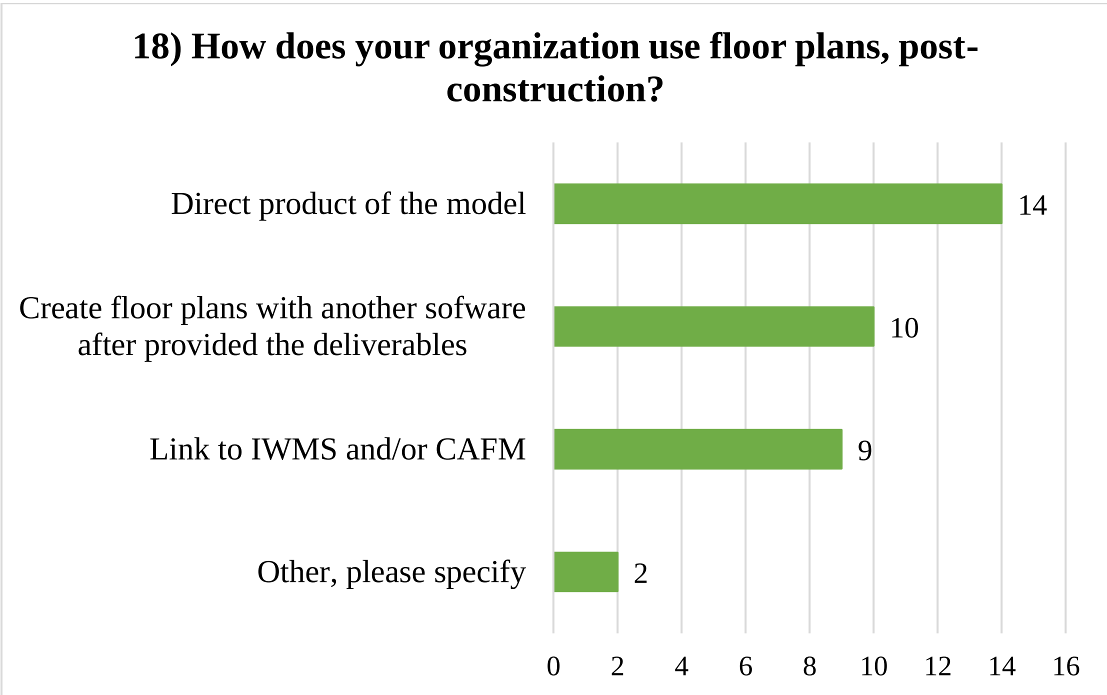

Figure 15. Question 18 of survey

This question asked participants how the organization uses floor plans, post-construction. The highest frequency was direct product of the model (14), followed by create floor plans with another software after the provided deliverables (10). Next was, link to IWMS and/or CAFM. Lastly, two participants selected other, please specify. The participants selecting that choice input the following:

- “Near future – Revit linked to Archibus”
- “IWMS, CMMS, and PDFs”

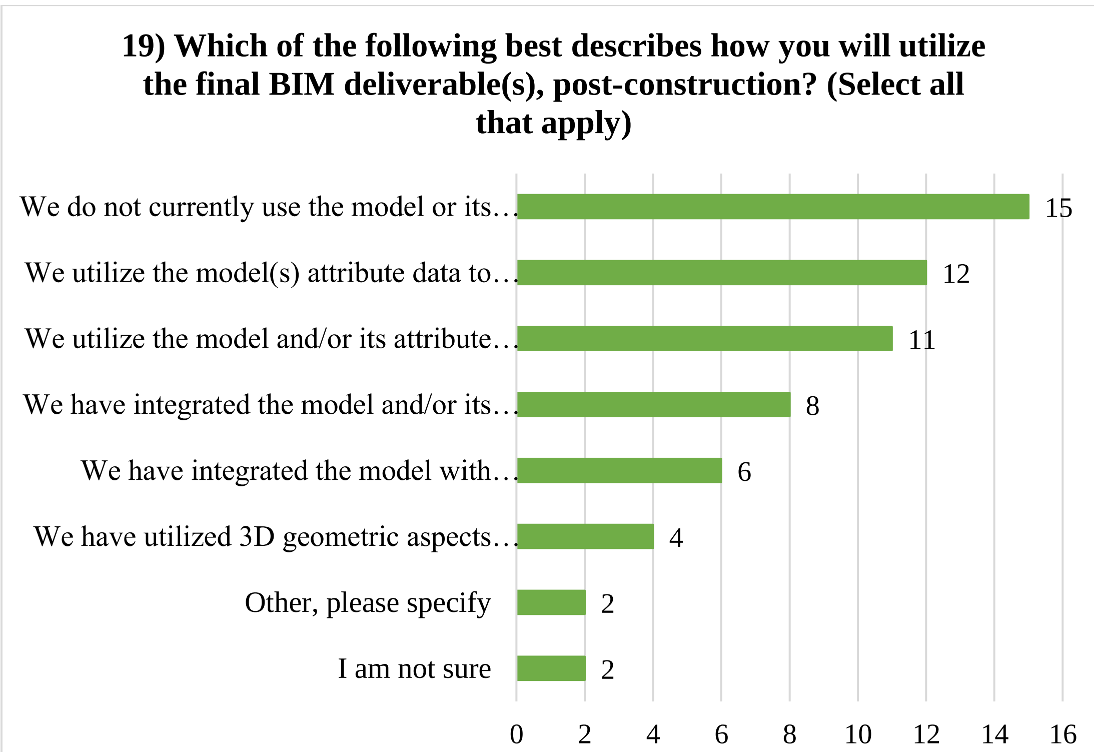

Figure 16. Question 19 of survey

This question asked participants how the organization would use the final BIM deliverable. The frequency for this question was 60, one higher than the number of surveys recorded. The answer choice with the highest frequency was “We do not currently use the model or its attribute data post construction,” which means 25% of the participants do not use the model for O&M. The reason it is not used for O&M could be one of the many BIM implementation issues identified in the literature review, such as, lack of trained in-house personnel, lack of standards, interoperability issues, etc. Previous research has shown that BIM can be used as an information container, assist in decision making, be integrated with CMMS, CAFM and/or IWMS. Some Owners have successfully implemented BIM for O&M, such as Olin, who gained numerous benefits from its adoption.

The second highest frequency answer choice was, “We utilize the model(s) attribute data to track space management” with “We utilize the model and/or its attribute data to track asset management” being a close third. The literature review discovered that space management and asset management are two ways to utilize BIM. As previously stated, Owners can utilize an OPR to ensure they are provided with the needed data for optimum O&M of the facility. The OPR can include but may not be limited to description of the project, space utilization table (i.e. number of spaces and type of space), special equipment standards, and utility baselines which the Owner can use to evaluate building performance. Azhar et al., (2015) developed a “Construction Dashboard” as well as a traditional BIM model. A case study was used to test the efficiency of the both. Participants were asked to complete three levels of tasks, an equipment task, functional task, and space task in both interfaces, as well as answer three levels of questions (coordination, management, and project-wise). Results of the case study discovered that completion times of tasks were significantly higher compared to traditional O&M functions for completing tasks. Participants noted the efficiency of the “Construction Dashboard” for displaying interactive data as well as the software being easy to work in.

The next categories based on frequency were “We have integrated the model and/or its attribute data into an IWMS/CMMS” and “We have integrated the model with existing civil infrastructure." As discussed previously, BIM can be integrated with an IWMS, CMMS, and/or CAFM. Civil infrastructure systems involve the design, analysis, and management of infrastructure supporting human activities (i.e. electric power, oil and gas, and buildings making up urban and rural communities). The focus of civil infrastructure is on how different structures behave as a system, and includes all phases of a project from design to O&M. BIM can be used to evaluate building performance allowing the Owner to develop baselines, which traditional handover is not capable of doing. A case study conducted by Yang & Ergan (2016) consisted of testing a "Construction Dashboard" for testing efficiency of worker productivity in resolving HVAC work orders. One benefit identified with this study was being able to determine patterns in performance and conduct cross-system analysis using historical and current information.

"We have linked 3D geometric aspects of the model with hyper-linked close-out documentation." Two participants selected "I am not sure" and two participants selected "Other, please specify." The participants selecting the latter input the following:

- "Future existing conditions"
- "models currently not in use, but plan to integrate GIS, CAFM, and maintain for distribution of existing condition records"

Over the last decade, the integration of GIS (Geographic Information System) with BIM has been examined. Several "GIS-BIM" benefits have been identified. They pertain to site analysis, such as assistance in determining if the sire meets project requirements (i.e. financial factors), reducing costs of utility demands and demolition, and minimizing possible hazard encounters on site (Azhar et al., 2015; CICRP, 2009). The benefits identified in previous research are more related to early project stages, but can be used for O&M. For example, reducing costs of utility demands could be associated with O&M. As was discussed in the methodology chapter, one participant working with a university in North Carolina provided excellent detail of his organization and offered feedback on the survey. One particular comment stated, “Your survey assumes my firm (university in this case) is at least conversant with BIM/GIS to the point where we have some rules and regulations for using it. We aren’t there yet, but we are interested in it because we know it represents the future. We just haven’t put a foot down in the future yet. Leadership is divided about when and how, not whether or not.” This feedback was significant. It illustrates that firms know BIM/GIS is the future but may not or have not reached that point yet. The participant also stated, ‘Pertaining to GIS and BIM, they receive models at handover but have no way to update them or distribute them as they have no dedicated staff or proficiency for this task. Furthermore, it was stated that the design and construction teams extract the construction documents and conduct analysis throughout the project and the organization archives the “derivative materials.”’ This question should have contained a “none of the above” answer choice, which may have resulted in a higher frequency for this question.

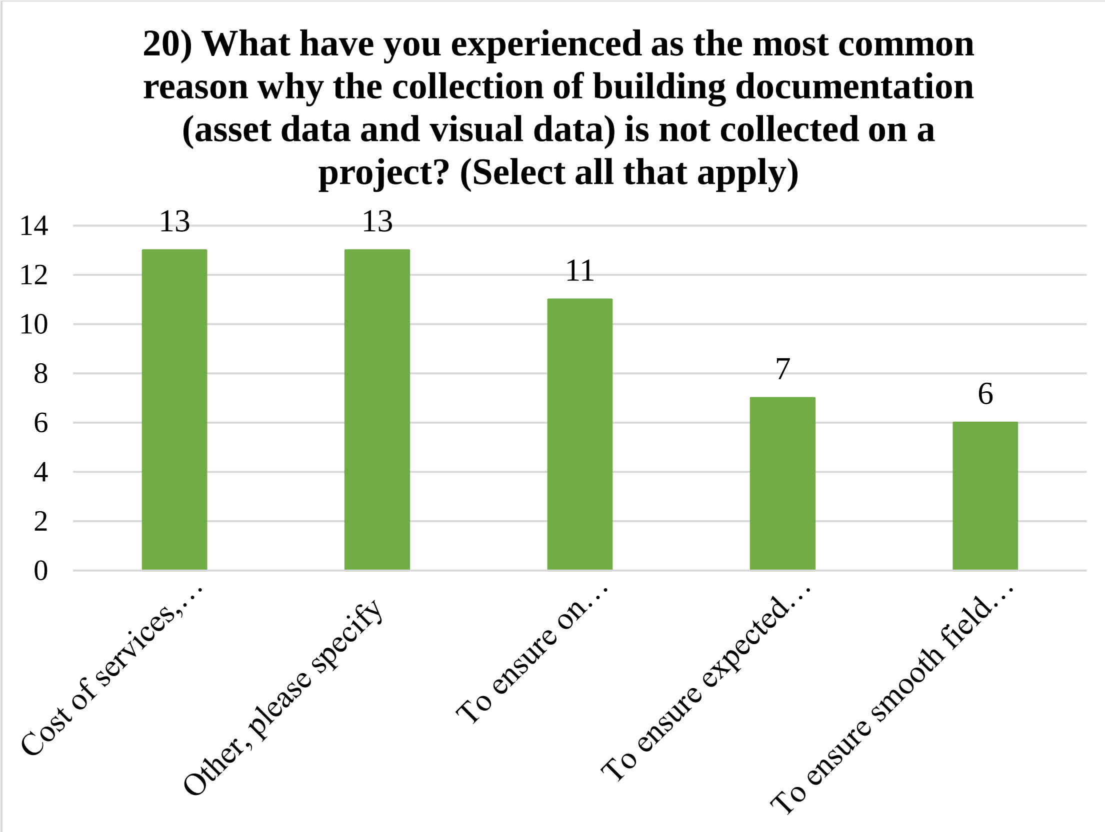

Figure 17. Question 20 of survey

The frequency for this question was 9 less than the 50 recorded surveys. The question asked participants what has been experienced pertaining to building documentation (asset data and visual data) not being collected. The highest frequency answer choices were, “Cost of services, equipment, and/or resources seem too high” and “Other, please specify.” The FM stage is the longest of the project stages and accounts for two-thirds of the building lifecycle costs (Chotipanich, 2004). With FM being the longest and most expensive of the project stages, why not spend extra resources in earlier project stages to assist in optimum O&M functions? Asset management focuses on the implementation of a building plan for the Owner to realize the lifecycle value from the building assets (The Institute of Asset Management, 2011). The British Standards Institute (2008) and Schraven et al., (2011) research noted that asset management attempts to find the optimal balance between risks, costs, and performance to achieve high standards of reliability, availability, maintainability, and safety throughout the lifecycle of the building. Again, why not spend the expend additional resources in the beginning of the project to ensure accurate and complete data is received at handover?

“Other, please specify” consisted of the following participant feedback:

- “I believe the question has an additional “not”
- “odd wording of question”
- “There is no review of the deliverable”
- Requirements not clearly stated in contracts”
- “We don’t personnel resources in-house to manage the BIM models (keep them updated)
- “campus Project Managers do not follow through on enforcement of handover”
- “Because our procurement are not aware of BIM requirements”
- “No staff who’s skilled in the task or has that responsibility (viewed as “overhead”)
- “Adaptability by FM Techs an limited mobile devices”
- “Clueless project management and construction teams taking advantage of it and playing dumb at the end when finance wants to close out the project”
- “Do not know”
- “project manager knowledge”

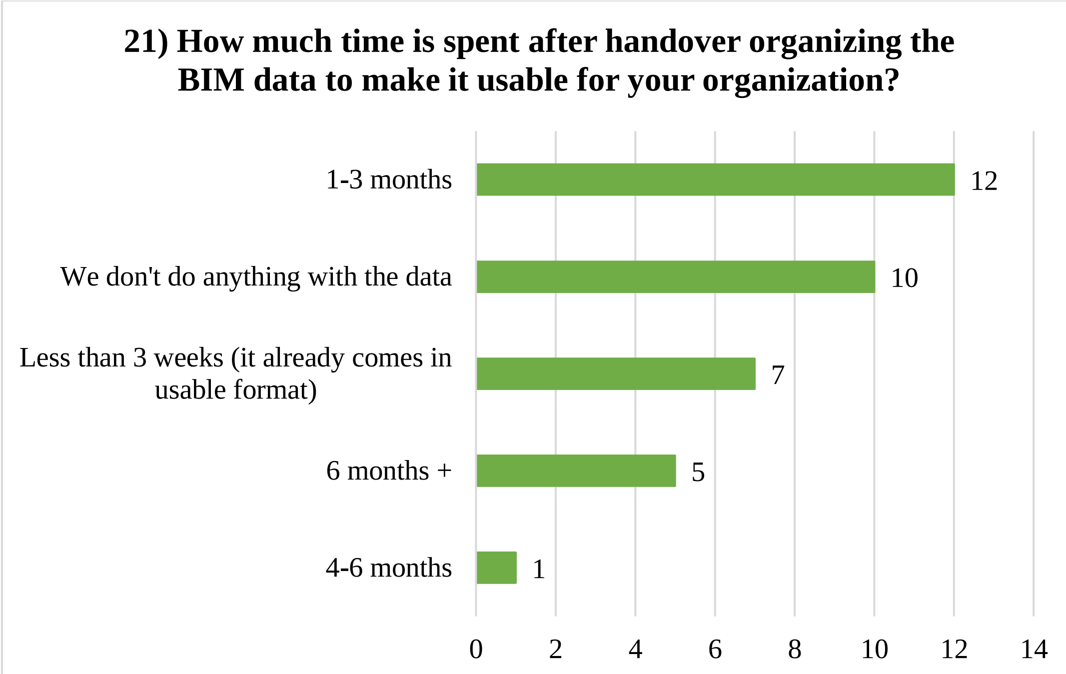

Figure 18. Question 21 of survey

The frequency for this question, asking how much time is spend after handover organizing BIM data so it is useable, was low at 35 meaning only 59% of survey participants answered this question. The low frequency could be due to not all participants taking the survey utilize BIM currently or other unknown reasons. The highest frequency answer choice was “1-3 months” with 12, followed by “We don’t do anything with the data” at 10, “Less than 3 weeks (it already comes in useable format)” at 7, “6 months +” at 5, and “4-6 months” at 1. It is promising that of the participants answering this question only 6 organizations have to spend 4 plus months making the data useable. “We don’t do anything with the data” could be a result of the organization not having a lot of knowledge on data formats. Bosche et al., (2015) research stated that BIM output is typically limited to 2D data as users cannot see, handle or deal with any other data format due to a lack of knowledge of data formats. Bosche et al., (2015) further states that the strength and potential of BIM offers are found in 4D (model + schedule), 5D (model + cost) and nD applications.

The time (i.e. 1 to 6 + months) spent on making data useable could possibly be decreased to less than 3 weeks if the organization requires an Information Delivery Model (IDM), an Owner Project Requirement (OPR), and/or open standards. An IDM is a model detailing lifecycle processes of assets, including data requirements for all processes to be completed. An OPR guides the Owner on project execution as well as forming a basis for measuring all activities and products during decision making throughout the facility's lifecycle addressing form, time, budget, and function. Open standards are data standards that are compatible and useable across a wide range of hardware and software platforms.

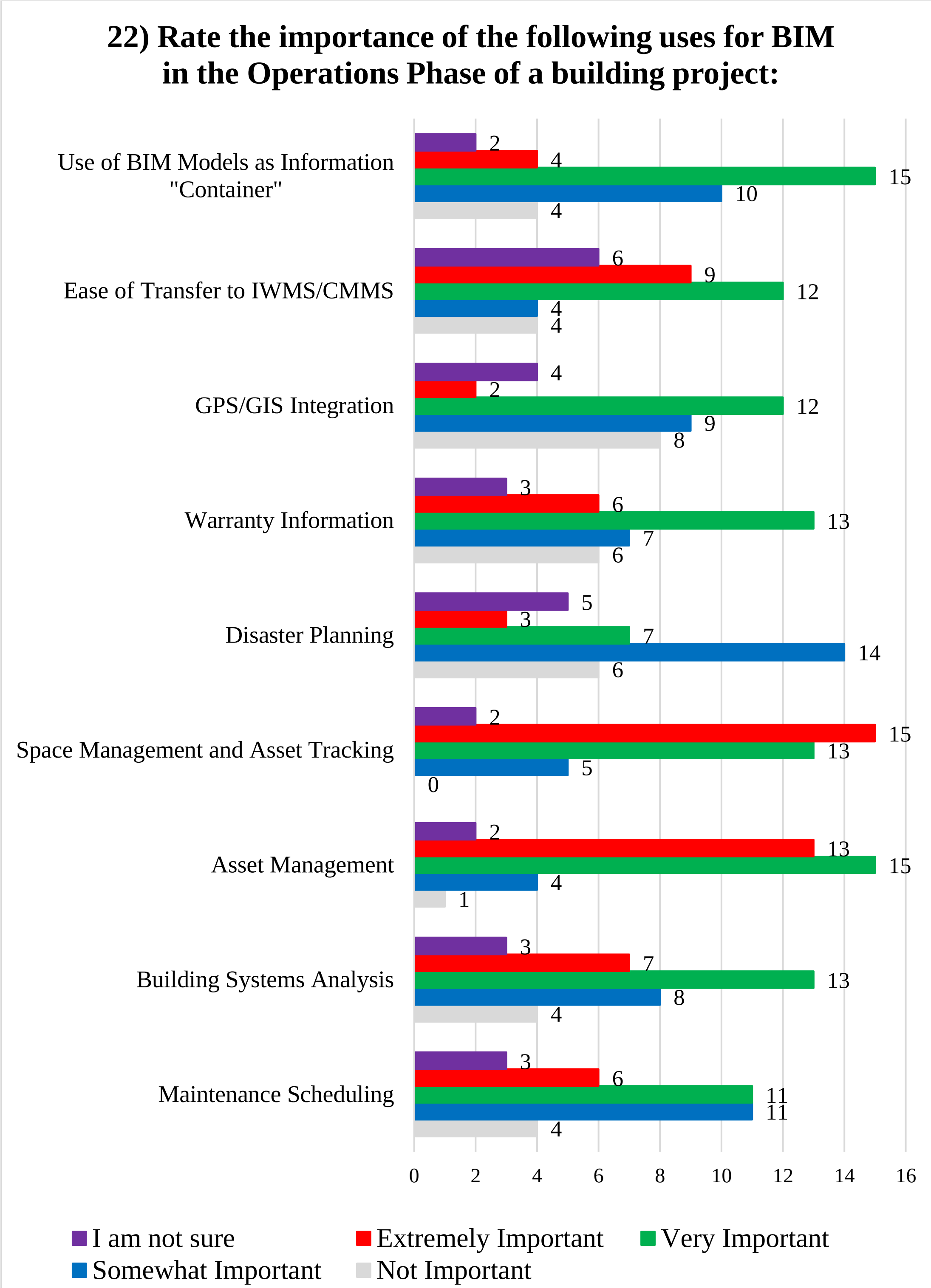

Figure 19. Question 22 of survey

This question asked participants to rate the importance of BIM during the O&M stage for the following uses:

- Use of BIM Models as Information "Container"
- Ease of transfer to IWMS/CMMS
- GPS/GIS Integration
- Warranty Information
- Disaster Planning
- Space Management and Asset Tracking
- Asset Management
- Building Systems Analysis
- Maintenance Scheduling

The graphic illustrates that each BIM use (list above) received a frequency of 35. Each BIM use was rated on importance; extremely important, very important, somewhat important, not important, and I am not sure.

The rating of extremely important is as follows:

- Space Management and Asset Tracking (15)
- Asset Management (13)
- Ease of Transfer to IWMS/CMMS (9)
- Building System Analysis (7)
- Maintenance Scheduling (6)
- Warranty Information (6)
- Use of BIM Model as Information Container (4)
- Disaster Planning (3)
- GPS/GIS Integration (2)

The rating of very important is as follows:

- Asset Management (15)
- Use of BIM Model as Information Container (15)
- Building System Analysis (13)
- Warranty Information (13)
- Space Management and Asset Tracking (13)
- GPS/GIS Integration (12)
- Ease of Transfer to IWMS/CMMS (12)
- Maintenance Scheduling (11)
- Disaster Planning (7)

The rating of somewhat important is as follows:

- Disaster Planning (14)
- Maintenance Scheduling (11)
- Use of BIM Model as Information Container (10)
- GPS/GIS Integration (9)
- Building System Analysis (8)
- Warranty Information (7)
- Space Management and Asset Tracking (5)
- Asset Management (4)
- Ease of Transfer to IWMS/CMMS (4)

The rating of not important is as follows:

- GPS/GIS Integration (8)
- Warranty Information (6)
- Disaster Planning (6)

- Use of BIM Model as Information Container (4)
- Ease of Transfer to IWMS/CMMS (4)
- Building System Analysis (4)
- Maintenance Scheduling (4)
- Asset Management (1)
- Space Management and Asset Tracking (0)

The rating of I am not sure is as follows:

- Ease of Transfer to IWMS/CMMS (6)
- Disaster Planning (5)
- GPS/GIS Integration (4)
- Building System Analysis (3)
- Warranty Information (3)
- Maintenance Scheduling (3)
- Use of BIM Model as Information Container (2)
- Space Management and Asset Tracking (2)
- Asset Management (2)

The BIM uses for this question were results of the literature review. Azhar et al., (2015) identified, Building Systems Analysis, Maintenance Scheduling, Asset Management, Space Management, and Disaster Planning and Management as uses for the FM team. "Ease of Integration to IWMS/CMMS" has been problematic for Owners and FM teams in the past. However, in "Improving Facility Management Through BIM Data" provided tips for overcoming these issues into FM systems. The three tips were, "Completing a review of FM BIM requirements," "Develop a BIM guideline," and "Data should be added over time." Bosche et al.,

(2015) research discussed how BIM enables more efficient integration of building documentation (i.e. warranty information) as well as supporting asset management through monitoring and benchmarking data. As previously stated, GPS/GIS can be integrated with BIM. Azhar et al., (2015) research stated that this integration can be beneficial for site analysis, determining hazards that may be encountered, decreasing utility costs, and reducing demolition costs. It was determined through conducting the literature review that many Owners and FM teams are not provided a model for the as-built environment for use of an O&M tool (Randall, 2011). Once an accurate and complete as-built model is provided, or created using 3D laser scanning, the model can be integrated with Building Automation Systems for Building System Analysis, be used to create O&M plans, promote safety and security plans, as well as act as an as-built data library. For example, the FM team can utilize the as-built model for completing maintenance tasks in a timely manner as the model will contain all necessary data needed by the technician. Specifically, the model can be used to locate assets, provide real-time data access, check maintainability, management of assets and spaces, among multiple others (Becerik-Gerber et al., 2012).

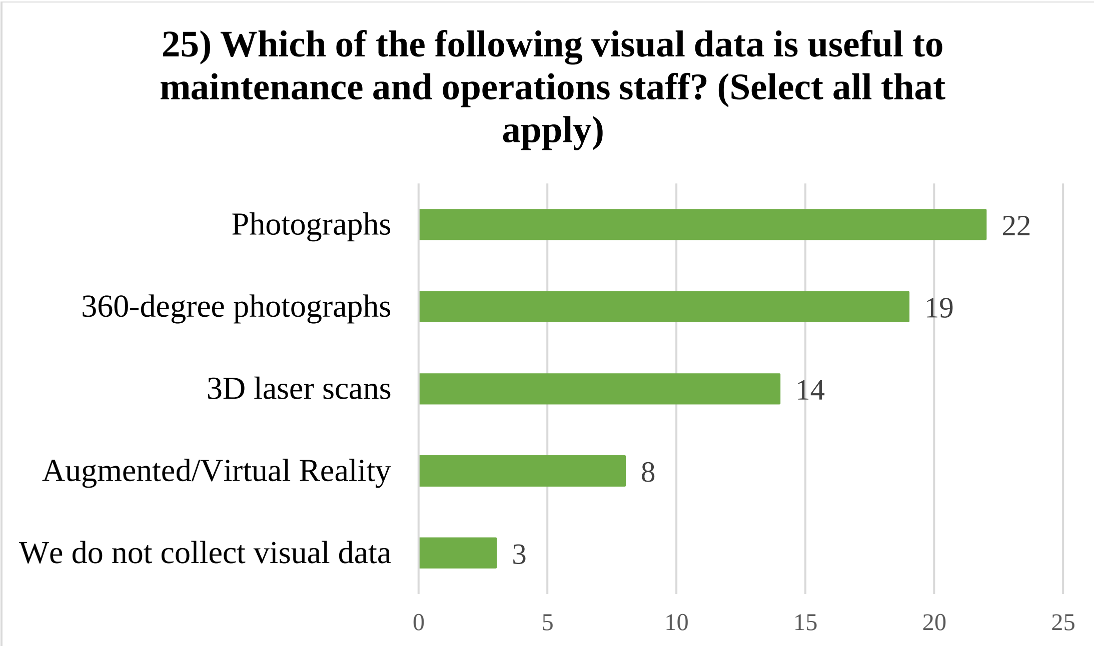

Figure 20. Question 25 or survey

This question asked participants which type of visual data is useful to O&M staff. The frequency for this question was slightly higher than the number of recorded surveys (59) at 66. Photographs had the highest frequency at 22. Followed by “360-degree photographs” (19), “3D laser scans” (14), “Augmented/Virtual Reality” (8), and “We do not collect visual data” at 3. Photographs can be incorporated during the Schematic Design stage to document existing conditions (Azhar et al., 2015). Research by El-Omari & Moselhi, 2008 utilized a case study on an active job site. The methodology used in this study aimed at automating data collection processes through integrating multiple data collection tools. Results found that when FM teams use both methods together data can be collected in multiple ways. Laser scans can be used to verify as-built models with as-design models. Photographs can be used as a quick data access tool if a technician should need to go into the field to complete a work order. When both photographs and 3D laser scanning technology are used together scan time can be deceased by up to 75% as cameras are able to reach areas the laser scanner cannot.

BIM can also be paired with photographs, 360-degree photographs, 3D laser scans, and Augmented/Virtual Reality technologies. Over the last decade 3D laser scanning has gained popularity in the Architecture, Engineering, and Construction (AEC) industry. Recently 360-degree photographs are joining in the popularity with 3D laser scanning as one 360-degree photograph can take the place of 10 still images (Hedmond, 2017, p.360). Additionally, 360-degree cameras are easy to transport, require no formal training, and have the capability to create virtual “job walks” allowing for the project team, especially the Owner, to easily orient themselves on the site to understand how the project is moving forward. Once the project reaches the FM stage, all of the technologies and formats discussed in this question can be used to show FM technicians what is inside the wall to allow them to better resolve issues with assets. It should be noted when the Owner decides to require any of these formats that a team member is responsible for reviewing the images and/or scans for proper location and quality (Hedmond, 2017, p.360).

Structionsite, a software company which utilizes 360-degree photographs can automate site documentation that will translate daily project updates into “actionable insights” (StructionSite – Construction Documentation & Project Tracking, n.d.). BIM can also be paired with 360-degree images. For example, 360-degree renderings can be produced from the model (i.e. AutoDesk Revit and Navisworks) which can be developed into a handover package. Before the project is complete, the 360-degree renderings can assist the design team with changes, site conditions, and other project models early in the project when the cost of modifications is lower. The Owner will appreciate this as it ensures they only pay for what they have at the time of payment (i.e. progress matches the Work in Progress reports). Skanska in New York is utilizing 360-degree photography on job sites. Skanska regional director, virtual design, and construction, Albert Zulps stated, “these photographs are game-changing. You can capture that space and then later you can actually look at versions of those photographs, go back in time, peel back the sheetrock and go into the wall.” Zulps further noted that 360-degree technology can be paired with models generated from 3D laser scans, VR headsets, and technology for mixed reality environments (Zeiba, 2019).

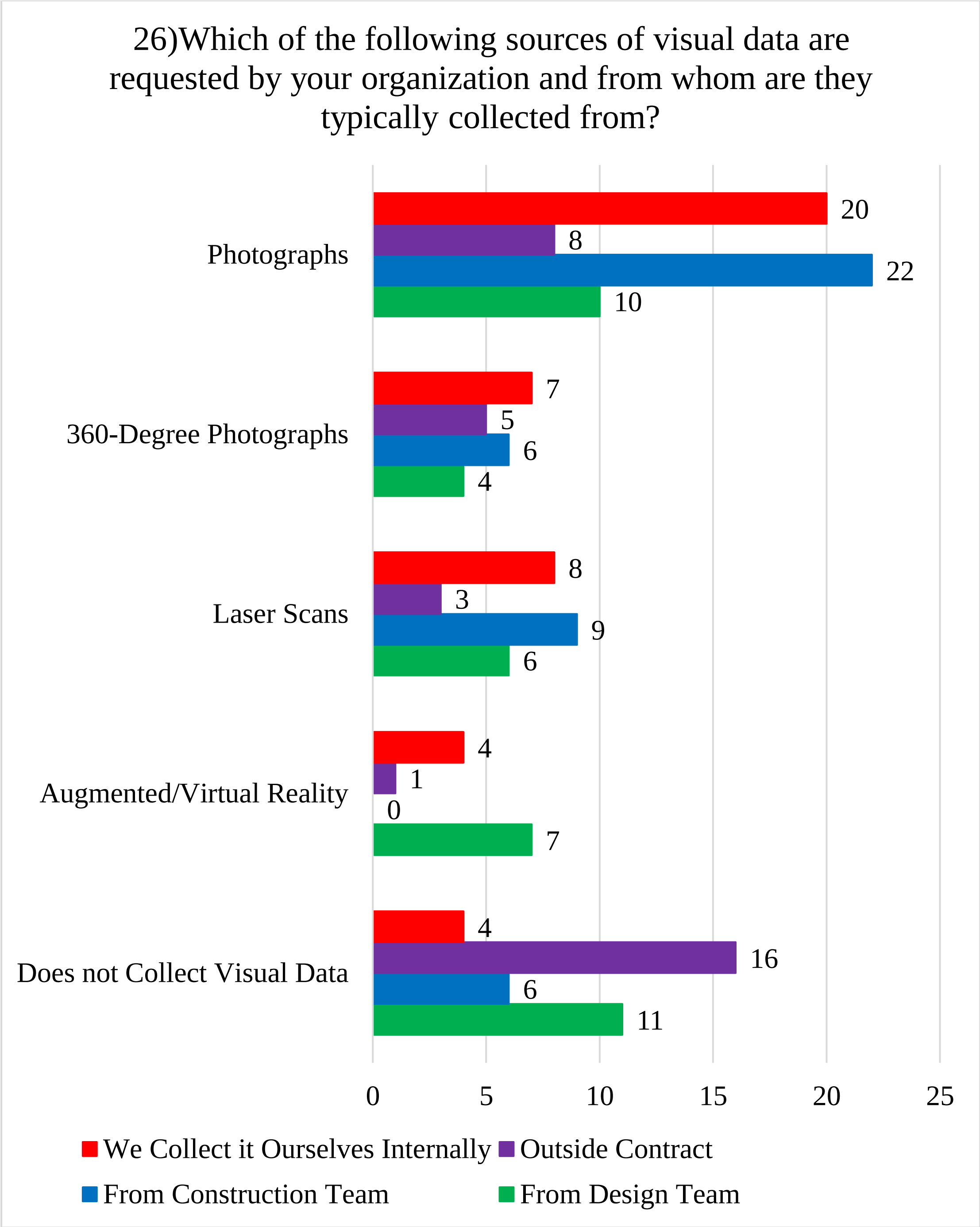

Figure 21. Question 26 of survey

This question asked participants which project team members the organization requested visual data from. The project team members were, the design team, the construction team, outside contract, and collected internally themselves. The visual data format choices were, photographs, 360-degree photographs, 3D laser scans, augmented/virtual reality (A/VR), and "does not collect visual data." The category with the highest frequency was photographs (60), "does not collect visual data" (37), 3d laser scan (26), 360-degree photographs (22), and A/VR (12). The number of surveys recorded was 59. It was interesting that the frequency for photographs was 60. It is unknown if the difference in frequency for photographs and total surveys. The graphic and numbers for analysis were exported directly form Qualtrics. It can be assumed this difference was a glitch in the software. Visual data requested from the design team had a frequency of 38. Visual data requested form the construction team had a frequency of 43. Visual data requested from an outside contract had a frequency of 33. Visual data collected internally by the organization had a frequency of 43.

The frequency of photographs can be broken down into the following:

- From Construction Team (22)
- Collected Internally (20)
- From Design Team (10)
- Outside Contract (8)

The frequency of 360-degree photographs can be broken down into the following:

- Collected Internally (7)
- From Construction Team (6)
- Outside Contract (5)
- From Design Team (4)

The frequency of 3D laser scans can be broken down into the following:

- From Construction Team (9)
- Collected Internally (8)
- From Design Team (6)

- Outside Contract (3)

The frequency of A/VR can be broken down into the following:

- From Design Team (7)
- Collected Internally (4)
- Outside Contract (1)
- From Construction Team (0)

The frequency of “Does not collect visual data” can be broken down into the following:

- Outside Contract (16)
- From Design Team (11)
- From Construction Team (6)
- Collected Internally (4)

As stated in the analysis of the previous question, the visual data formats discussed in this question have many benefits for all project stages. They can be used in combination with BIM or as stand-alone technologies. Owners and FM teams stand to gain the most benefits from the use of these visual data formats.

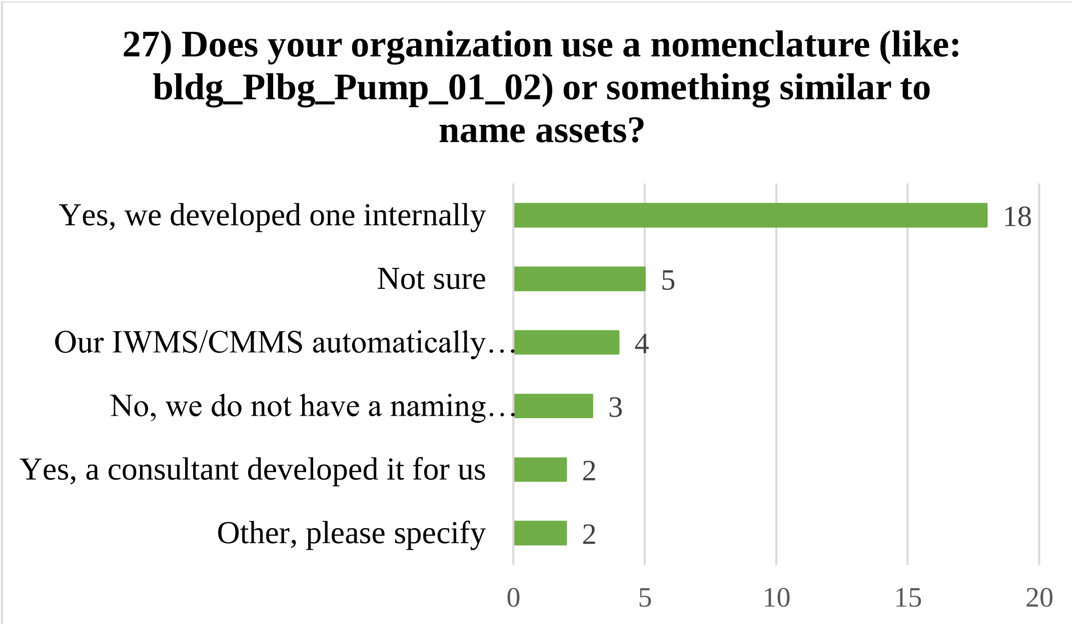

Figure 22. Question 27 of survey

This question as input into the survey as there is minimal research on nomenclature. Participants were asked if the organization uses a nomenclature similar to the format provided in the question. The frequency total for this question was 34, 25 less than the number of surveys recorded. The answer choice with the highest frequency was “Yes, we developed one internally” at 18. Five participants were not sure of the nomenclature the organization used. Four participants had asset numbers automatically assigned through the IWMS/CMMS system. Three organizations did not have a naming convention, while two participants noted that a consultant developed the nomenclature. Lastly, two participants selected “Other, please specify.” However, there was no feedback input for that answer choice. Research conducted by Judge, 2014 discussed five reasons why BIM will be used more on U.S. campuses. The second reason, “Improved Space Management” noted that spaces are best managed when the FM team has access to data such as, how the space is being used. Higher education institutes require large volumes of data that is often dispersed across multiple departments. However, the naming and coding of the space is typically very different based on the department. CMMS as well as other systems used by FM teams need to have spaces named in the same format and structure to be useful. Assets are not the only thing to need nomenclature, photographs, 360-degree photographs, and 3D laser scans will also need nomenclature to ensure FM teams can access them to obtain the data needed. Nomenclature can be used to provide the location of the asset. For example, the example in the question (bldg._Plbg_Pump_01_02) shows the FM team member the building the asset it in, type of asset, the number of its kind, and the building floor it is installed.

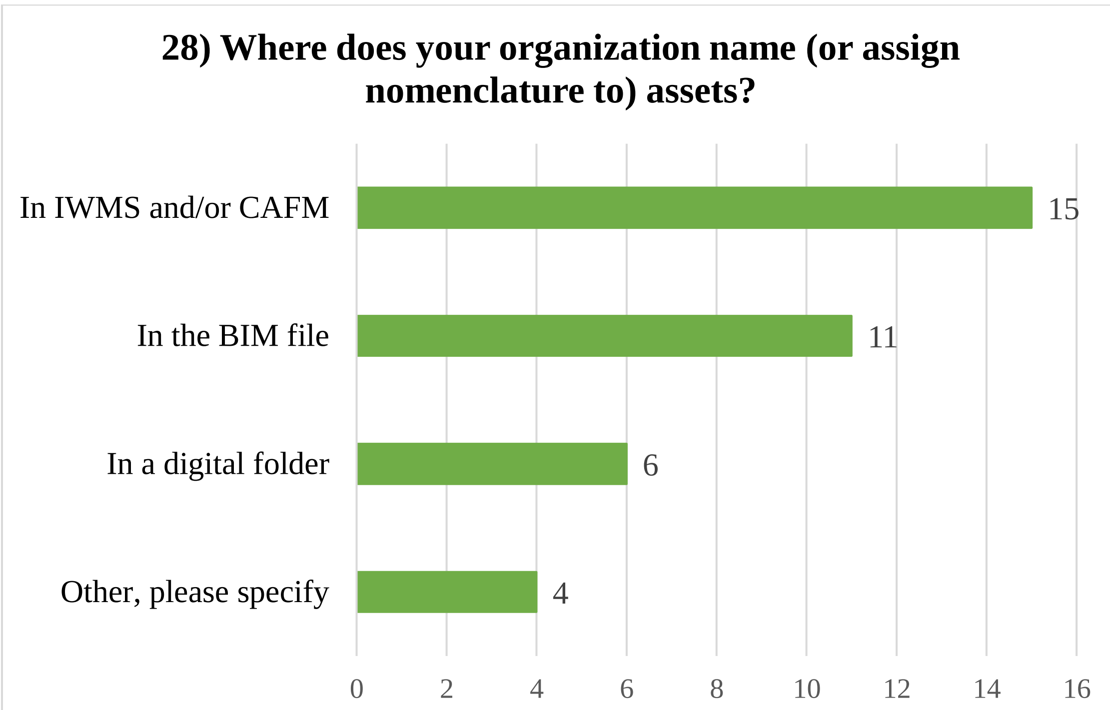

Figure 23. Question 28 of survey

This question asked participants where the organization name (or assign nomenclature to) assets. The frequency for this question was 23 less than the number of surveys recorded (59). It was hoped that there would be a higher frequency of responses for this question to obtain more valuable information from this question to gain further knowledge on nomenclature of assets. The highest frequency category was “In IWMS and/or CAFM” with 15 “In the BIM file” was second with 11. The third was “In a digital folder” with 6 and the lowest frequency was “Other, please specify" with 4. The participants selecting "Other, please specify" was input as the following:

- "General Inventory"
- "database"
- "Asset Management Program"
- "CMMS"

BIM can be used as data repository and has many capabilities catering to FM functions. For example, BIM data can be used for asset inventories and registries. *Xavier University Realizes the Benefits of BIM* discusses the benefits gained by Xavier when BIM was adopted. Greg Meyer, Assistant Director for Facilities Assessment at Xavier, stated "Maintenance people have access to the information they need to help keep our building operating efficiently. Decision makers can make more informed budgeting and space management decisions. BIM data helped me to prepare a comprehensive, 10-year capital plan for Xavier. The data demonstrated that additional funding for maintenance and renovations was needed to support the school's mission. As a result, Xavier's administration raised the facilities budget from US $750,000 per year to US $12 million per year." This case study is one example of how beneficial BIM can be to FM teams, especially when they contain the same nomenclature for assets so they are easily accessed.

Asset Management is a vital part of the FM stage, which focuses on the implementation of a building plan for the Owner to realize the lifecycle value from the assets within the building (The Institute of Asset Management, 2011). BIM can assist in the asset management process for O&M since it manages data without being dependent on time and people, which allows for more efficient integration of building documentation and asset management support (Bosche et al., 2015). CMMS is a software tool available to FM teams as they provide benefits for work order management, asset management, and configurable ability to support specific needs. Cavka et al., (2015) research worked with the University of British Columbia (UBC) to identify challenges faced at handover. UBC, like many other organizations, lack a method for checking accuracy and completeness of handover documents, defined standards for how handover data is formatted, and a process for generating an asset database in a reusable format, among others. The organization which input "database," could be using a software similar to CMMS or it could be an internally developed system. The participant did not specify the type of database.

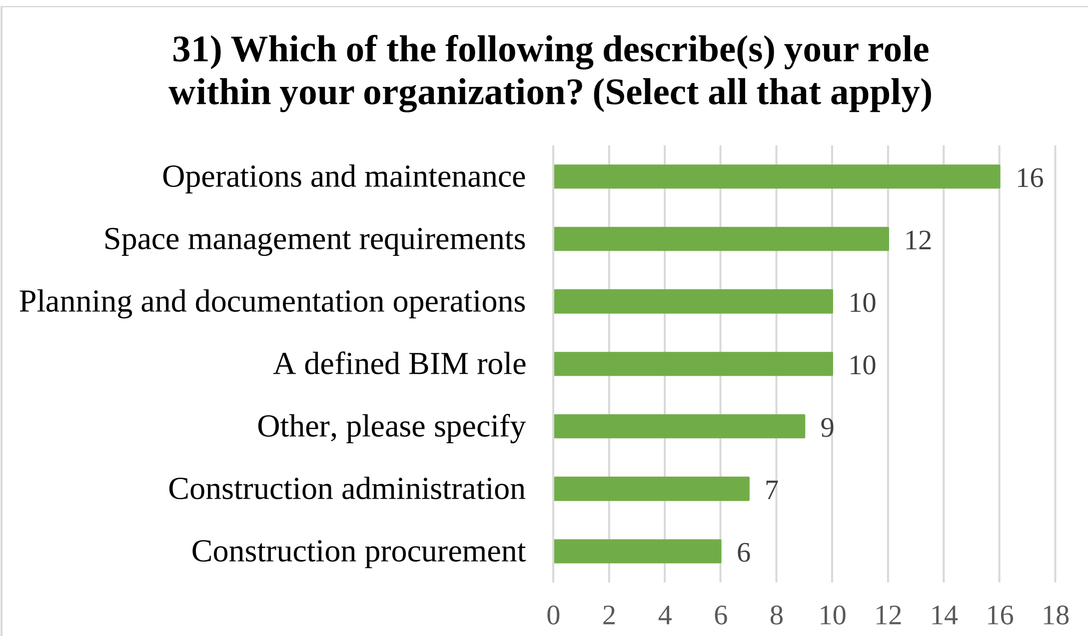

Figure 24. Question 31 of survey

This question asked participants to describe their role within their organization. Like multiple other questions the frequency for this question (70) was higher than the number of recorded surveys (59). The categories based on frequency from highest to lowers was as follows: O&M (16), space management and requirements (12), planning and documentation operations (10), a defined BIM role (10), other, please specify (9), construction administration (7), and construction procurement (6). It can be assumed for this question, given the variation in frequency and surveys recorded, that several participants play more than one role within their organization. Participants selecting "other, please specify" input the following:

- "Facilities Information Systems Manager"
- "GIS"
- "FCAP"
- "Facilities Engineering"
- "smart building technology"
- "Records Manager"
- "VDC Consultant for all phases of architecture, engineering construction and ownership"
- "Director, Leader"
- "Director"

Q32 - If you have any further comments you would like to share, please use the space provided.

Participants were given the option to provide any comments pertaining to the survey. Five participants chose to input feedback, it was as follows:

- "I will be happy to share what we have done. Contracts, guidelines etc…reach out to me lburdi@massport.com"
- "We enjoyed providing the information for your research. Please know that this information was collected from our experience as a VDC Company as well as a representative for owners."
- "I hope these responses are helpful. I have only recently come online to help UVA manage BIM in hopes of improving services for UVA and AEC consultants."

- “Let us know if you need further information as follow-up. Good luck.”
- “I’m very interest to read the results. I will be sharing with my network to try to get you more participation and data. I wanted to do my master’s thesis on facilities issues but had so much trouble finding complete or current data I gave up. lol.”

All participants providing additional feedback completed the survey (100%). Four of the five participants providing feedback have 1-3 people with dedicated BIM roles within the organization. The fifth participant noted their organization has 10 + people with dedicated BIM roles. For the question asking what format is requested for handover deliverables, all five selected BIM model and three selected “visual (360-degree photographs, 3D laser scans, etc.). When asked how much time is spent after handover organizing the BIM data to make it useable, all five participants selected 1-3 months. This is significant in that each of the five participant organizations have created several BIM requirements. For example, three of the five organizations created model progression specifications outlining the required LOD. Four of the five organizations created interoperability/ file sharing procedures and created O&M/DM data requirements for the model. All five require construction handover deliverables. It was also interesting to see that four of the five selected 360-degree photographs as visual data useful to O&M staff. The literature review found little previous research on the use of 360-degree photographs for the FM stage. However, it was selected as a useful O&M visual data tool.

Additionally, the participant stating, “I will be happy to share what we have done. Contracts, guidelines, etc…reach out to me” noted their organization has designated staff members responsible for model management and QA/QC, as well as element validation being performed to ensure all model objects are defined correctly and consistently. The literature review identified many reasons why building documentation (i.e. asset data and visual data) is not collected, such as cost of services and equipment. The participant noted that cost of services, equipment, and/or resources seem too high along with “to ensure expected quality/accuracy is achieved” as reasons why building documentation is not collected. The literature review noted that a benefit of BIM is QA/QC for building documentation to help the FM team know the data received is correct and complete. However, the answer choice “to ensure expected quality/accuracy is achieved” was chosen as a reason why building data is not collected. This could be seen as a gap between the industry professionals and research professionals of the AEC industry.

Q33 - We will be creating a summary document of our results. In order to receive the results of survey findings, please provide your email address in the space provided:

Participants were able to provide email addresses to receive a summary document of results for this research. Table # below lists the emails provided by participants. Twenty-four were interested and provided an email address. Ten of the emails provided are from higher education institutes. This is significant as for BIM to be successfully implemented experiences should be shared between organizations.

4.2 Analysis of Individual Questions – College/University Only

This section examined how the participants selecting college/university when asked how to best describe the organization. Analysis was conducted on this type of organization as a report will be created and provided to the UNC-Charlotte FM department to assist in BIM implementation and processes. One question of the survey asked how many people have dedicated BIM roles within the organization, none, 1-3, 4-6, 7-9, or 10 +. When college/university was selected the number of dedicated BIM roles within the organization was found to be none, 1-3, or 4-6. Responses were examined based on these 3 groups.

After examining survey responses for college/university only, 16 of the 59 recorded surveys were completed by a university/college employee and all of the 16 were completed 100%. The number of dedicated roles within the organization (Q3) were found to be, none (frequency of 5), 1-3 (frequency of 10), and 4-6 (frequency of 1).

Analysis began by examining responses for the organizations having no dedicated BIM roles within the organization, frequency of 5. The section asking questions pertaining to BIM personnel and requirements was investigated first. When asked what types of leadership roles were required on BIM-assisted projects the organization required, the answer choice with the highest frequency was no specific provisions have been made. A project BIM manager to assist in construction administration and BIM coordinators for each technical trade/discipline were tied for second.

When asked the percentage of projects using BIM, none of the organizations use BIM on all projects. Figure 25 below illustrates the frequencies for all options.

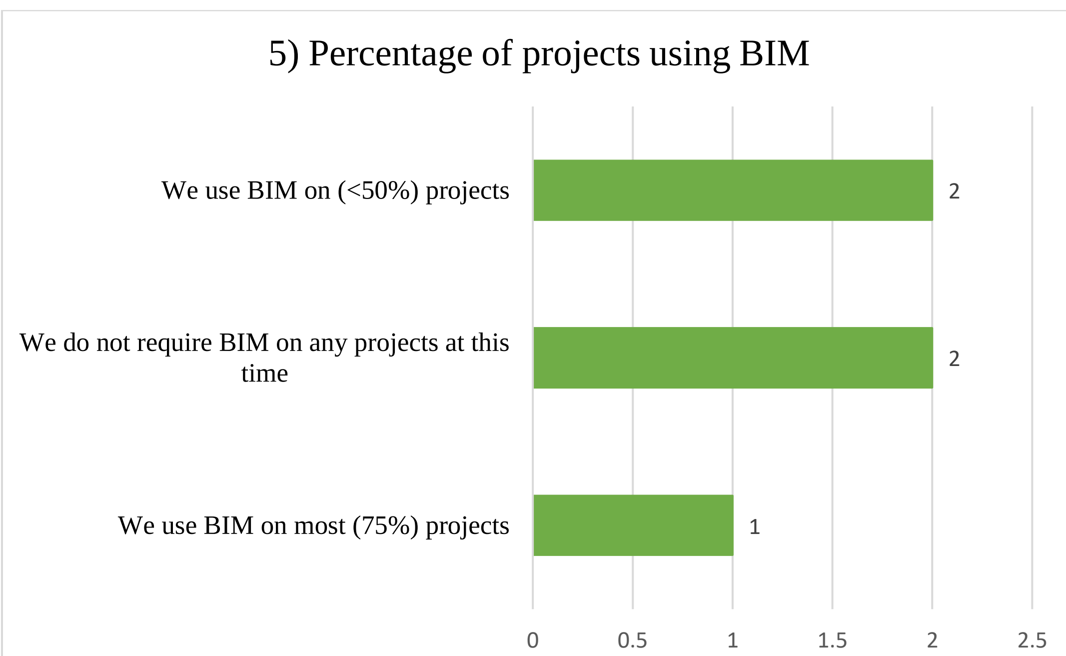

Figure 25. Question 5 for college/university with no dedicated BIM roles

When asked what provisions the organization has made to assist in BIM implementation only one participant input a response, “We use BIM only in that our staff uses Revit. The option with the highest frequency was no specific provisions have been made. BIM/VDC requirements or specifications received a frequency of 1.

If the organization does not currently require BIM or if adoption issues have been encountered participants were asked to select answer choices that apply. The option with the highest frequency was found to be lack of trained in-house personnel. Figure 26 illustrates the frequency for all options. The two participants selecting, other, please specify input the following:

- “Staff size and cost restrictions.”
- “Use/need not identified”

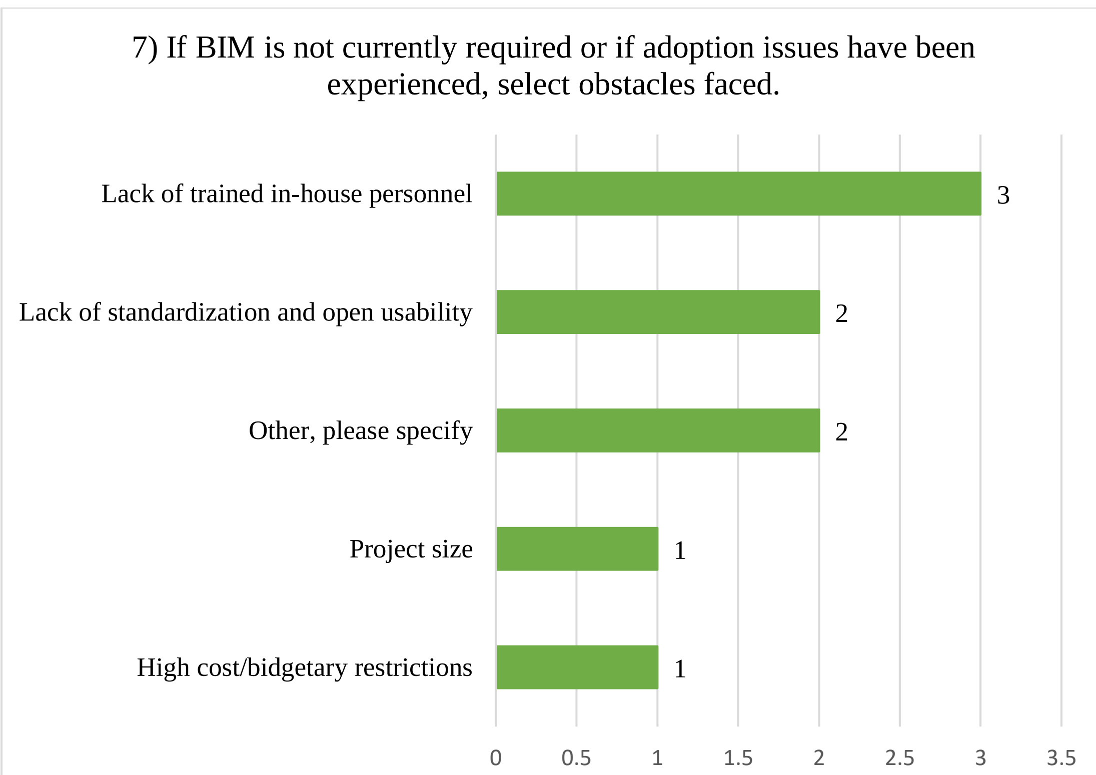

Figure 26. Question 7 for college/university with no dedicated BIM roles

The last question related to BIM personnel and requirements asked what BIM requirements were created by the organization. Figure 27 below illustrates the frequency for all options. The highest frequency category was the organization having no contractual agreements or requirements pertaining to BIM. All other options received a frequency of 1. It should be noted that one participant selected all options with a frequency of 1.

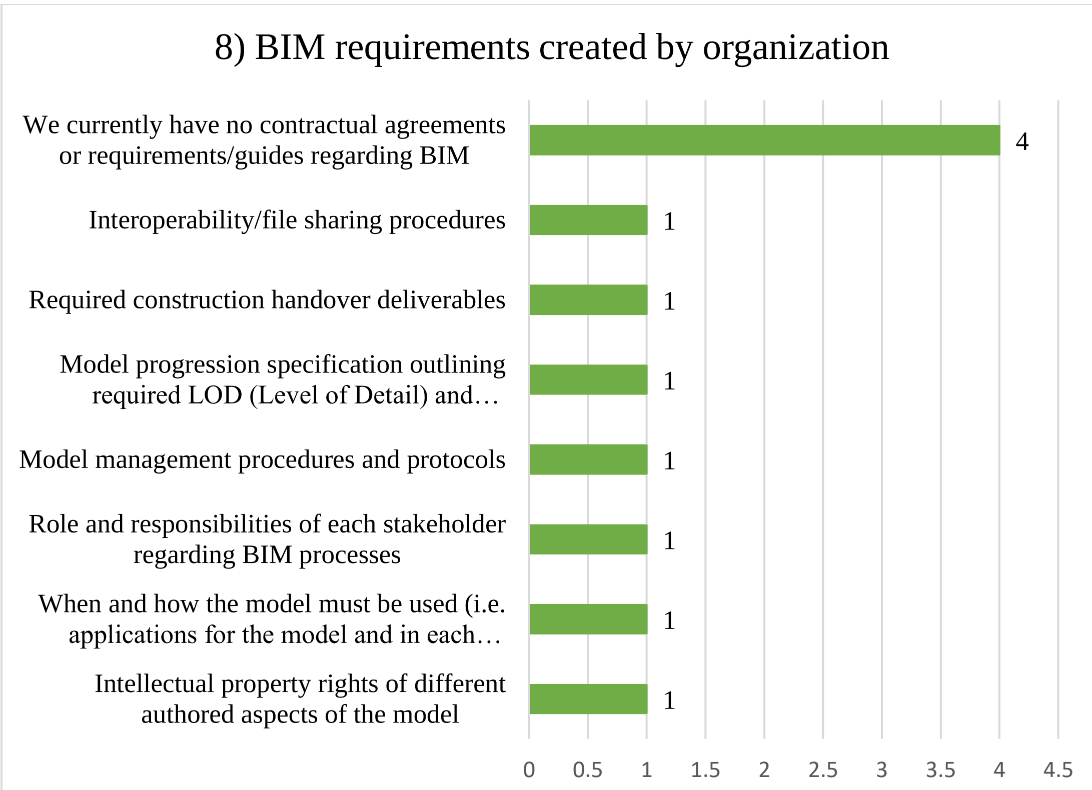

Figure 27. Question 8 for college/university with no dedicated BIM roles

Next, the section pertaining to construction deliverables was inspected. The first question asked how asset data is checked and/or collected during construction. The option with the highest frequency was that asset data is not tracked during construction (frequency of 3). One participant selected BIM360 spreadsheet (native inside BIM360). The last participant selected I don’t know.

The next question asked what format handover deliverables are requested. The options were BIM model, electronic, and paper. Electronic received the highest frequency of 4, with

BIM model and paper both having a frequency of 3. This option had 9 options for handover deliverables and only 3 were chosen by all participants. Two participants selected BIM model, electronic, and paper. One participant selected only BIM model. Another selected only Electronic, while the fifth selected paper and electronic.

The last question of the construction deliverables section asked what BIM deliverables are mandated by the organization at construction handover. One participant noted the organization requires as-built models from both the design and construction team. The frequencies for all options are illustrated in the graph.

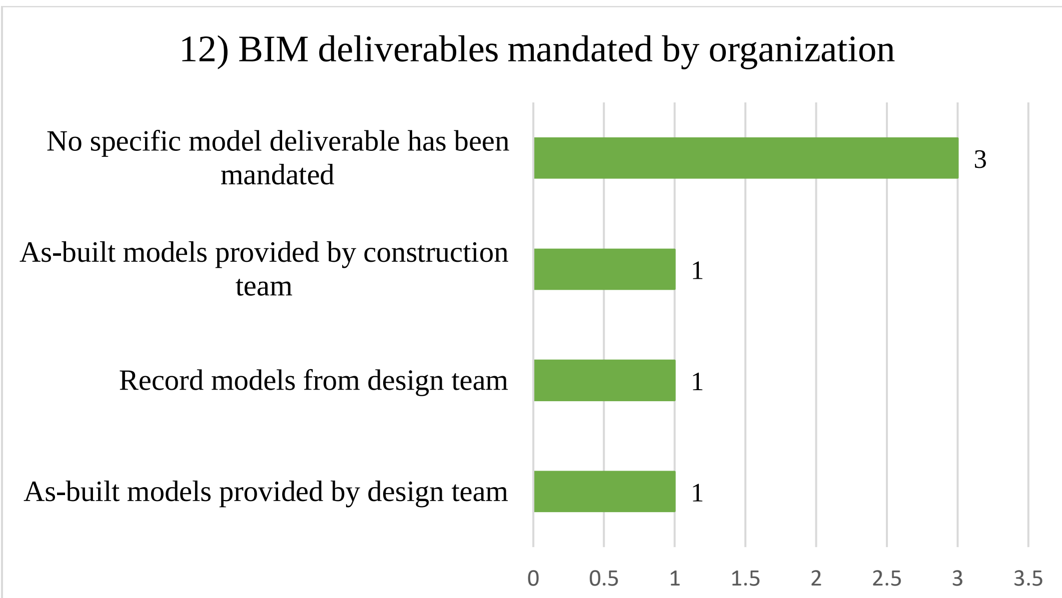

Figure 28. Question 12 for college/university with no dedicated BIM roles

Questions from the facilities management section were examined next. When asked what time intervals the organization requires reviews of the model for coordination and QA/QC from the designer, 3 participants noted the organization does not have QA/QC review processes and 2 participants noted that it is based on the design phases.

When asked how to best describe the QC procedures used to assess the accuracy and completeness of model-based deliverables, 4 participants chose the option for no formal QA/QC processes for the models. The other participant selected options for having designated staff member(s) for model management and QA/QC along with conducting interference checks of stakeholder models.

The format most used by maintenance and FM staff to reference building data needs, post-construction, was asked next. The frequencies for all options are illustrated in the graph. One participant selected CAD drawings and input "PDF scans." One participant selected four options, hard copy, CAD drawings, IWMS or CAFM, and floor plans imported into CMMS. Another participant selected hard copy and CAD drawings. While another selected CAD drawings and floor plans imported into CMMS.

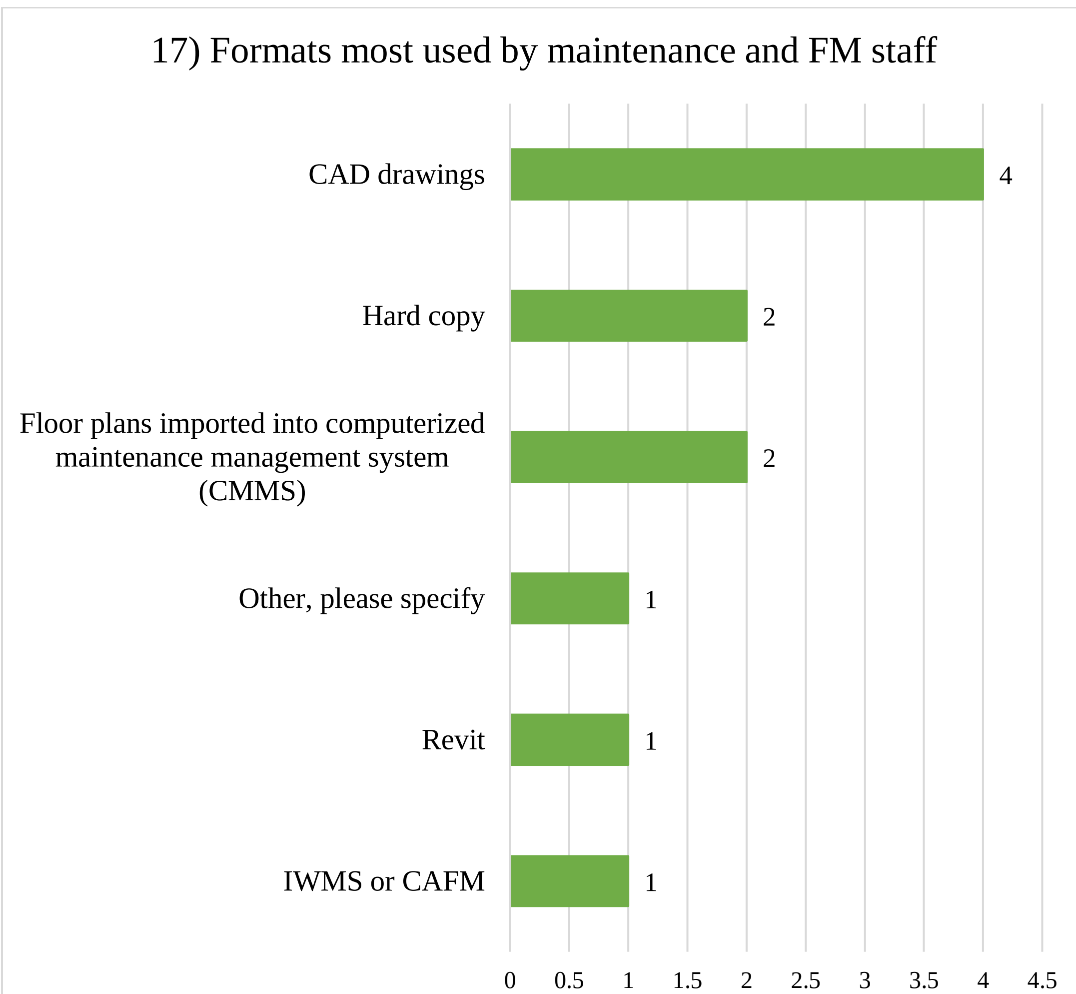

Figure 29. Question 17 for college/university with no dedicated BIM roles

When asked how floor plans are used, post-construction, 3 participants selected that floor plans are created with another software after the provided deliverables. The other 2 participants selected floor plans are linked to IWMS and/or CAFM.

The next question of the FM section asked how the final BIM deliverable will be used post-construction. All 5 participants noted the organization does not currently use the model or its attribute data post construction.

When asked what the organization has experienced pertaining to building documentation not being collected, 3 participants noted the cost of services equipment, and/or resources seem too high. Another participant input, “We don’t personnel resources in-house to manage the BIM models (keep them updated).” The last participant input, “Do not know.”

All 5 participants noted that the organization does not do anything with the data when asked how much time is spent after handover organizing the BIM data to make it useable.

The last question within the FM section of the survey asked participants to rate the importance of uses for BIM in the O&M phase. The frequencies for each use are illustrated in the graph. The uses were rated as not important, somewhat important, very important, extremely important, and not sure.

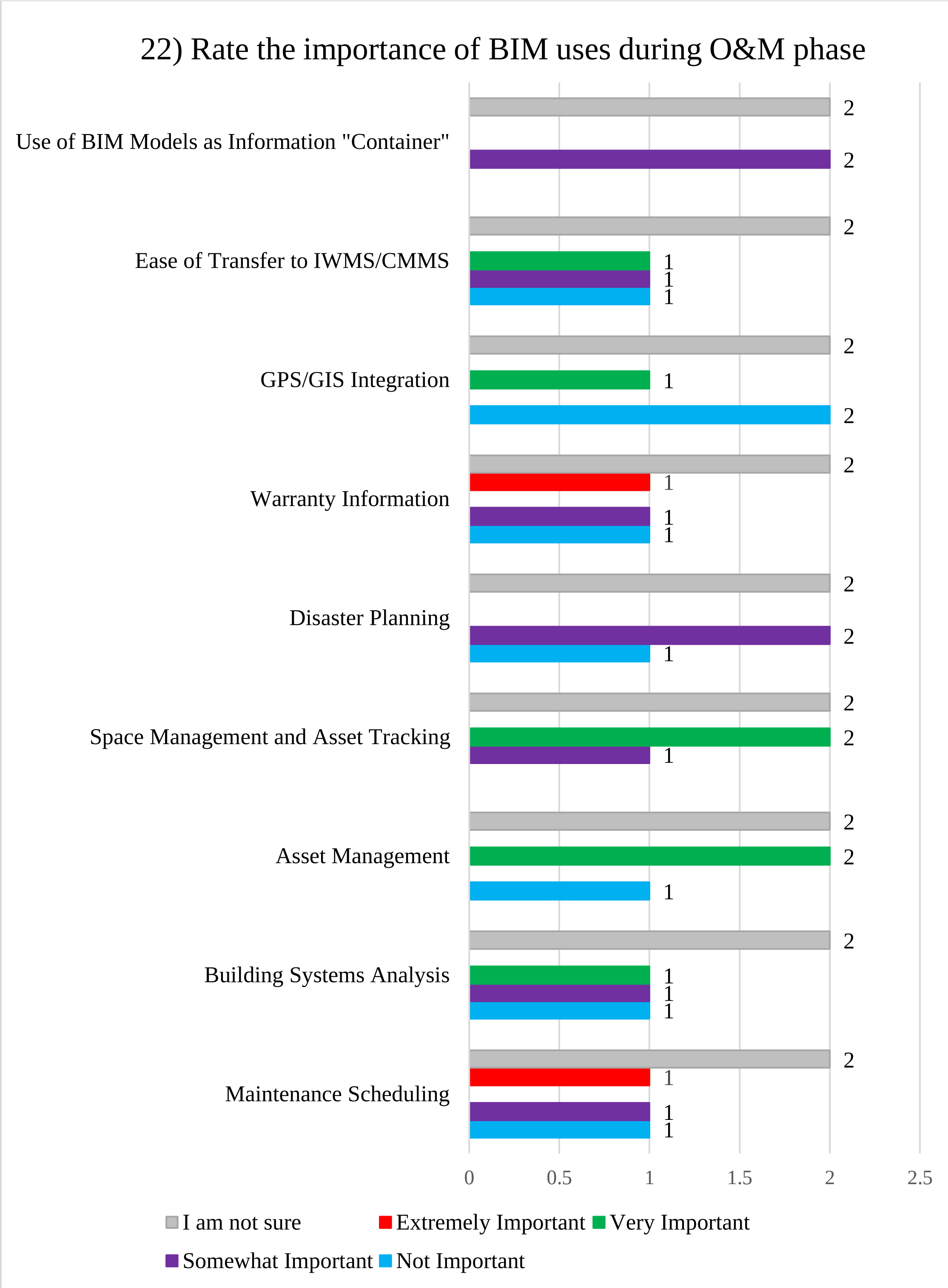

Figure 30. Question 22 for college/university with no dedicated BIM roles

Next, the Visualization and Asset Management section was analyzed. The first question of this section asked participants which type of visual data is useful to O&M staff. The frequencies for the formats seen as useful are illustrated in the graph.

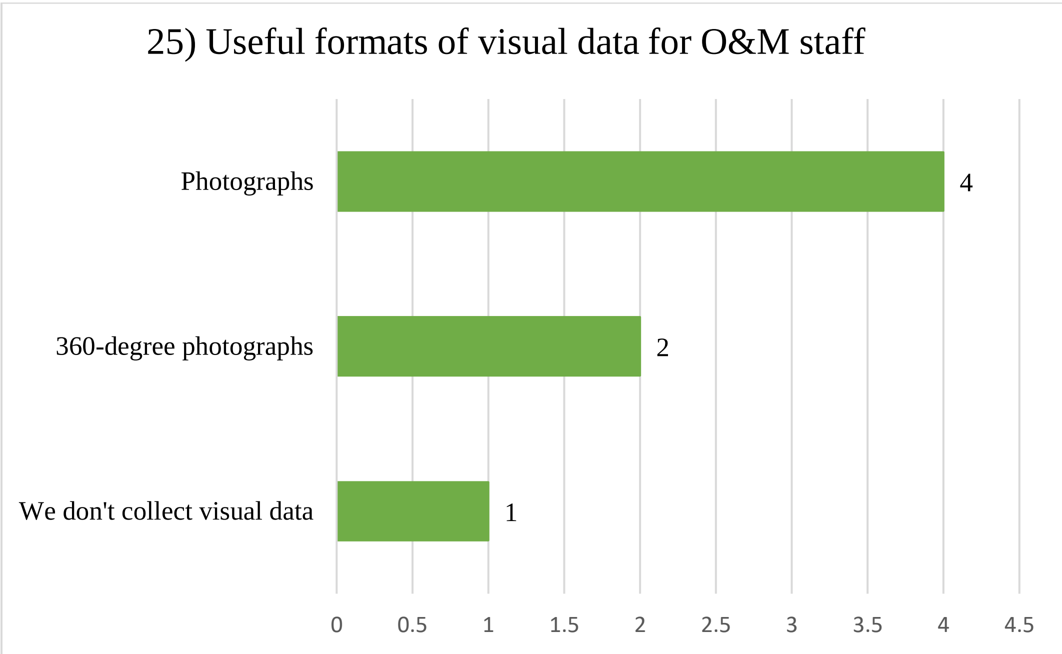

Figure 31. Question 25 for college/university with no dedicated BIM roles

When asked what visual data is requested and by whom it is requested from, none of the participants request augmented/virtual reality. Two participants only collect photographs internally. The second response analyzed collects photographs internally and from the construction team. Another participant selected multiple formats from the construction team, one from the design team, and one internally. From the construction team, photographs, 360-degree photographs, and laser scans are requested and obtained. Additionally, the organization obtains photographs from the design team and collects them internally. Only one participant selected does not collect visual data for each format.

When asked if the organization uses a nomenclature similar to bldg._Plbg_Pump_01_02 or similar to name assets, 3 participants noted the organization developed one internally. Another participant noted the organization has no naming convention. The last participant was not sure about a naming convention within the organization.

The last question of the Visualization and Asset Management section asked participants where the organization names or assigns nomenclature to assets. Two participants selected IWMS and/or CAFM. One participant selected in a digital folder. Another participant input, “CMMS.” The last participant input, “Asset Management Program.”

When asked to best describe the participant’s role within the organization, 2 input the following, “Facilities Information Systems Manager” and “Records Manager.” One respondent noted Space management requirements and Planning and documentation operations. One participant selected Construction administration. The last participant selected Space management requirements and input “GIS.”

The college/university participant organizations with 1-3 dedicated BIM roles were examined next. Again, based on survey sections with BIM personnel and requirements first. Leadership roles required by the organization for BIM-assisted projects had the following frequencies.

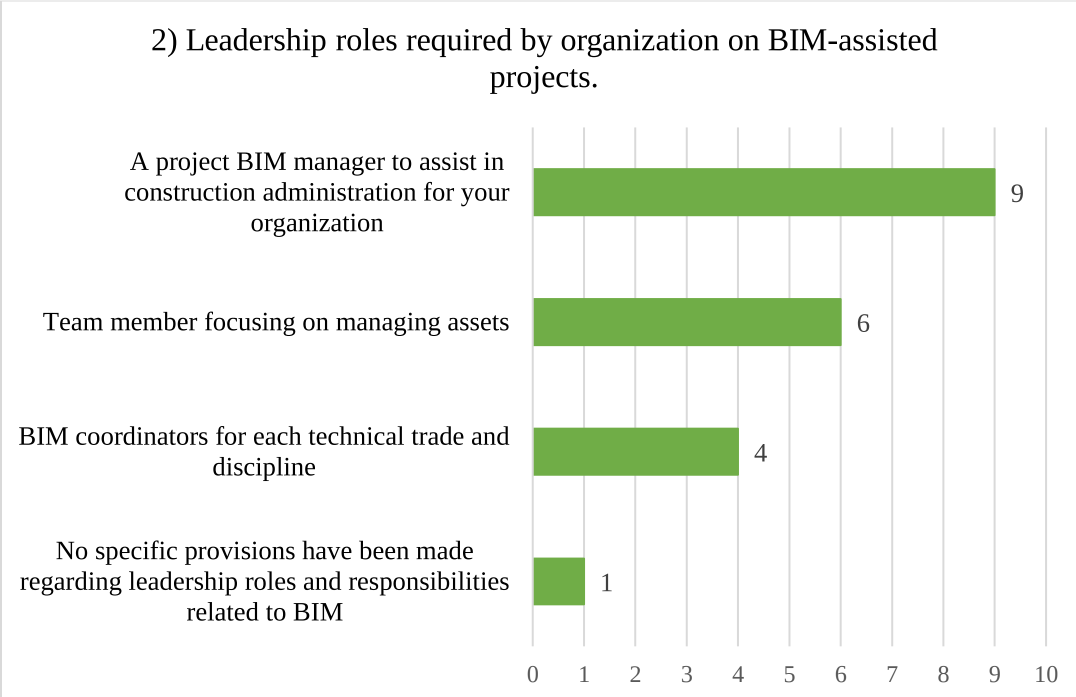

Figure 32. Question 2 for college/university with 1-3 dedicated BIM roles

The participant noting that no specific provisions have been made also input "We have provisions to receive BIM models, but did not have internal people or processes to take advantage of those deliverables until 8 months ago. We now have a BIM Project Manager (me) to define project protocols, receive and process models, and to develop strategies for using BIM moving forward." It should be noted that 6 of the 10 participants selected multiple options for this question, all of which contained a project BIM manager to assist in construction administration, which was the highest frequency answer choice. The second highest category was having a team member focusing on managing assets. Ensuring the model is updated with accurate and complete information is vital for successful BIM implementation. The two highest frequency categories confirm these discoveries from the literature review.

Of the 10 organizations with 1-3 dedicated BIM roles, 5 use BIM on <50% projects, 3 use BIM on 75% projects, 1 use BIM on 50% projects, and 1 does not require BIM currently.

The graph below illustrates the frequencies when asked what provisions have been made by the organizations to assist in BIM implementation.

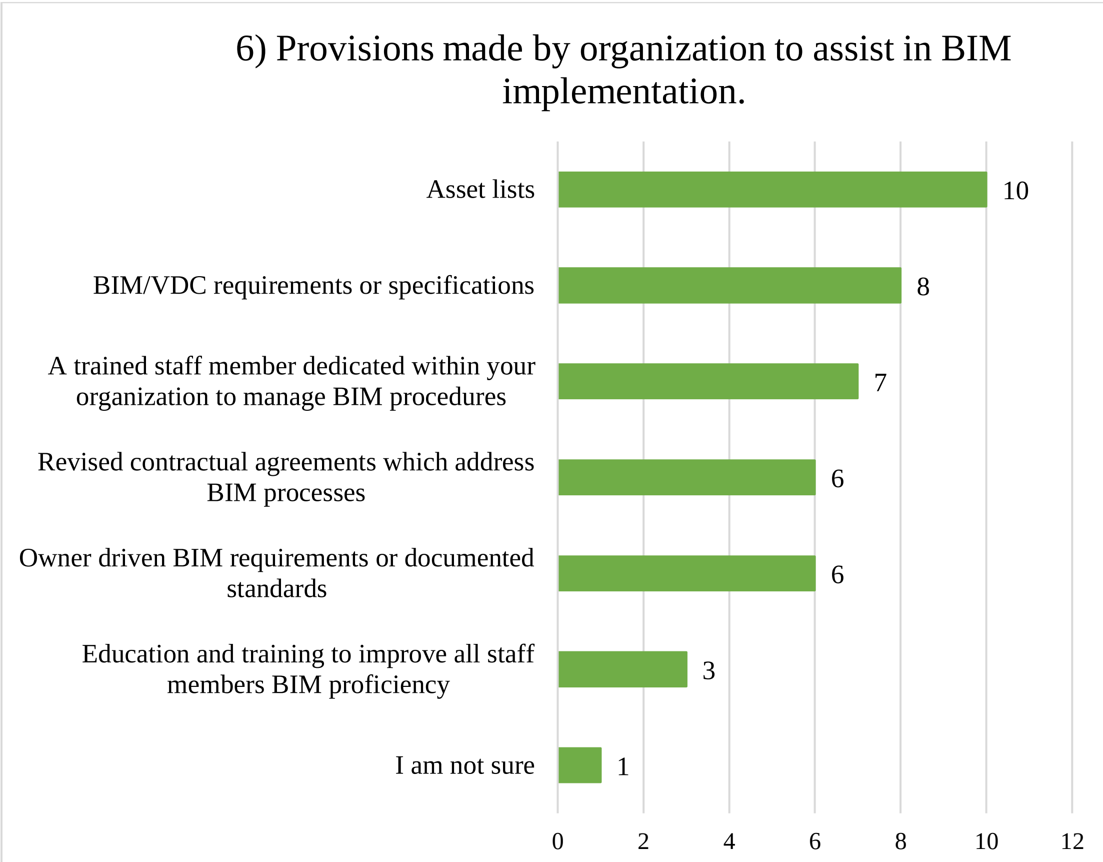

Figure 33. Question 6 for college/university with 1-3 dedicated BIM roles

One participant also input "Revit templates." Of the 10 organizations examined, only 1 made a single provision (Asset lists) to assist in BIM adoption. Asset lists was the highest frequency category, followed by BIM/VDC requirements or specifications, and having a trained staff member dedicated to managing BIM procedures. All answer choices for this question were identified as needs to BIM adoption from the literature review. Asset lists is one use of BIM that could improve FM technician's productivity for work orders.

The next question asked if BIM is not currently required or if adoption issues have been faced to identify the obstacles. Five of the participants did not answer this question. It could be interpreted to mean those organizations did not face any obstacles or the options provided are not what was faced. Of the 5 that did answer, all but one chose at least two options. Lack of standardization and open useability and lack of trained in-house personnel were two of the most recurring reasons for slow BIM implementation for FM purposes. The frequencies for the options are shown in the graph.

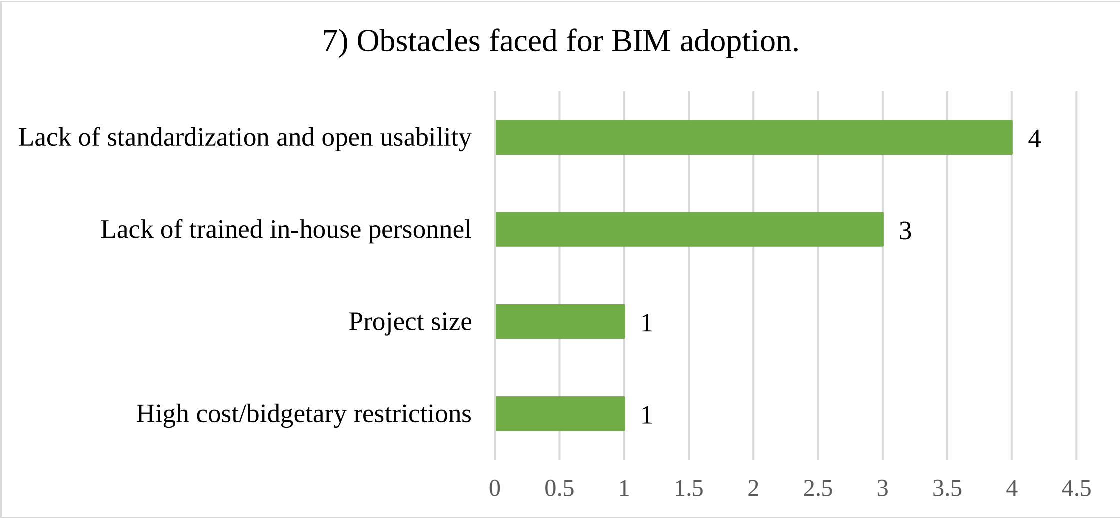

Figure 34. Question 7 for college/university with 1-3 dedicated BIM roles

The last question within the BIM personnel and requirements sections asked what BIM requirements were created by the organization. One participant input, “The above are currently in development.” This participant selected six of the above options for this question. The graph illustrates the frequencies for each option.

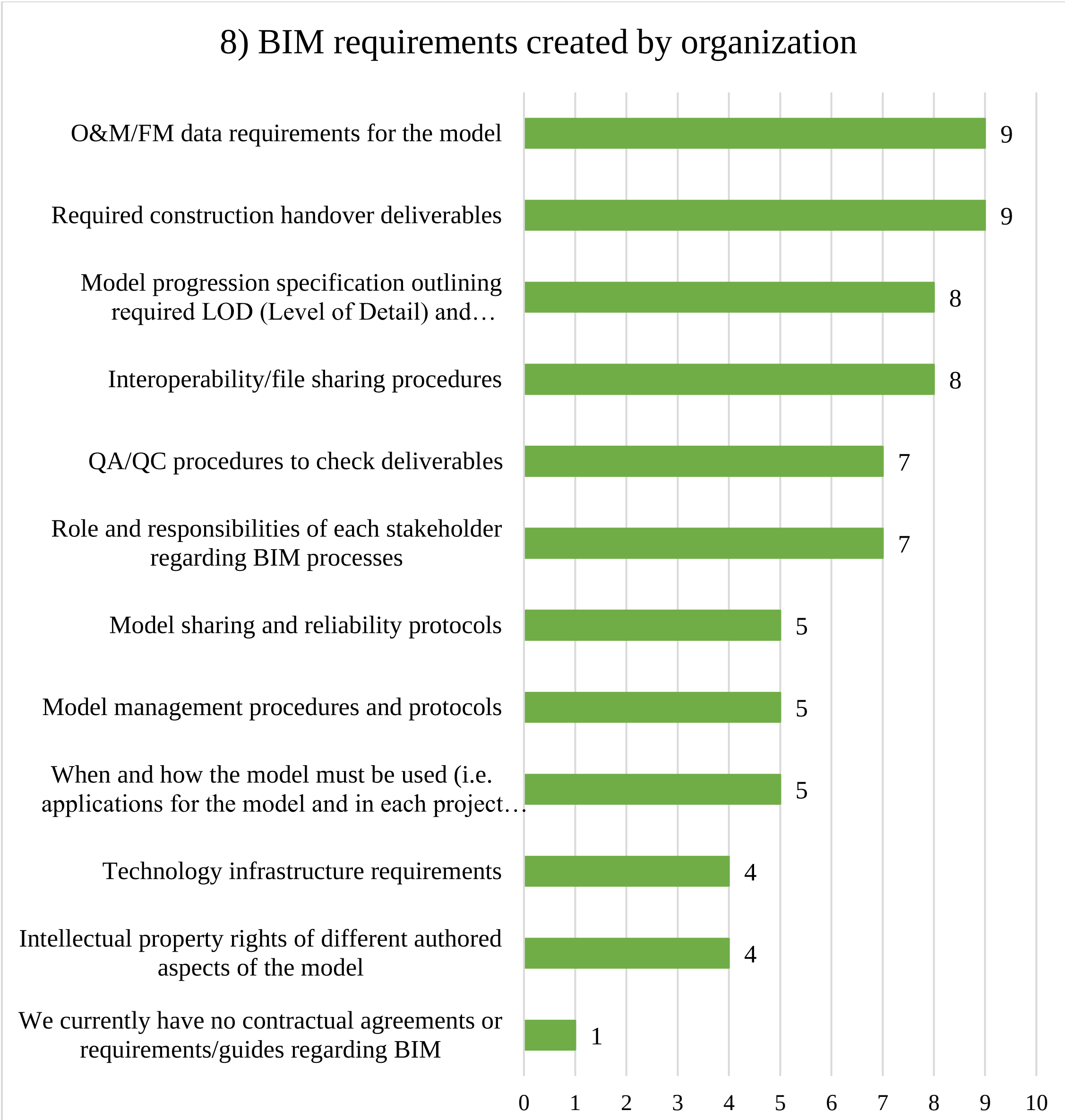

Figure 35. Question 8 for college/university with 1-3 dedicated BIM roles

Next, questions within the construction deliverables section were analyzed. Participants were asked how asset data is collected and/or checked during construction. The graph shows the frequencies of each option.

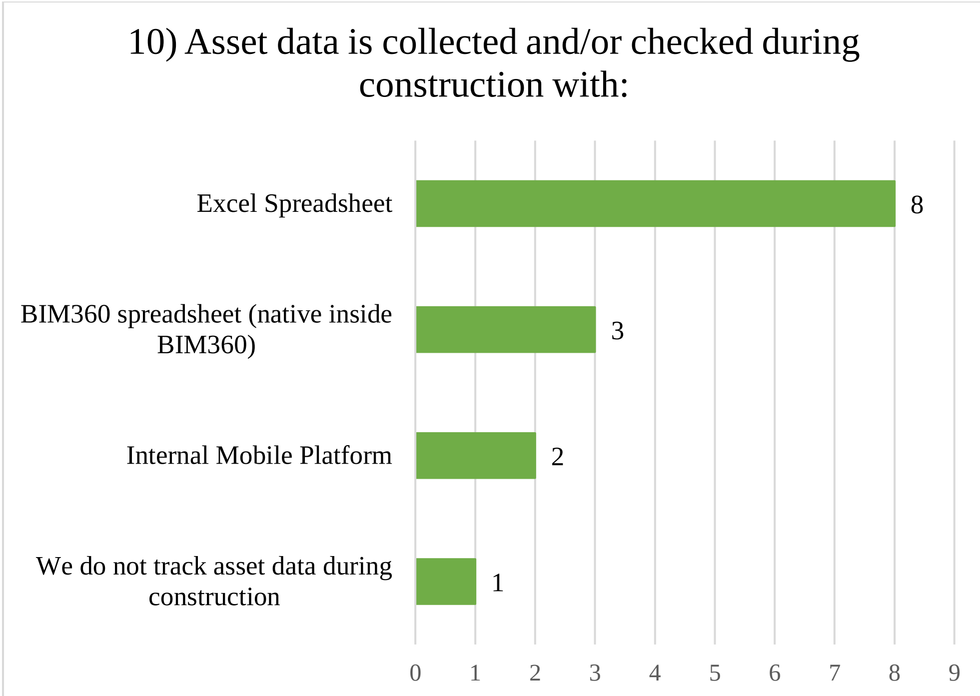

Figure 36. Question 10 for college/university with 1-3 dedicated BIM roles

The next question asked what formats handover deliverables were requested in. As with other questions, many participants selected multiple answers. Four participants selected 3 or more answer choices. One participant selected 4 answer choices. Two participants selected 5 answer choices. Only two participants selected one option. The graph illustrates the frequencies for this question.

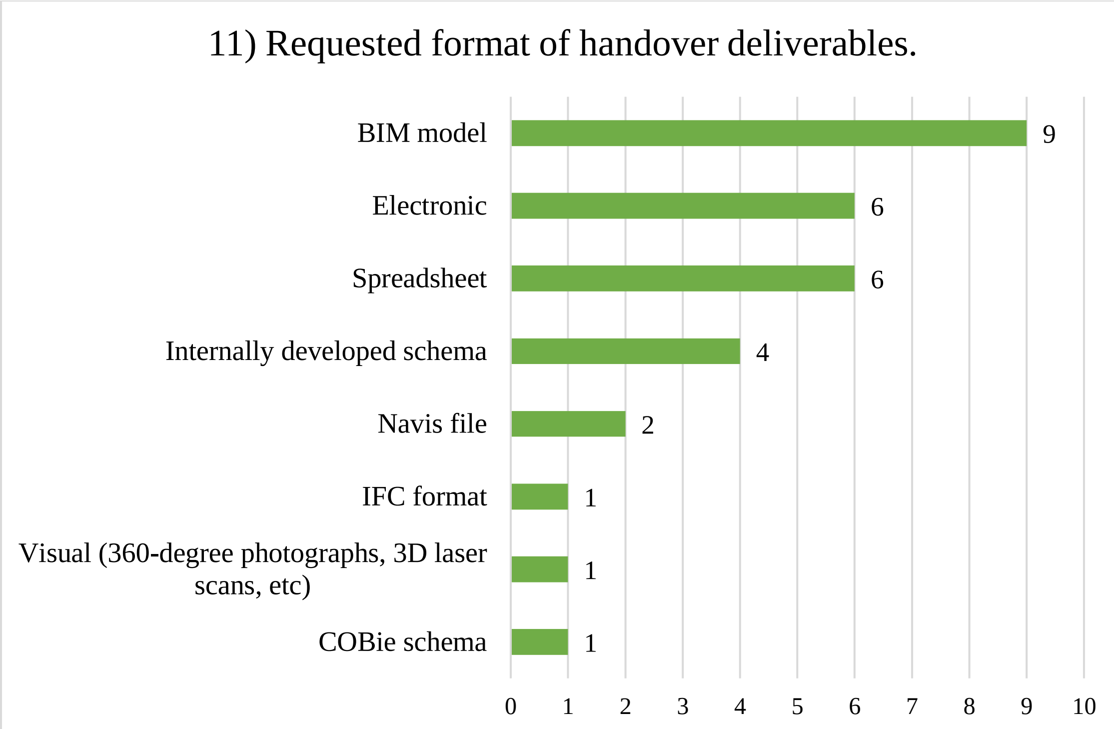

Figure 37. Question 11 for college/university with 1-3 dedicated BIM roles

Participants were then asked what types of BIM deliverables are mandated by the organization. One participant input “depends on the ILM plan for that project.” Two participants selected only one answer choice while three selected two answer choices. Three participants selected 3 answer choices and 1 participant selected 4 answer choices. The frequencies for each answer choice are shown in the graph.

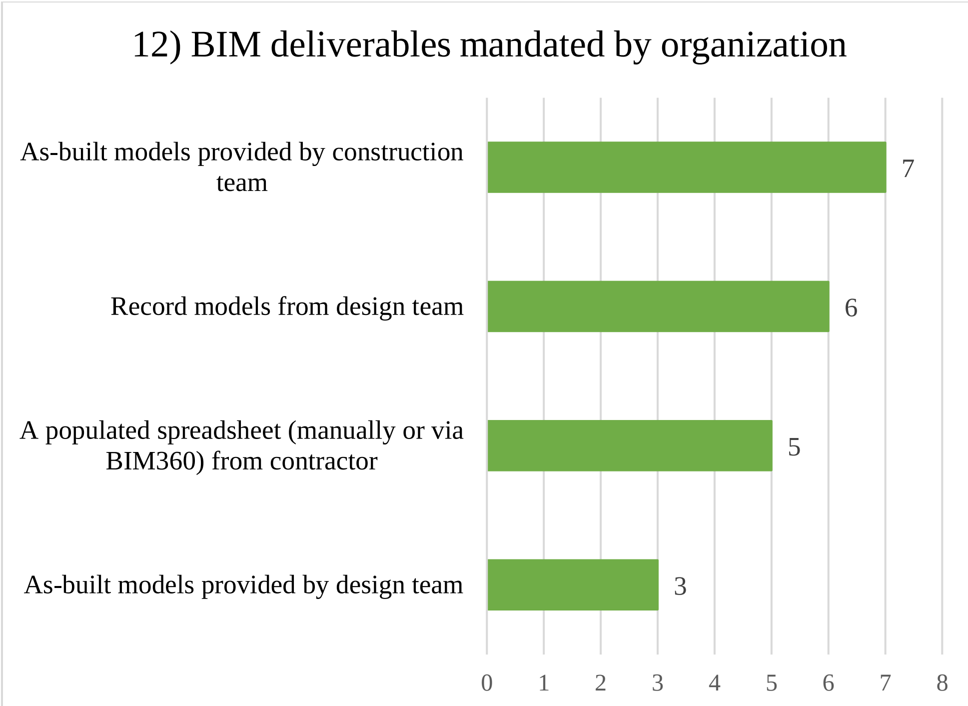

Figure 38. Question 12 for college/university with 1-3 dedicated BIM roles

The FM section was the largest section of the survey with 8 questions. The first question within this section asked participants what time intervals the organization requires reviews of the model for coordination and QA/QC from the designer. Seven of the participants noted it was based on design phases. One participant noted the organization does not have implemented QA/QC review processes. Two participants noted the models are reviewed after the project is complete.

When asked to identify which of the following best describes QC procedures used to assess the accuracy and completeness of model-based deliverables, only one participant input an answer. That participant stated, “The 3rd party commissioning authority is involved in the QA/QC. Also, we require the construction team BIM coordinator to use the Model Checker as part of the QA/QC process.” The frequency for the answer choices are illustrated in the graph. Of the 9 participants that selected answers provided, only 1 organization uses 3 QC procedures. The 3 QC procedures selected were having a designated staff member responsible for model management and QA/QC, conducting interference checks of stakeholder models, and element validation to ensure model objects are consistent and correctly defined. Four participants selected 2 answer choices provided, while 4 selected only 1 answer

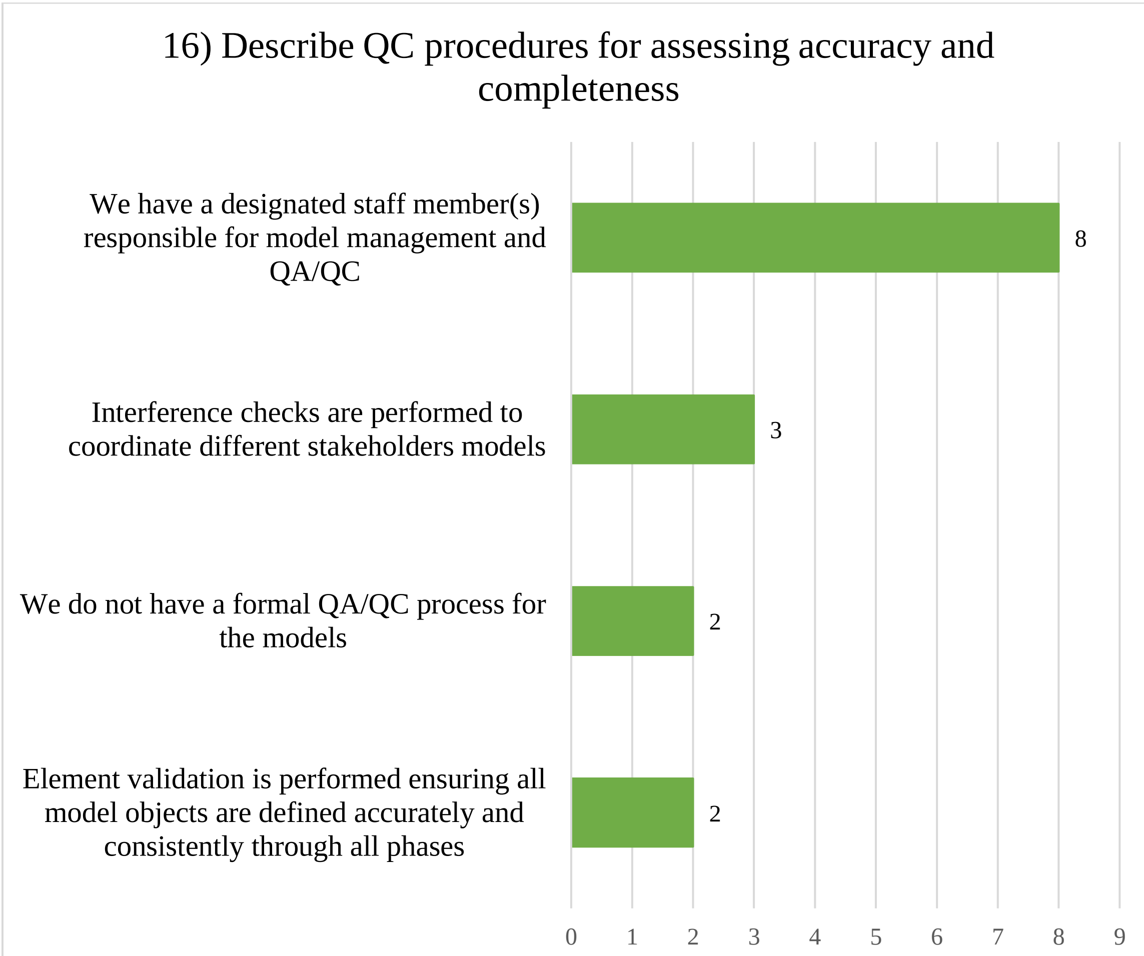

Figure 39. Question 16 for college/university with 1-3 dedicated BIM roles

The next question asked for the participant to describe the most used format by the maintenance and FM staff for referencing building data needs, post-construction. The frequency for each option is shown in the graph. As with other questions multiple participants selected more than one answer choice. Only 3 participants chose only one answer, either Revit (frequency of 2) or CAD drawings (frequency of 1). Five participants selected 3 choices, either Revit (frequency of 2), CAD drawings (frequency of 5), floor plans imported into CMMS (frequency of 4), or IWMS or CAFM (frequency of 3). One participant selected 4 choices; the top 4 highest frequency categories listed above.

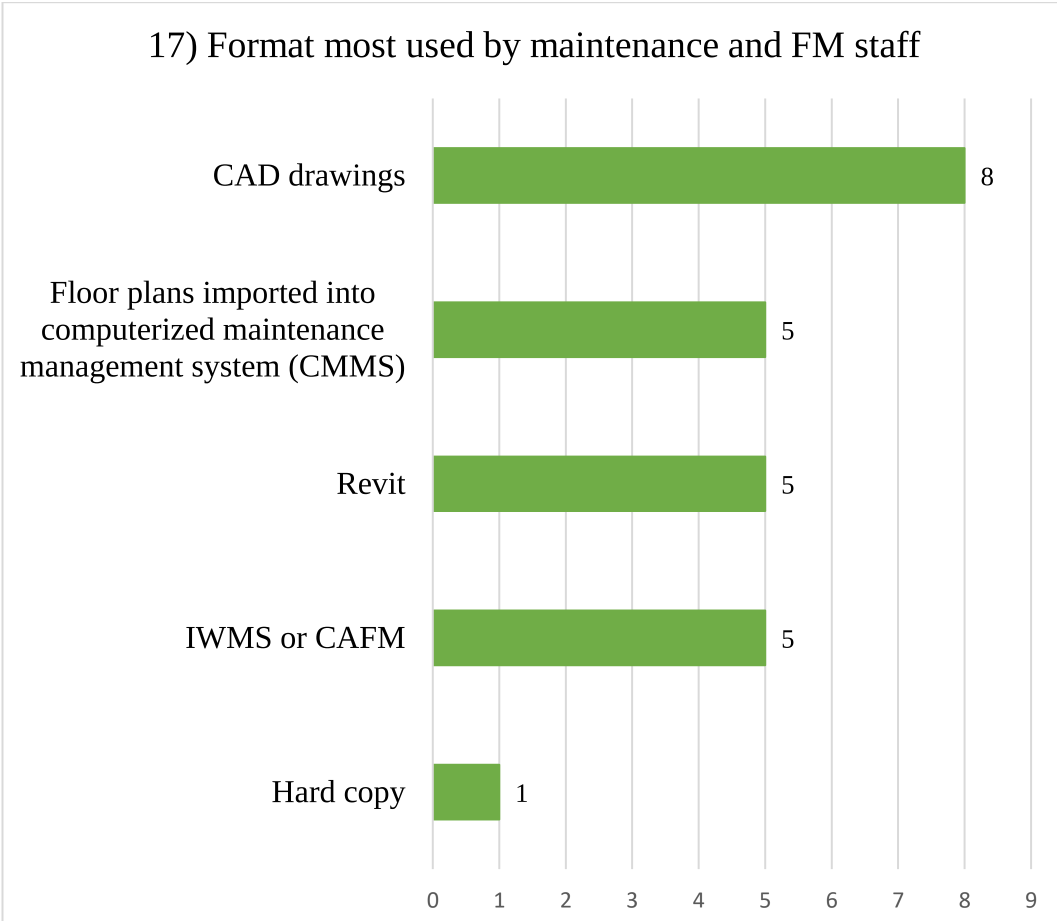

Figure 40. Question 17 for college/university with 1-3 dedicated BIM roles

When asked how the organization uses floor plans, post-construction, only 1 participant input a response, “Near future – Revit linked to Archibus.” The frequencies for the other 9 participants are shown in the graph.

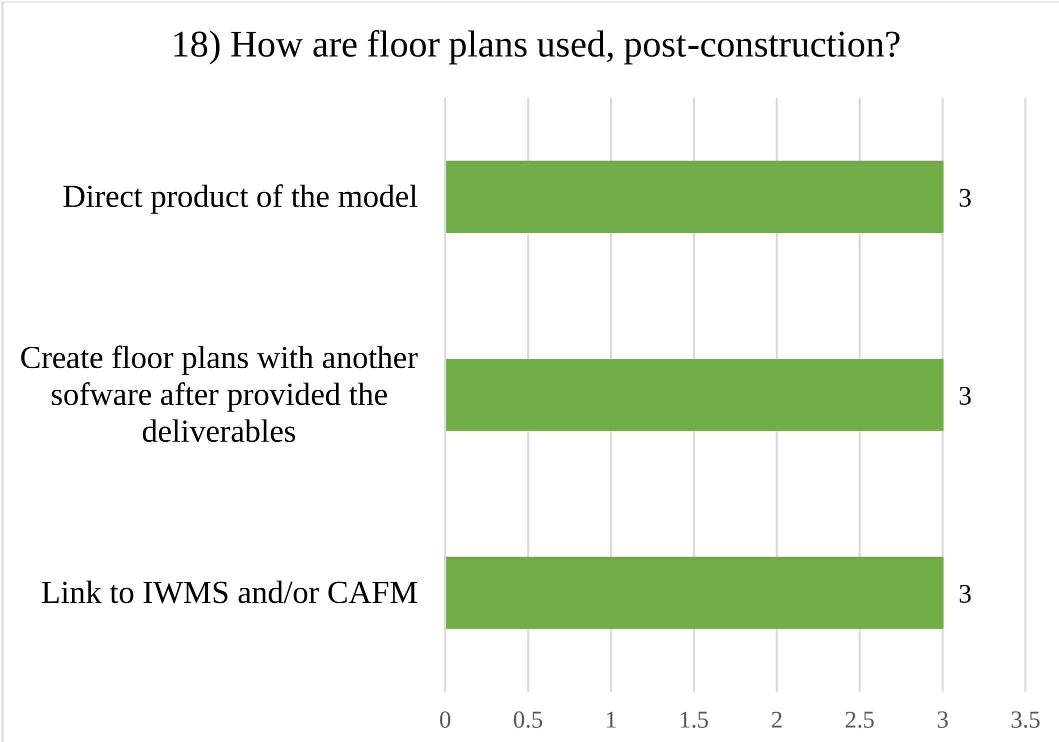

Figure 41. Question 18 for college/university with 1-3 dedicated BIM roles

Utilization of the final BIM deliverable(s), post-construction was asked next. Two participants input a response, “models currently not in use, but plan to integrate into GIS, CAFM, and maintain for distribution of existing condition records” and “Future existing conditions.” The frequencies for each option are illustrated in the graph. Of all 10 participants, only one organization utilizes the final BIM deliverable(s) in all 5 options provided. This is significant, as it illustrates a BIM success story. The organization utilizes the model for the most common FM uses discovered in the literature review.

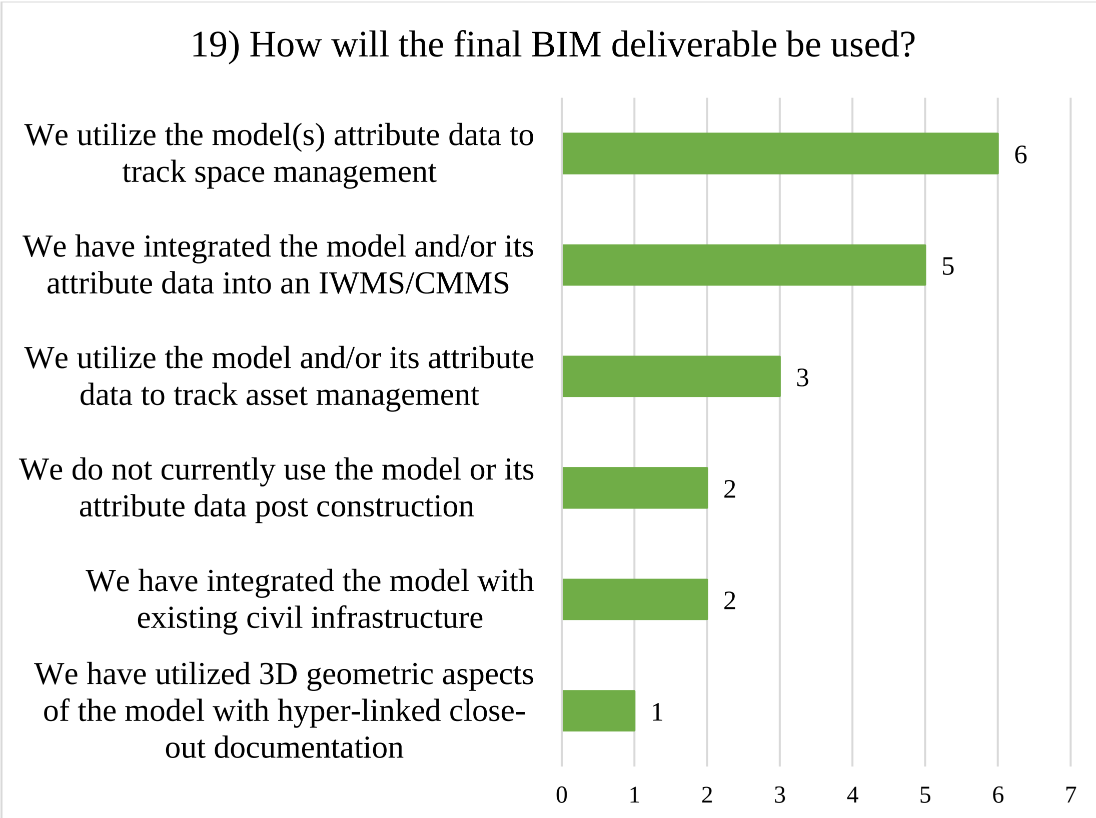

Figure 42. Question 19 for college/university with 1-3 dedicated BIM roles

Building documentation (i.e. asset data and visual data) is not always collected on a project. This question asked participants to identify what the organization has experienced pertaining to building documentation not being collected. Three participants input a response and did not select any other option. The input responses are as follows:

- "Requirement not clearly stated in contracts."
- "Because our procurement are not aware of BIM requirements"
- "campus Project Managers do not follow through on enforcement of handover"

One participant input a response, "project manager knowledge," as well as selected two answer choices. The two choices selected were, cost of services, equipment, and/or resources seem too high and to ensure on time/schedule delivery. The frequencies for all answer choices are as shown in the graph.

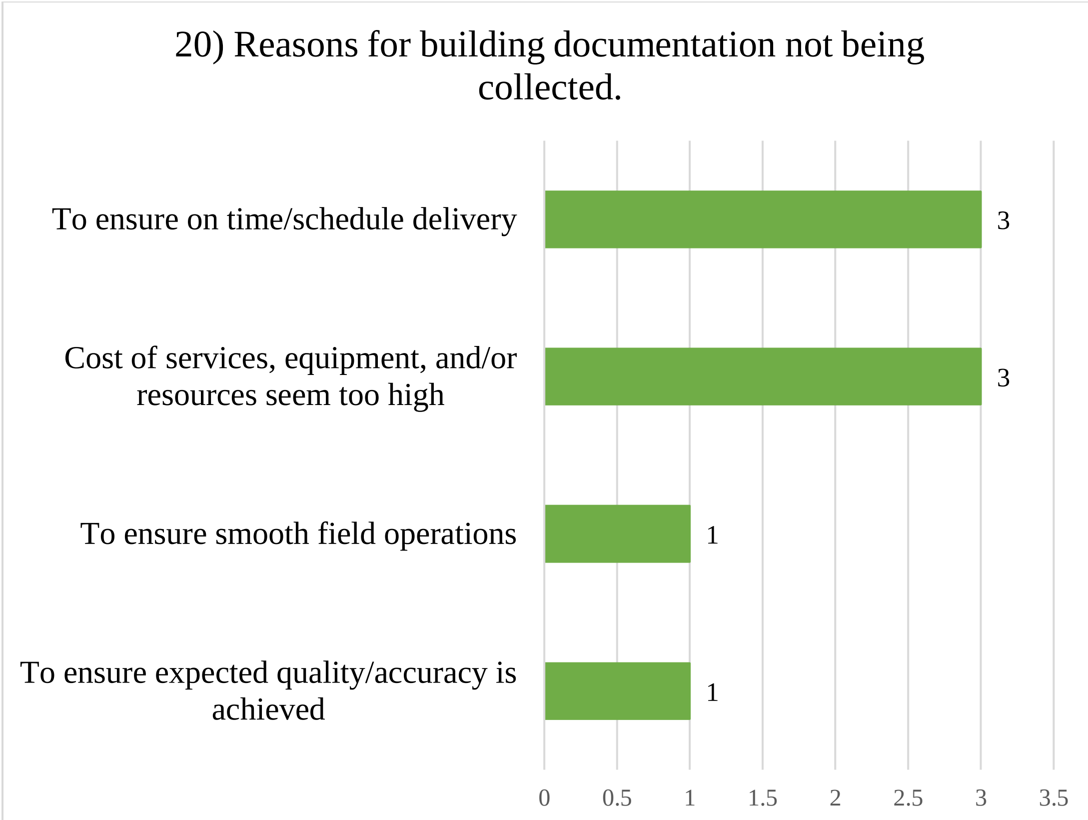

Figure 43. Question 20 for college/university with 1-3 dedicated BIM roles

Participants were then asked how much time is spent after handover organizing the BIM data to make it useable. The highest frequent category was found to be 1-3 months. This is exciting as the literature review noted several times that FM teams are often required to spend twice as long to make data useable for the organization. With the organizations having 1-3 dedicated BIM roles the times selected could decrease if the project is not extremely large. The frequencies are illustrated in the graph

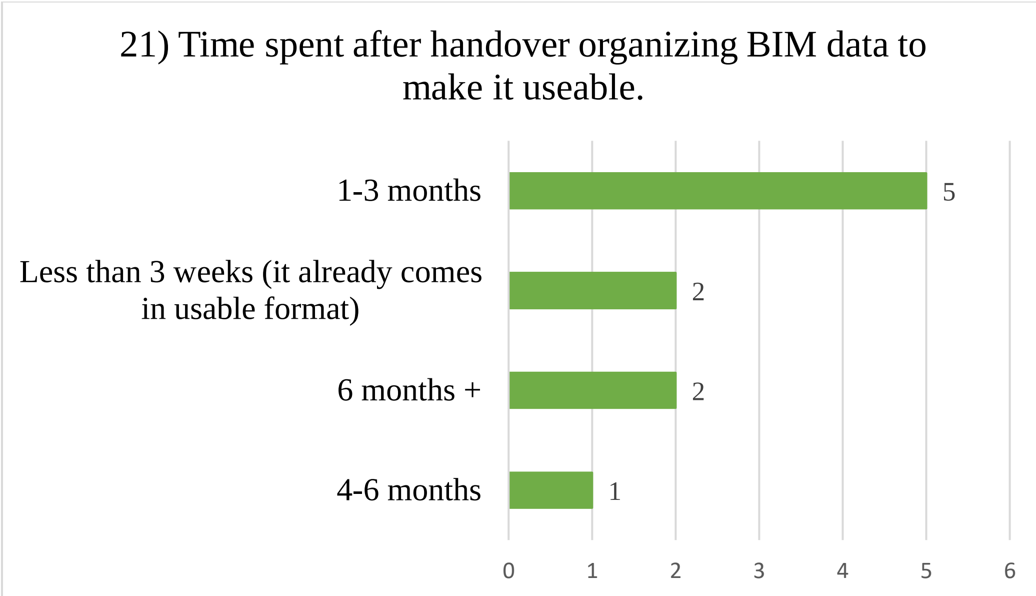

Figure 44. Question 21 for college/university with 1-3 dedicated BIM roles

The last question within the FM section asked participants to rate the importance of BIM uses for the O&M phase. The uses were rated based on being not important, somewhat important, very important, extremely important, and “I am not sure.”

The following graph illustrates the rating and use for each category.

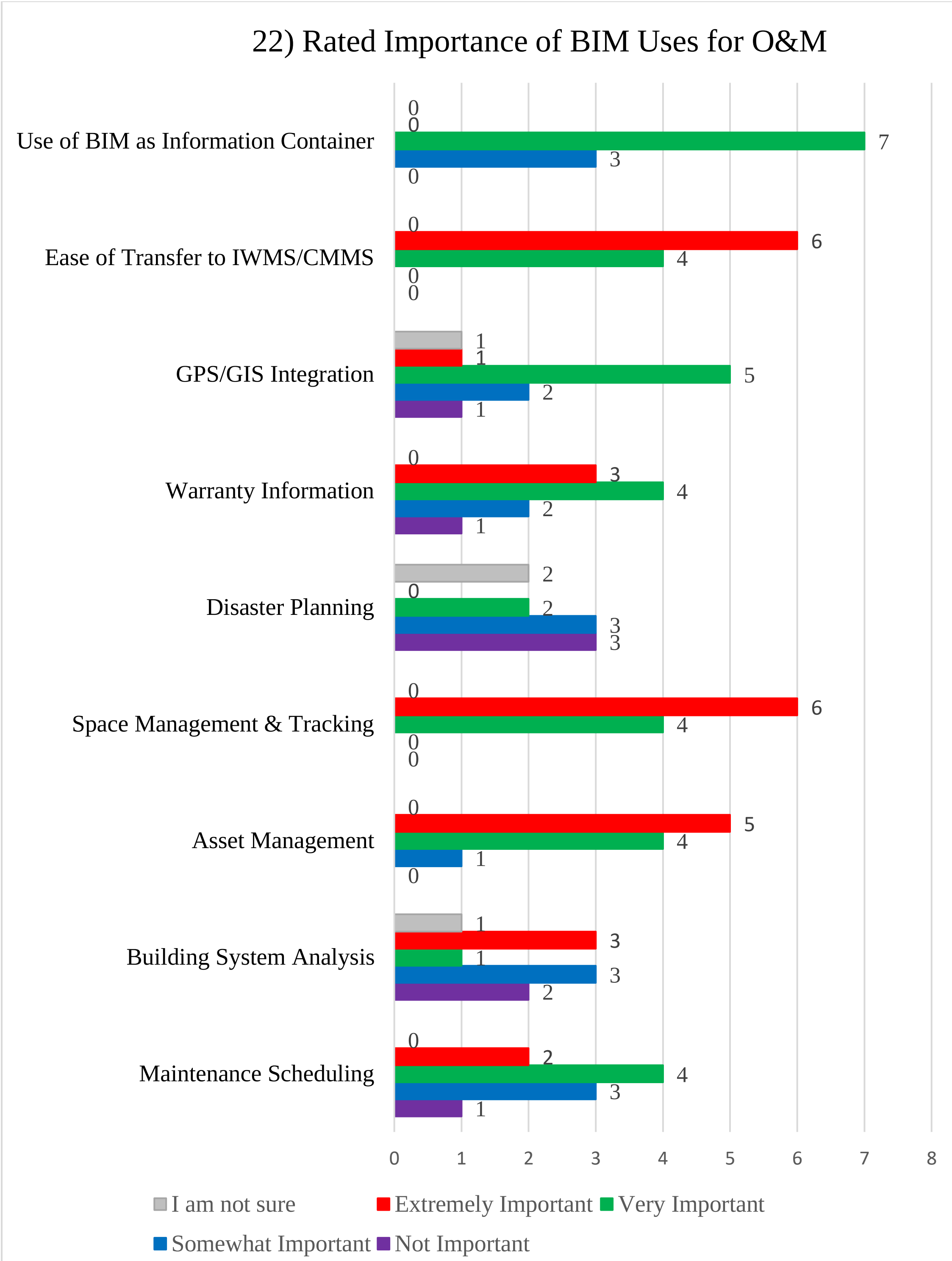

Figure 45. Question 22 for college/university with 1-3 dedicated BIM roles

The next section of the survey investigated was the Visualization and Asset Management section. The first question asked participants which visual data is useful to O&M staff. The frequencies are shown in the graph.

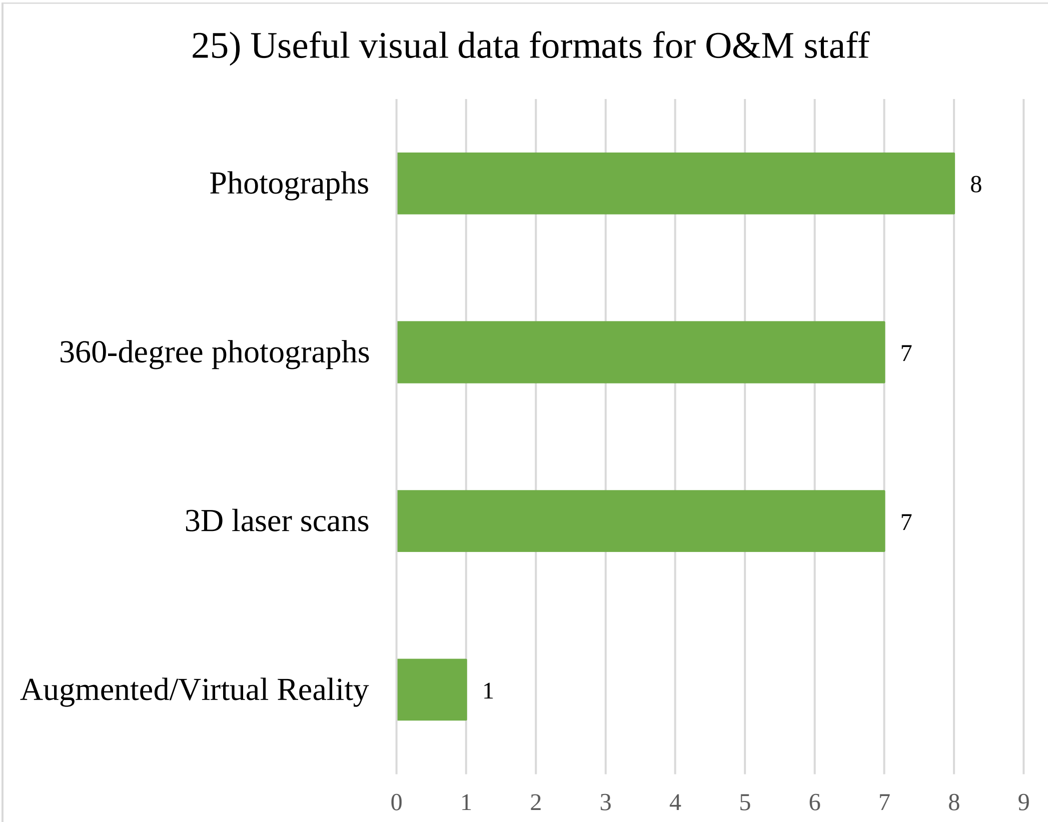

Figure 46. Question 25 for college/university with 1-3 dedicated BIM roles

All of the participants organizations collect visual data in some form. Eight of the 10 utilize photographs. The 2 not using photographs utilize 360-degree photographs or 3D laser scans. The highest frequency category was photographs, with 360-degree photographs and 3D laser scanning being tied for second. Only two participants selected one answer choice, either photographs or 360-degree photographs. Three participants selected two visual data formats, photographs, and/or 360-degree photographs, 3D laser scans. Five participants selected 3 formats, photographs, 3d laser scans, and/or 360-degree photographs, augmented/virtual reality.

Augmented/virtual reality was only selected by one participant, who also selected photographs and 3D laser scans.

Participants where then asked what visual data formats are required by the organization and from whom they are provided by. The visual data formats were, photographs, 360-degree photographs, 3D laser scans, and augmented/virtual reality. The providers of said visual data were from the design team, construction team, an outside contract, or collected internally by the organization. Only 2 participants receive augmented/virtual reality, which is provided by the design team. Photographs are most provided the most by the construction team, as well as being the most used visual data format. 3D laser scans are the second most used format of the provided options with 360-degree photographs as third. The following graph illustrates the frequencies for each provider and visual data format.

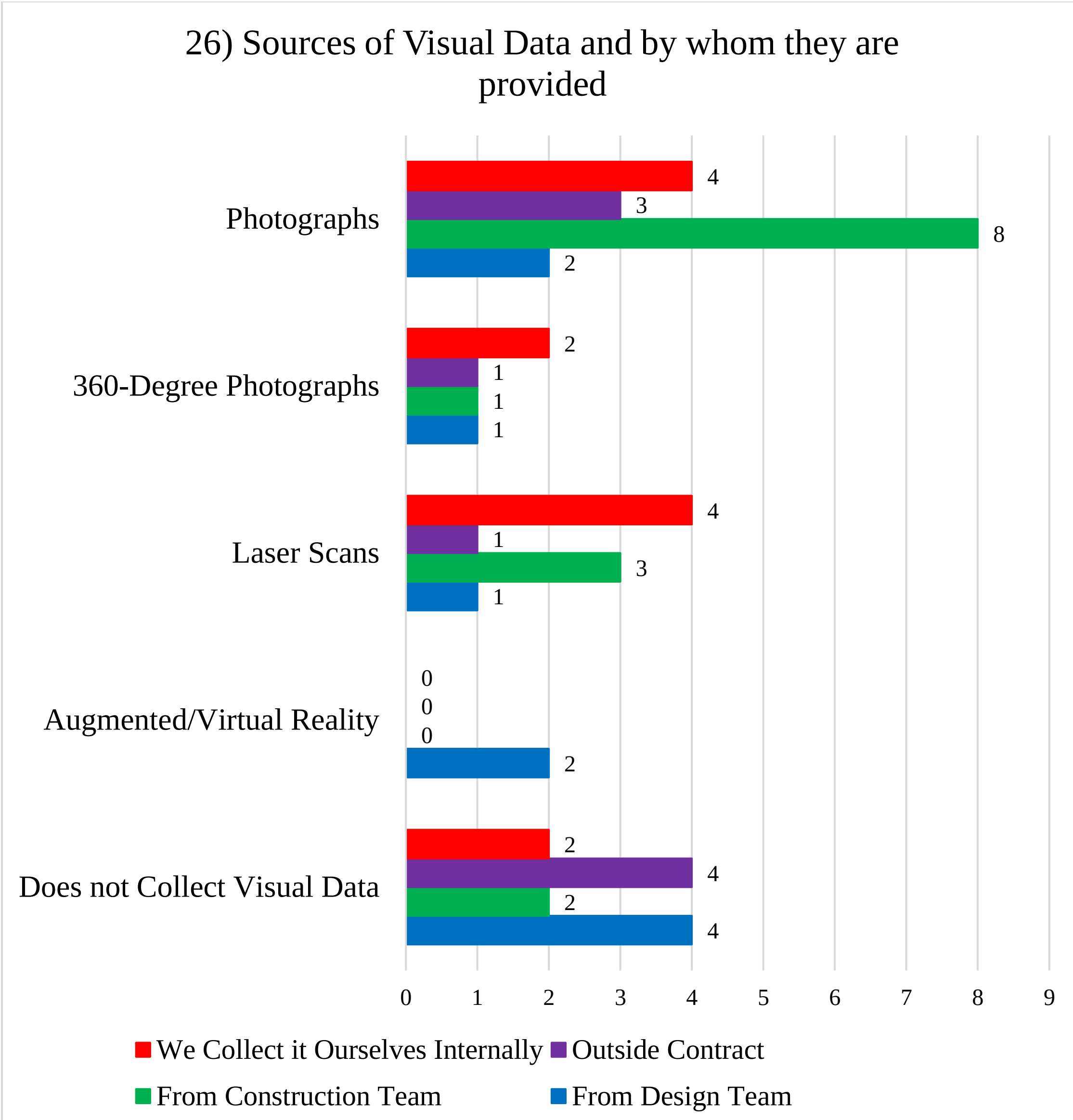

Figure 47. Question 26 for college/university with 1-3 dedicated BIM roles

Participants were asked if the organization uses a nomenclature (like: bldg._Plbg_Pump_01_02) or similar to name assets. The frequencies are shown in the graph.

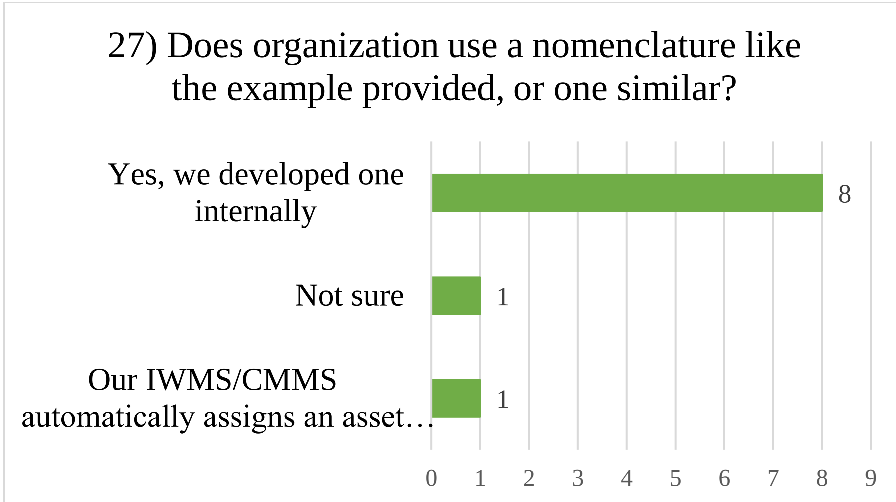

Figure 48. Question 27 for college/university with 1-3 dedicated BIM roles

Next, participants were asked where the organization names (or assign nomenclature to) assets. As with other questions, some participants selected multiple answer choices. These participants selected BIM file and in IWMS and/or CAFM. Seven participants selected only one location. The frequencies are illustrated in the graph.

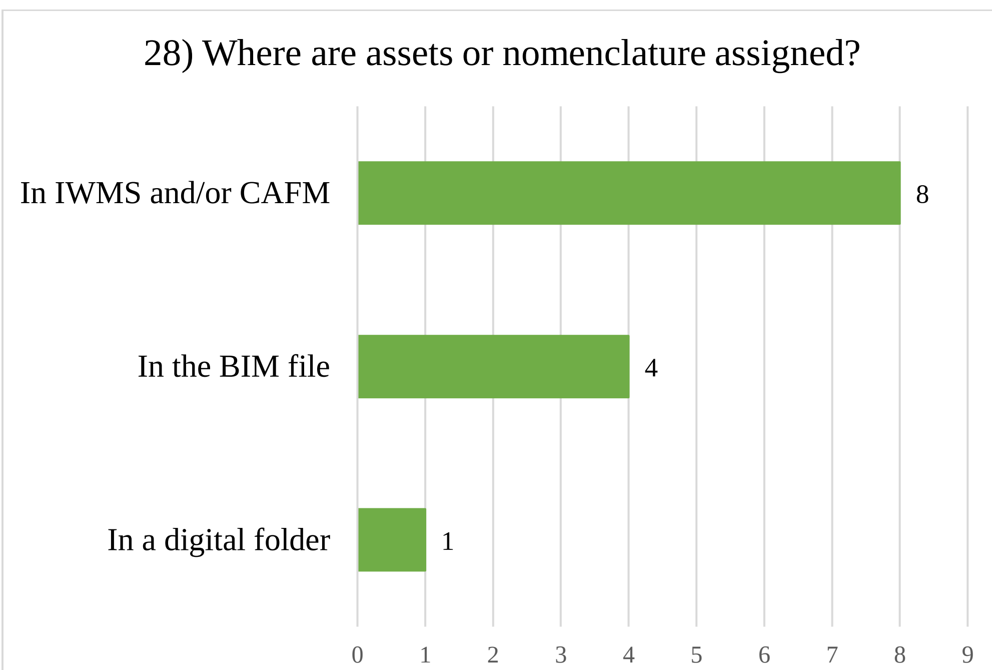

Figure 49. Question 28 for college/university with 1-3 dedicated BIM roles

The last question asked participants their role within the organization. One participant input a response, “FCAP.” Another input a response, “Director, Leader” along with selecting operations and maintenance. The frequencies for the categories are shown in the graph.

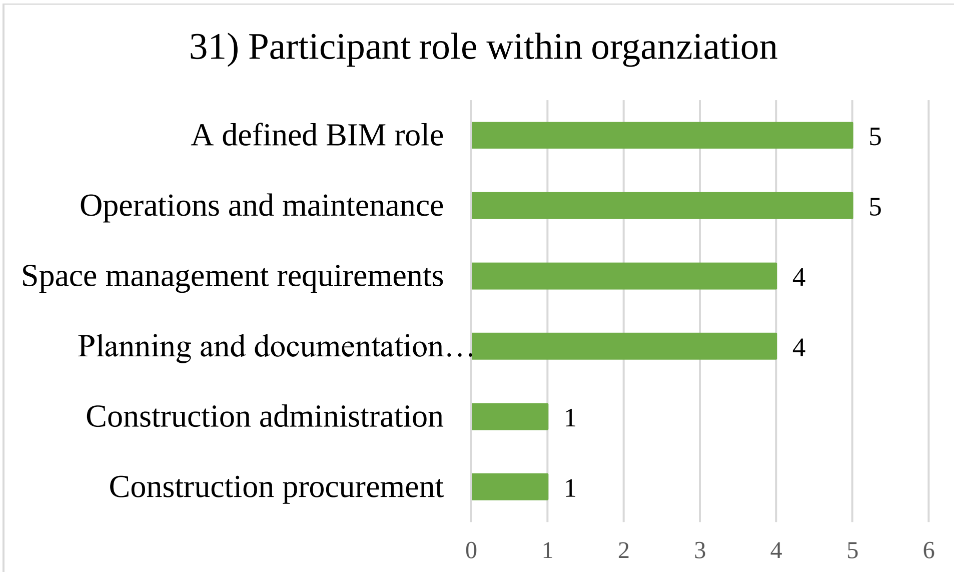

Figure 50. Question 31 for college/university with 1-3 dedicated BIM roles

For the FM sector to successfully implement BIM the literature review noted the importance of having a dedicated BIM staff member. This was recommended as the model must be continuously updated, the data checked for accuracy and completeness, as well as someone who knows the BIM processes and requirements well.

Participants were also given the opportunity to provide comments if so desired. Two participants provided feedback.

- “Let us know if you need further information as follow-up. Good luck.”
- “I hope these responses are helpful. I have only recently come online to help UVA manage BIM in hopes of improving services for UVA and AEC consultants.”

The last chosen option of dedicated BIM roles within an organization analyzed was 4-6. Only one participant chose this option. When asked what types of leadership roles were required for BIM-assisted projects, the participant selected BIM coordinators for each technical trade and discipline. This organization uses BIM on 75% of projects. When asked what provisions the organization has made to assist in implementing BIM, the participant selected education and training to improve all staff members' proficiency in BIM. The obstacle chosen slowing BIM adoption was identified as lack of trained in-house personnel. The last question pertaining to BIM personnel and requirements asked what BIM requirements were created by the organization. The participant chose QA/QC procedures for checking deliverables.

The next section of the survey contained questions pertaining to construction deliverables. The first question of this section asked how asset data is collected and/or checked during construction. The organization uses BIM360 spreadsheet (native inside BIM360). Handover deliverables are requested in the formats of a BIM model and Navis file. BIM deliverables mandated by the organization at construction handover were a populated spreadsheet (manually or via BIM360) from contractor. Model reviews for coordination and QA/QC from the designer are required after the project is complete. The participant noted that the organization sends deliverables to an external auditor/consultant to check the model as a QA/QC procedure. When asked to describe the format most used by maintenance and FM staff for referencing building data needs, post-construction, the participant selected IWMS or CAFM. Floor plans are used post-construction by the organization via a link to IWMS and/or CAFM. The participant was then asked how the final BIM deliverable will be used, post-construction. The participants organization integrates the model and/or its attribute data into an IWMS/CMMS.

The participant was asked what the most common reason for asset data and visual data not being collected on a project. To ensure expected quality/accuracy is achieved was chosen. The next question asked how much time is spent after handover organizing BIM data to make it useable. The participant selected 6 + months. Within the FM section of the survey, the last question asked the participant to rate the importance of BIM uses in the O&M phase. The ratings for uses are as follows:

- Maintenance scheduling – extremely important
- Building systems analysis – extremely important
- Asset management – extremely important
- Space management and tracking – extremely important
- Disaster planning – extremely important
- Warranty information – extremely important
- GPS/GIS integration – extremely important
- Ease of transfer to IWMS/CMMS – extremely important
- Use of BIM models as an information container – very important

The next section of the survey analyzed was Visualization and Asset Management. The first question asked what type of visual data is useful for the O&M staff. The participant selected augmented/virtual reality. The second question of this section asked which visual data formats are requested and by whom. The participant noted the organization collects 360-degree photographs from the design team and photographs from the construction team. Additionally, the organization collects augmented/virtual reality internally. The participant noted that the organizations IWMS/CMMS automatically assigns an asset number like bldg._Plbg_Pump_01_02 or similar for naming assets. The organization also named (or assigns nomenclature to) assets in IWMS and/or CAFM. Lastly, the participant was asked to select the answer choices best describing their role within the organization. Six answer choices were selected, construction procurement, construction administration, space management requirements, operations and maintenance, planning and documentation, and a defined BIM role.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Survey analysis was conducted on individual questions for all recorded surveys, for only college/university as the organization type, for 100% BIM use, and organizations not currently requiring BIM. When comparing those **not requiring BIM** and participants selecting 100% BIM use it is easily seen why those using BIM on all projects are more successful adopters. Twelve participants selected the option for **not currently requiring BIM.** Nine (75%) selected that they have no dedicated BIM personnel, 3 (25%) participants chose 1-3 dedicated BIM personnel when asked how many people within the organization have dedicated BIM roles. When asked about adopted leadership roles to assist on BIM projects, 7 (58%) participants chose none and 2 (17%) chose the options for not sure. One participant input, “BIM not yet used” and another input, “We have provisions to receive BIM models, but did not have internal people or processes to take advantage of those deliverables until 8 months ago. We now have a BIM Project Manager (me) to define project protocols, receive and process models, and to develop strategies for using BIM moving forward.” Only 1 participant chose an option for leadership roles adopted to assist on BIM projects, which was having a team member focusing on managing assets. Examining the results for 100% BIM use of the same questions, all 100% of the organizations have adopted a project BIM manager to assist in construction administration. Four (67%), also adopted BIM coordinators for each technical trade and a team member focusing on managing assets.

All 6 organizations adopted BIM/VDC requirements or specification. Five (84%) also adopted asset lists and education and training to improve all staff members’ BIM proficiency. Four options had a selection rate of 67%, revised contractual agreement addressing BIM processes, a trained staff member dedicated within the organization to manage BIM procedures, and owner driven requirements or documented standards. Colleges/University's utilizing BIM adopted those same provisions along with a trained staff member responsible for managing assets. None of the **organizations not requiring BIM** currently adopted BIM/VDC requirements or specifications, revised contractual agreements addressing BIM, or education/training to improve all staff members' BIM proficiency. No specific provisions was the answer selected by 84% of participants **not using BIM**. Only 1 participant selected 1 option, asset lists. The last participant selected asset lists, trained staff member dedicated within organization to manage BIM procedures, and owner driven BIM requirements or documented standards.

Organizations using BIM on all projects adopted at least 2 BIM requirements. Two (33%) participants selected all 11 options provided for BIM requirements adopted. Two (33%) participants selected 8 of the 11 options, with, model progression specifications, interoperability/file sharing procedures, model management procedures, required construction handover deliverables, roles/responsibilities of each stakeholder pertaining to BIM processes, and when/how the model must be used as common selections. Only 1 participant selected a single option, model sharing and reliability protocols. The 3 options with the highest frequency (83%) for organizations using BIM on all projects were, model management procedures, role/responsibilities of each stakeholder regarding BIM processes, and when/how the model must be used.

Analyzing the 12 organizations that are **not requiring BIM** at this time found that 7 (58%) have no contractual agreements regarding BIM processes. One participant only input, "At this time, we are backing into BIM by experimenting with GIS. That database is managed by a GIS contractor to our University. If you think of it as "macro", we imagine facilities BIM integration will be "micro" databasing that we will back into (eventually). Large new project designers use BIM and share it, but we do not have facilities to tap the models nor the expertise to manage them---yet." Another participant selected only O&M/FM data requirements for the model. The remaining 3 selected at least 4 of the options pertaining to model progression specifications, model sharing protocols, interoperability, model management procedures, intellectual property rights, O&M/FM data requirements, QA/QC procedures, technology infrastructure, and construction handover deliverables. The option with the highest frequency among organizations **not requiring BIM** was O&M/FM data requirements for the model, which was chosen by 33% of the participants. Interoperability/file sharing procedures was the second highest frequency option chosen by 25% of participants.

When asked how asset data is collected during construction, 5 organizations (42%) **not currently using BIM** do not track asset data during construction. Six organizations (50%) organizations track asset data during construction with Excel spreadsheets. One participant input, "Assetworks (AiM)." Once again, the results varied greatly from organizations using BIM on all projects. Four (67%) track asset data during construction with Excel spreadsheets, 2 (34%) use BIM360 spreadsheets, 1 selected asset data is not tracked during construction. For the remaining two, 1 chose internal mobile platform along with BIM360 spreadsheet and Excel spreadsheet. The remaining participant responded, "We currently provide low level data check as a part of our services. The asset data checks are not specifically part of our requested scope."

When asked what handover deliverable formats are requested by the organization, analysis of organizations **not using BIM** on any projects found that paper and electronic were each chosen the most by 58% of participants. Spreadsheet had the second highest frequency at 42%). Six (50%) chose 2 or more formats. Options receiving only 1 selection were internally developed schema and BIM model. One participant input, “For everything: mylars and dwgs. Approved shop drawings: paper or digital. Our trade shops have been using Assetworks only for about 3-4 years to any practical effect.” Options receiving no selections were COBie schema, IFC format, Navis file, and Visual (360-degree photographs, 3D laser scans, etc). Analyzing formats requested for handover deliverables by organizations using BIM on all projects found, electronic to have the highest frequency (83%), followed by BIM model and Navis file (67%) tying for second. Five (83%) participants selected 2 or more formats. Two (33%) participants selected Visual (360-degree photographs, 3D laser scans, etc.), which is significant as there is minimal research (if any) that quantifies the requests for visual data (aside from BIM visuals). COBie schema was the only option receiving 1 selection. IFC format and internally developed schema did not get selected.

All organizations using BIM 100% selected as-built models from the design team. Five (84%) also selected record models from the design team. Four (67%) added to that and also selected as-built models from the construction team. Only 1 participant selected only 1 option, as-built models from the design team. One participant selected as-built models and record models from the design team, along with inputting, “Data upload to BIM360 Ops.” When asked what BIM deliverables are mandated by the organization, 25% of the college/university’s collect at least 3 of the 4 options provided. As-built models provided by the construction team had the highest frequency at 8 with record models from the design team a close second with a frequency of 7. Analysis of **organizations not requiring BIM** found that 75% of organizations have no specific model deliverables mandated. Only 1 participant selected multiple options, record models from design team, as-built models from construction team, and a populated spreadsheet from contractor. Two participants selected only 1 option, as-built models from design team.

Collection of BIM deliverables requires QA/QC procedures to verify the data is complete and needed. When asked what QA/QC procedures are used by the organization (**not currently requiring BIM**), 7 (58%) participants selected no specific QA/QC provisions. Three (25%) participants did not answer this question. One participant selected the option for sending the deliverables to an external auditor/consultant to check the model. The remaining participant selected the option for having designated staff member(s) responsible for model management and QA/QC.

For organizations using BIM on all projects, 2 (33%) participants selected 2 or more QA/QC procedures. Having a designated staff member(s) responsible for model management and QA/QC, conducting interference checks to coordinate different stakeholders' models, and element validation is performed to ensure all model objects are defined all tied with the highest frequency of 33%. Two (33%) participants selected only the option for having no formal QA/QC procedures and 1 selected that option along with having interference checks to coordinate different stakeholders' models. The remaining participant using BIM on all project selected only the option for having a designated staff member(s) responsible for model management and QA/QC. Ten (63%) of the 16 college/universities have at least 1 QA/QC process. The highest frequency (44%) option for college/universities was found to be having a designated staff member(s) responsible for model management and QA/QC, followed by conducting interference checks to coordinate different stakeholders' models (19%).

The next question asked what format is most used by maintenance and FM staff to reference building data needs. Staying with organizations **not currently requiring BIM** on any projects, analysis found that 3 participants did not answer this question. Four (33%) participants selected only 1 option. The highest frequency (67%) option was CAD drawings, hard copy was second at 42%, followed by floor plans imported into CMMS (33%). Moving to organizations using BIM on all projects, four (67%) find 2 or more formats useful. Two organizations (40%) find 3 formats useful, all selecting the option for floor plans imported into CMMS. One participant works for FM consultants meaning this question does not apply. Revit and floor plans imported into CMMS were selected 3 times each. IWMS/CMMS was selected only once, followed by hard copy and CAD drawings being selected only twice.

Analysis of when the final BIM deliverable will be used post-construction found that of the organizations **not using BIM currently**, 58% do not use the model and/or its attribute data post-construction. One participant selecting the model and/or its attribute data is not used post-construction also selected the options for utilizing 3D geometric aspects of the model with hyper-linked close-out documentation and utilizing the model and/or its attribute data to track asset management. The other participant selecting the option for not using the model and/or its attribute data post-construction input, “models currently not in use, but plan to integrate into GIS, CAFM, and maintain for distribution of existing condition records.” Three (25%) participants did not answer this question. The options specifying uses of the model and/or its attribute data post-construction were for 3D geometric aspects of the model with hyper-linked close-out documentation, to track asset management, and to track space management. Lastly, one participant selected the option, “I am not sure.”

Examination of organizations using BIM on all projects found a significant difference in results. One participant selected the option for not currently using the model or its attribute data post-construction. Four (80%) of the 5 using the final BIM deliverable, utilize it in at least two ways, with utilizing the model and/or its attribute data to track asset management having the highest frequency (67%). The second highest frequency (50%) option was utilizing the model’s attribute data to track space management. Only 1 participant selected one option, which was to track asset management. The organizations using the final BIM deliverable to track asset and/or space management rated the importance of BIM uses in the FM stage as very important or extremely important for a majority of responses (87%). **Organizations not using BIM** currently showed different results. Three (25%) participants did not answer the question. One participant selected "I am not sure" for each of the 8 BIM uses in the O&M stage. The remaining participants selected "I am not sure," not important, or somewhat important for 61% of the BIM uses for O&M functions. Examining the college/university responses, 72% will use the final BIM deliverable, with the utilization of attribute data to track space management and integrating the model into an IWMS/CMMS tying in first with the highest frequencies.

The question asking which visual data formats most useful to O&M staff was analyzed next. Only 1 participant which selected BIM use on all projects did not answer this question. Of the 5 participants that did answer and did not choose the option for not collecting visual data, 80% selected 2 or more formats. 3D laser scans had the highest frequency (80%), followed by photographs and 360-degree photographs which tied for second with 60%. AR/VR had the lowest frequency at 33%. **Organizations not requiring BIM** on any projects found the following formats useful, photographs (50%), 360-degree photographs (25%), and 3D laser scans and AR/VR tied at 8%. Only 3 (25%) participants selected 2 formats.

Visualization tools such as 360-degree photographs and AR/VR can be paired with BIM or used as stand-alone technologies. One 360-degree photograph can show a FM technician what equipment is in a mechanical room. 360-degree cameras are light weight, easily transported, and require no formal training to operate. Visualization tools can also be used to document the elements located within a wall. NavisWorks has a plug-in which allows for BIM information to be matched to the related 360-degree image. There are many visualization technologies available to assist FM in performing their daily functions and many of the technologies can improve productivity. Indications from the survey show that many owners understand that visual information is extremely valuable (over 60%) and responses show that almost all of those requested this type of visual specially in their contract language. The importance of this information is that there is minimal research (if any) that quantifies the requests for visual data (aside from BIM visuals).

What visual data required and from whom are they obtained was analyzed next. For **organizations not requiring BIM currently**, very little visual data is required. Four (33%) of participants did not answer this question. The only visual data requested from the design team were photographs (25%) and 3D laser scans (16%). The only required visual data obtained from the construction team were, photographs (50%), 360-degree photographs (16%), and 3D laser scans (16%). Photographs (25%) were the only visual data requested and obtained from outside contracts. Photographs (50%) and 3D laser scans (25%) were the only formats collected internally. Organizations using BIM on 100% projects request more visual data. One participant did not answer this question, so the results are based on the 5 participants that did answer. From the design team, photographs (33%), 3D laser scans (33%), AR/VR (33%), and 360-degree photographs (16%). From the construction team, photographs (33%), 360-degree photographs (33%), and 3D laser scans (50%) are requested and obtained. Obtained from outside contracts found the following, photographs (50%), 360-degree photographs (33%), 3D laser scans (33%), and AR/VR (17%). Additionally, all visual data options were collected internally, photographs (67%), 360-degree photographs (33%), 3D laser scans (17%), and AR/VR (33%).

Two (33%) of the organizations using BIM on all projects developed a naming convention for assets internally. One participant selected the option for having a consultant developing the naming convention. One participant did not answer, as the participant works for a FM consultant company. The remaining 2 input, “Mixture of consultant and internal development” and “We are trying to implement one.” When asked where the asset and/or nomenclature is assigned, 67% selected BIM file, 17% selected in IWMS and/or CAFM. The participant working for a FM consultant did not answer, as the question does not apply. **Organizations not using BIM currently** analysis for these questions found that 3 (25%) are not sure if the nomenclature was developed internally or by a consultant. Two (17%) organizations do not have a naming system. Three (25%) did not answer this question and 25% developed the naming system internally. None of the **organizations not requiring BIM** currently assign the name in the BIM file. Three (25%) assign the name in a digital folder and 17% assign the name in the IWMS/CAFM. Three (25%) input a response, “CMMS,” “database,” and “General Inventory.”

After conducting the literature review and analyzing the survey results, a list of recommendations will be offered to UNCC FM Department. BIM is a process and cannot be successfully adopted overnight. UNCC should use BIM an all possible projects, document lessons learned, and identify processes that work best with organizational structure of UNCC. Additionally, BIM processes should be continuously updated and modified to produce optimum results. Literature states that the BIM manager and FM team should be actively involved from the start of the project. Including both early in the project will ensure the design will be maintainable, ensure the required data will be collected, and allow BIM to be used analysis (i.e. energy analysis and/or design analysis).

Clearly defining all data requirements will assist in complete and accurate data collection. The use, storage, and access of the data will need to be defined as well. Establish BIM requirements and stick to them (i.e. model sharing and reliability protocols, QA/QC processes to check deliverables, and required construction handover deliverables). Project stakeholders should be aware of when project deliverables are to be provided, the proper format for the deliverables, and what data should be included. Project stakeholders should be held accountable for not meeting any requirements laid out by the Owner. Additionally, the Owner should be actively involved in all project stages to ensure all project requirements are achieved. The FM team having the technical knowledge of installed systems should also be actively involved, which will support the project documents focusing on Owner requirements rather than designer's agenda. One participant in the survey input, "Record documents are required, the PM leadership fails at not placing responsibility into the contract, as to who is responsible for update and turnover." This is a case of not having requirements clearly defined in the contract and lack of holding stakeholders accountable for their actions and neglecting their responsibilities.

Asset data should be collected and tracked throughout the project. Waiting until the project is ending causes data loss and being provided inconsistent and incomplete data. A designated staff member should be responsible for checking the data collected/tracked to ensure it is consistent and meets established data standards. BIM standards will also need to be developed to promote easy integration of stakeholder models. If stakeholders use different standards, additional issues will arise when the BIM manager integrates the various models into one federated model, which can lead to expending more cost and time resources. When creating BIM standards include modifications to be performed, such as, removing irrelevant data. BIM can be used as an information container. Take advantage of this ability. Data required for asset management, space management, maintenance scheduling, building system analysis, and ease of transfer to IWMS and/or CAFM.

Some questions had wording that several participants commented on, calling it "odd wording." Perhaps if certain questions, such as the question asking about provisions the organization made to assist in implementing BIM, more participants would have answered it. For that question specifically some participants selected options for provisions and the option for no specific provisions made. The questions pertaining to naming assets/nomenclature and where the organization names them did not flow with the survey well. These questions were important as having a proper naming system aids in FM functions. Additionally, if more mature owners had participated in the survey, questions inquiring about naming systems could have received a higher response rate. One participant provided the following feedback:

- "Your survey assumes my firm (university in this case) is at least conversant with BIM/GIS to the point where we have some rules and regulations for using it. We aren't there yet, but we are interested in it because we know it represents the future."
- "The survey asks about how records are kept within the organization, what kinds of records, and what is or is not required in BIM models, these could not be answered without explaining the organization's position in its complete context."

The survey could have also excluded some participants as the wording implied assumptions of participants. The first feedback response verifies this as the participant stated that the survey assumes participants are "at least conversant with BIM/GIS."

The wording of the survey also prohibited detailed data analysis from being conducted. When in-depth data analysis was attempted (per Ch. 3 METHODOLOGY) it was discovered that the results would need significant rework to enable a detailed statistical analysis. The deadline for the research would not permit the rework for inclusion into this document. However, the rework will be conducted, and statistical data analysis will be provided in a journal article.

REFERENCES

Access To BIM Data Improves Facility Management Operations. (n.d.). Retrieved August 9, 2020, from https://facilityexecutive.com/2018/11/improving-facility-management-through-bim-data/

Adán, A., & Huber, D. (n.d.). *Reconstruction of Wall Surfaces Under Occlusion and Clutter in 3D Indoor Environments*. 34.

Adan, A., & Huber, D. (2011). 3D Reconstruction of Interior Wall Surfaces under Occlusion and Clutter. *2011 International Conference on 3D Imaging, Modeling, Processing, Visualization and Transmission*, 275–281. https://doi.org/10.1109/3DIMPVT.2011.42

Allen, R. K., Becerik, B., Pollalis, S. N., and Schwegler, B. R. (2005). "Promise and barriers to technology enabled and open project team collaboration." *J. Prof. Issues Eng. Educ. Pract.*, 131(4), 301–311.

American Institute of Architects - Committee on Integrated Practice. *Report on integrated practice*, American Institute of Architects, Washington, DC.

Alsyouf, I. (2007). The role of maintenance in improving companies' productivity and profitability. *International Journal of Production Economics*, *105*(1), 70–78. https://doi.org/10.1016/j.ijpe.2004.06.057

American Institute of Architects - Committee on Integrated Practice. (2006). *Report on integrated practice*, American Institute of Architects, Washington, DC.

Associated General Contractors of America (2005) *The Contractor's Guide to BIM*, 1st ed, AGC Research Foundation, Las Vegas, NV

Anderson, A., Marsters, A., Dossick, C. S., & Neff, G. (2012). Construction to Operations Exchange: Challenges of Implementing COBie and BIM in a Large Owner Organization. *Construction Research Congress 2012*, 688–697. https://doi.org/10.1061/9780784412329.070

Anil, E. B., Akinci, B., & Huber, D. (2011, June 29). *Representation Requirements of As-Is Building Information Models Generated from Laser Scanned Point Cloud Data*. 28th International Symposium on Automation and Robotics in Construction, Seoul, Korea. https://doi.org/10.22260/ISARC2011/0063

Anumba, C., et al. (2010). *The BIM project execution planning guide and templates—version 2.0*, CIC Research Group, Dept. of Architectural Engineering, Pennsylvania State Univ., University Park, PA.

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): Now and beyond. *Construction Economics and Building*, *12*(4), 15–28. https://doi.org/10.5130/AJCEB.v12i4.3032

Autodeck, (2003). *Building information modeling,* Autodesk, San Rafael, CA.

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application Areas and Data Requirements for BIM-Enabled Facilities Management. *Journal of Construction Engineering and Management*, *138*(3), 431–442. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000433

Bentley, K., and Workman, B. (2003). *Does the building industry really need to start over? A response from Bentley to Autodesk*'*s BIM/Revitproposal for the future,* Bentley Systems, Exton, PA.

Bernstein, H. M., et al. (2010). *The business value of BIM in Europe*, McGraw-Hill Construction, Bedford, MA

BIM: Who, what, how and why. (n.d.). Facilitiesnet. Retrieved August 25, 2020, from https://www.facilitiesnet.com/software/article/BIM-who-what-how-and-why--7546

BIM-FM-Consortium-BIM-Guide-v2_1.pdf. (n.d.). Retrieved August 7, 2020, from https://it.ifma.org/wp-content/uploads/2019/04/BIM-FM-Consortium-BIM-Guide-v2_1.pdf

Bonett, D. G., & Price, R. M. (2012). Adjusted Wald Confidence Interval for a Difference of Binomial Proportions Based on Paired Data. *Journal of Educational and Behavioral Statistics*, *37*(4), 479–488. https://doi.org/10.3102/1076998611411915

Bosch, A., Volker, L., & Koutamanis, A. (2015). BIM in the operations stage: Bottlenecks and implications for owners. *Built Environment Project and Asset Management*, *5*(3), 331–343. https://doi.org/10.1108/BEPAM-03-2014-0017

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, *31*(7), 971–980. https://doi.org/10.1016/j.ijproman.2012.12.001

BSI (2008). PAS55:2008-1:2008. *Specification for the optimized management of physical assets.* British Standards Institution.

Business-value-of-bim-for-owners-smr-2014.pdf. (n.d.). Retrieved August 8, 2020, from https://group.skanska.com/48f2cd/siteassets/about-us/building-information-modeling/business-value-of-bim-for-owners-smr-2014.pdf

Carmona, J. and Irwin, K. (2007) ‘BIM: Who, What, How and Why’, *Building Operating Management*, October 2007

Cavka, H. B., Staub-French, S., & Poirier, E. A. (2017). Developing owner information requirements for BIM-enabled project delivery and asset management.*Automation in Construction*, *83*, 169–183. https://doi.org/10.1016/j.autcon.2017.08.006

Cavka, H. B., Staub-French, S., & Pottinger, R. (n.d.). *EVALUATION OF ORGANISATIONAL CONTEXT AND REQUIREMENTS FOR LEVERAGING BUILDING INFORMATION MODELS TO SUPPORT HANDOVER AND OPERATIONS & MAINTENANCE*. 10.

Cooperative Research Centre for Construction. (2008). *Adopting BIM for facilities management: Solutions for managing the Sydney Opera House*. CRC for Construction Innovation. http://www.construction-innovation.info

Cyon Research Corporation. (2003). *The building information model: A look at Graphisoft*'*s Virtual Building concept, White paper*, Bethesda,M.D

D'Agostino, B., Mikulis, M., and Brdigers, M. (2007). *FMI/CMAA Eighth Annual Survey of Owners: The perfect storm* - *construction style,* FMI Corp./Construction Management Association of America, Raleigh, NC.

de Jong, T. M., & van der Voordt, D. J. M. (2002). *Ways to Study and Research Urban, Architectural and Technical Design*. IOS Press. http://ebookcentral.proquest.com/lib/uncc-ebooks/detail.action?docID=1109540

Dossick, C. S., and Neff, G. (2010). "Organizational divisions in BIM- enabled commercial construction." *J. Constr. Eng. Manage.*, 136(4), 459–467.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). *BIM handbook—A guide to building information modeling for owners, managers, designers, engineers, and contractors, Wiley, Hoboken, NJ.*

Eastman, C., Teicholz, P., Sacks, R. and Kaner, I. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* John Wiley & Sons, Inc.

Eastman, C. M. (1976). "General purpose building description systems." *Comput. Aided Des.*, 8(1), 17–26.

Eastman, C. M., Fisher, D., Lafue, G., Lividini, J., Stoker, D., and Yessios, C. (1974). *An outline of the Building Description System, Research Rep.*l Planning, Carnegie Mellon Univ., Pittsburgh.

El-Omari, S., & Moselhi, O. (2008). Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. *Automation in Construction, 18*(1), 1–9. https://doi.org/10.1016/j.autcon.2008.05.006

J.Frazier, B. Akinci, S. Ergan, An approach for capturing requirements of collaborative design teams to facilitiate evaluation of energy efficient retrofit design options, Proceedings of Architecture Engineering Instititute, 2013.

Gilligan, B., and Kunz, J. (2007). "VDC use in 2007: Significant value, dramatic growth, and apparent business opportunity." Construction Users Roundtable (CURT) National Meeting, Center for Integrated Facility Engineering (CIFE), Stanford Univ., Stanford, CA.

Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Automation in Construction*, *19*(5), 522–530. https://doi.org/10.1016/j.autcon.2009.11.003

Gu, N., and London, K. (2010). "Understanding and facilitating BIM adoption in the AEC industry." Autom. Constr., 19(8), 988–999.

H. Hajian, B. Becerik-Gerber, A research outlook for real-time project information management by integrating advanced field data acquisition systems and building information modeling, Proceedings of the International Workshop on Computing in Civil Engineering, 2009, Austin, USA, 2009.

Hartmann, T. (2008). "A grassroots model of decision support system implications by construction project teams." PhD. dissertation, Stanford Univ., Palo Alto, CA.

Hedmond, S. (2017, August 9). *How 360° Images Take Construction Documentation to the Next Level—Construction Junkie*. Construction Junkie. https://www.constructionjunkie.com/blog/2017/8/8/how-360-images-take-construction-documentation-to-the-next-level

Heydarian, A., Carneiro, J. P., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2015). Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations. *Automation in Construction*, *54*, 116–126. https://doi.org/10.1016/j.autcon.2015.03.020

Hou, L., Wang, Y., Wang, X., Maynard, N., Cameron, I., Zhang, S., & Maynard, Y. (2014). Combining Photogrammetry and Augmented Reality Towards an Integrated Facility Management System for the Oil Industry. *Proceedings of the IEEE*, *102*(2), 204–220. https://doi.org/10.1109/JPROC.2013.2295327

Information Overload: An International Challenge for Professional Engineers and Technical Communicators | Wiley. (n.d.). Wiley.Com. Retrieved November 4, 2020, from https://www.wiley.com/en us/Information+Overload%3A+An+International+Challenge+for+Professional+Engineers+and+Technical+Communicators-p-9781118230138 *International Facility Management* (1st ed.). (2013). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118771686

The Institute of Asset Management, What is asset management?, Accessed 28th May 2013, available at http://theiam.org/what-asset-management 2013.

Joroff, M. L., & Project 2000, C. R. E. (1993). *Strategic Management of the Fifth Resource: Corporate Real Estate*. Industrial Development Research Foundation. https://books.google.com/books?id=bcp9twAACAAJ

Joyce, E. (2012). *Augmented Reality for Facilities Management Leaping Into Use*. https://www.enr.com/articles/8828-augmented-reality-for-facilities-management-leaping-into-use?v=preview

Judge, M. (n.d.). *Introducing Building Information Modeling for Campuses*. Retrieved August 8, 2020, from https://campusinsights.aramark.com/resources-blog/introducing-building-information-modeling-for-campuses

Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, *20*(2), 126–133. https://doi.org/10.1016/j.autcon.2010.09.010

Khemlani, L. (2007b). *Top criteria for BIM solutions: AECbytes survey results, AECbytes Special Report*, ⟨http://www.aecbytes.com/feature/ 2007/BIMSurveyReport.html⟩ (Aug. 1, 2012).

Kiviniemi, A., & Codinhoto, R. (2014). Challenges in the Implementation of BIM for FM—Case Manchester Town Hall Complex. *Computing in Civil and Building Engineering (2014)*, 665–672. https://doi.org/10.1061/9780784413616.083

Korman, T., and Tatum, C. (2006). "Using construction, operations, and maintenance knowledge to better coordinate mechanical, electrical, and plumbing systems in buildings." *Proc., 2006 Architectural Engineering National Conf.,* ASCE, Reston, VA, 1-9.

Kreider, R., Messner, J., and Dubler, C. (2010). "Determining the fre- quency and impact of applying BIM for different purposes on building projects." *Proc., 6th Int. Conf. on Innovation in Architecture, Engineer- ing and Construction (AEC)*, Pennsylvania State Univ., University Park, PA, USA.

Kuo, C.-H., Tsai, M.-H., & Kang, S.-C. (2011). A framework of information visualization for multi-system construction. *Automation in Construction*, *20*(3), 247–262. https://doi.org/10.1016/j.autcon.2010.10.003

Ku, K. and Taiebat, M. (2011) 'BIM Experiences and Expectations: The Constructor's Perspective', *International Journal of Construction Education and Research,* **7** (3), 175-197

Kymmell, W. (2008). *Building information modeling: Planning and managing construction projects with 4D CAD and simulations*. McGraw-Hill.

Laiserin, J. (2003). "The BIM page: Building information modeling - the great debate." *Laiserin Lett.,* (http://www.laiserin.com/features/bim/index.php) (October 29, 2003).

Lee, C.-J., Lee, G., and Won, J.-S. (2009). "An analysis of the BIM software selection factors." *J. Archit. Inst. Korea*, 25(7), 153–163.

Lee, J., Jeong, W., Faghihi, V., & Kang, J. (2013, August 11). *Automatic Generation of COBIE Data from Revit*. 30th International Symposium on Automation and Robotics in Construction and Mining; Held in conjunction with the 23rd World Mining Congress, Montreal, Canada. https://doi.org/10.22260/ISARC2013/0071

Life-Cycle Cost Analysis (LCCA) | WBDG - Whole Building Design Guide. (n.d.). Retrieved November 4, 2020, from https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca

Love, P. E. D., Matthews, J., Simpson, I., Hill, A., & Olatunji, O. A. (2014). A benefits realization management building information modeling framework for asset owners. *Automation in Construction*, *37*, 1–10. https://doi.org/10.1016/j.autcon.2013.09.007

Love, P. E. D., Simpson, I., Hill, A., & Standing, C. (2013). From justification to evaluation: Building information modeling for asset owners. *Automation in Construction*, *35*, 208–216. https://doi.org/10.1016/j.autcon.2013.05.008

Lucas, J., & Addagalla, S. E. (2017). *Building Information Modeling Implementation for Facilities Management on U.S. University Campuses*. 9.

McFarlane, D. (2013). Technical vs. Process Commissioning. *ASHRAE Journal*, 5.

Nitithamyong, P., & M Skibniewski. (2007). KEY SUCCESS/FAILURE FACTORS AND THEIR IMPACTS ON SYSTEM PERFORMANCE OF WEB-BASED PROJECT MANAGEMENT SYSTEMS IN CONSTRUCTION. *ITcon*, *12*, 22.

O'Brien, W. J. (2000). Implementation Issues In Project Web Sites: A Practioner's Viewpoint. *Journal of Management in Engineering*, *16*(3), 34–39. https://doi.org/10.1061/(ASCE)0742-597X(2000)16:3(34)

Patacas, J., Dawood, N., & Kassem, M. (2015). *A framework for the development of Asset Information Models to support Asset Information Requirements throughout the lifecycle of buildings*. 10.

Post, N. (2009) 'Building Team Members See Progress and Problems', *Engineering News-Record*, **22** (12), 28

Prototyping for Tiny Fingers. (n.d.). Brian Donnelly UX. Retrieved November 4, 2020, from https://briandonnellyux.com/blog-summary/2019/11/15/prototyping-for-tiny-fingers

Randall, T. (2011). Construction Engineering Requirements for Integrating Laser Scanning Technology and Building Information Modeling. *Journal of Construction Engineering and Management*, *137*(10), 797–805. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000322

Rebolj, D., Pučko, Z., Babič, N. Č., Bizjak, M., & Mongus, D. (2017). Point cloud quality requirements for Scan-vs-BIM based automated construction progress monitoring. *Automation in Construction*, *84*, 323–334. https://doi.org/10.1016/j.autcon.2017.09.021

Reddy, K. P., & Reddy, K. P. (2012). *BIM for Building Owners and Developers: Making a Business Case for Using BIM on Projects*. John Wiley & Sons, Incorporated. http://ebookcentral.proquest.com/lib/uncc-ebooks/detail.action?docID=817341

Rosenburg, T.L. (2007) *Building Information Modeling*, online at http://www.ralaw.com/resources/documents/Building%20Information%20Modeling%20-%20Rosenberg.pdf

Rubenstone, J. (2012) 'Autodesk Steers Users Toward the Cloud With Expanded Subscription-based Services', *Engineering News Record*, April 16, 2012

Schraven, D., Hartmann, A., & Dewulf, G. (2011). Effectiveness of infrastructure asset management: Challenges for public agencies. *Built Environment Project and Asset Management*, *1*(1), 61–74. https://doi.org/10.1108/20441241111143786

Selzan, D., Mao, C., & Balfour BEatty Construction. (n.d.). *Integration of BIM and Facility Maintenance: What Does the FM Crew Really Need? | Autodesk University*. AutoDesk. Retrieved August 7, 2020, from https://www.autodesk.com/autodesk-university/class/Integration-BIM-and-Facility-Maintenance-What-Does-FM-Crew-Really-Need-2016

Smith, D. K., & Tardif, M. (2012). *Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*. John Wiley & Sons.

Stine, D. J. (2011). *Design Integration Using Revit 2012*. SDC Publications.

StructionSite—Construction Documentation & Project Tracking. (n.d.). StructionSite. Retrieved August 9, 2020, from https://structionsite.com/

Succar, B., & Sher, W. (2014). A Competency Knowledge-Base for BIM Learning. *Australasian Journal of Construction Economics and Building - Conference Series*, *2*(2), 1. https://doi.org/10.5130/ajceb-cs.v2i2.3883

Taylor, J. E., and Levitt, R. (2007). "Innovation alignment and project network dynamics: An integrative model for change." *Project Manage. J.,* 38(3), 22-35.

Thabet, W., & Lucas, J. (2017). Asset Data Handover for a Large Educational Institution: Case-Study Approach. *Journal of Construction Engineering and Management*, *143*(11), 05017017. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001389

The BPEL Cookbook- BPEL with Reliable Processing. (n.d.). Retrieved November 9, 2020, from https://www.oracle.com/technical-resources/articles/qualcomm-bpel.html

The Contractor's Guide to BIM - 2nd Edition. (n.d.). Retrieved November 22, 2020, from https://www.agc.org/news/2010/04/28/contractors-guide-bim-2nd-edition

Welcome to the National BIM Standard—United States | National BIM Standard—United States. (n.d.). Retrieved August 7, 2020, from https://www.nationalbimstandard.org/

Weygant, R.S. (2011) *BIM Content Development*: *Standards, Strategies and Best Practices*, NJ: John Wiley and Sons

William East, E., Nisbet, N., & Liebich, T. (2013). Facility Management Handover Model View. *Journal of Computing in Civil Engineering*, *27*(1), 61–67. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000196

Won, J., Lee, G., Dossick, C., & Messner, J. (2013). Where to Focus for Successful Adoption of Building Information Modeling within Organization. *Journal of Construction Engineering and Management*, *139*(11), 04013014. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000731

Van Nederveen, G. A., and Tolman, F. P. (1992). "Modelling multiple views on buildings." *Autom. Constr.*, 1(3), 215–224.

Won, J., Lee, J., and Lee, G. (2008). "A case study on BIM collaboration

Van riel, A. (2010), *De Strategische Inzet Van Vastgoed (Using Real Estate Strategically),* Weka Publishers, Amsterdam.

Xavier University Realizes the Benefits of BIM | Autodesk. (n.d.). Retrieved August 7, 2020, from https://www.autodesk.com/solutions/bim/hub/xavier-university-realizes-benefits-of-bim

Xiong, X., Adan, A., Akinci, B., & Huber, D. (2013). Automatic creation of semantically rich 3D building models from laser scanner data. *Automation in Construction*, *31*, 325–337. https://doi.org/10.1016/j.autcon.2012.10.006

Xiong, X., & Huber, D. (2010). Using Context to Create Semantic 3D Models of Indoor Environments. *Procedings of the British Machine Vision Conference 2010*, 45.1-45.11. https://doi.org/10.5244/C.24.45

Y. Furukawa, B. Curless, S.M. Seitz, R. Szeliski, Reconstructing building interiors from images, in: Proceedings of the International Conference on Computer Vision (ICCV), 2009, (URL http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5459145).

Yang, X., & Ergan, S. (2014). Evaluation of visualization techniques for use by facility operators during monitoring tasks. *Automation in Construction*, *44*, 103–118. https://doi.org/10.1016/j.autcon.2014.03.023

Yang, X., & Ergan, S. (2016). Design and Evaluation of an Integrated Visualization Platform to Support Corrective Maintenance of HVAC Problem–Related Work Orders. *Journal of Computing in Civil Engineering*, *30*(3), 04015041. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000510

Yang, X., Y. Liu, B. Akinci, R.M. Leicht, J.I., Messner, Lessons learned from developing immervsive virtual mock-ups to support energy efficient retrofit decision making, Comput. Civ. Eng. ASCE (2013) 210-217.

Young, N. W., Jr., Jones, S. A., and Bernstein, H. M. (2008). *Building information modeling (BIM)—Transforming design and construction to achieve greater industry productivity*, McGraw-Hill Construction, Bedford, MA.

Young, N. W., Jr., Jones, S. A., Bernstein, H. M., and Gudgel, J. E. (2009). *The business value of BIM*, McGraw-Hill Construction, Bedford, MA.

Zeiba, D. (2019, May 15). *Skanska puts 360-degree photography to work on New York job sites*. The Architect's Newspaper. https://www.archpaper.com/2019/05/skanska-puts-360-degree-photography-to-work-on-new-york-job-sites/

APPENDIX

Owner's Documentation Survey 2020

Start of Block: BIM (Building Information Modeling) Personnel

Q1 This survey is being conducted by the University of North Carolina-Charlotte (UNCC) to gain insight on how facility owners use BIM (Building Information Modeling) and other forms of visual data (3D laser scanning and 360 degree photographs) throughout the project life cycle. The survey consists of six sections which are directed to facility owners and their team(s). If you wish to contact UNCC about this survey, you may contact Dr.Glenda Mayo (Glenda.Mayo@uncc.edu) or Jesse Mallard (jmallard@uncc.edu).

Your participation in this survey will benefit UNCC and the industry as a whole in the following ways:
A) The results of the survey will assist in validating research for a thesis that has a focus on handover format types, storage of the data and the data use. B) Facilities Management personnel will benefit from the survey results by assessing the ways that BIM and visual data is used within the industry currently, and assist in closing knowledge gaps between Owners and Design and Construction teams.

Q2 On BIM-assisted projects that your organization has required, what **types of leadership roles** (internal and/or external) were required? (Select all that apply)

- ▢ A project BIM manager to **assist in construction administration** for your organization (1)
- ▢ **BIM coordinators** for each technical trade and discipline (2)
- ▢ Team member focusing on **managing assets** (3)
- ▢ **No specific provisions** have been made regarding leadership roles and responsibilities related to BIM (4)
- ▢ I am not sure (5)
- ▢ Other specific requirements, please specify (6) ____

Q3 How many people in your organization have **dedicated BIM roles**?

- 0 (none) (1)
- 1-3 (2)
- 4-6 (3)
- 7-9 (4)
- 10+ (5)

End of Block: BIM (Building Information Modeling) Personnel

Start of Block: BIM Requirements

Q4 Great! Now we would like to understand more about any BIM requirements your organization has.

Q5 Relative to the use (mandating and using the model in some way) of BIM, which of the following **best describes** your organization?

- We **use** BIM on all **(100%)** projects (1)
- We **use** BIM on most **(75%)** projects (2)
- We **use** BIM on some **(50%)** projects (3)
- We **use** BIM on **(<50%)** projects (5)
- We **do not** require BIM on any projects at this time (4)

Q6 Which of the following provisions has your organization made to **assist in implementing BIM?** (Select all that apply)

- ▢ **BIM/VDC** requirements or specifications (1)
- ▢ **Asset** lists (2)
- ▢ Revised contractual agreements which **address BIM processes** (3)
- ▢ A trained staff member dedicated within your organization to **manage BIM procedures** (4)
- ▢ Education and training to improve all staff members' **BIM proficiency** (5)
- ▢ **Owner driven** BIM requirements or documented standards (7)
- ▢ **No specific** provisions have been made (6)
- ▢ I am not sure (8)
- ▢ Other specific requirements, please specify (9) ____

Q7 If you do **not** currently require BIM **or** if you have adoption issues, please explain some of the **obstacles you are facing in BIM adoption.** (Select all that apply)

- ☐ High **cost/budgetary** restrictions (1)
- ☐ **Lack of experience** from design and construction side. They are unable to provide BIM deliverable at this time. (2)
- ☐ **Lack of trained i**n-house personnel (3)
- ☐ **Lack of standardization** and open usability (5)
- ☐ Project size (4)
- ☐ Other, please specify (6) ____________________

Q8 If **BIM requirements** were **created by your organization**, which of the following areas were addressed in the document? (Select all that apply)

- ▢ **Model progression specification** outlining required LOD (Level of Detail) and responsible MEAs (1)
- ▢ Model **sharing and reliability** protocols (2)
- ▢ **Interoperability/ file sharing** procedures (3)
- ▢ **Model management** procedures and protocols (4)
- ▢ **Intellectual property rights** of different authored aspects of the model (5)
- ▢ **O&M/FM** data requirements for the model (6)
- ▢ Quality Assurance and Control **(QA/QC)** procedures to check deliverables (7)
- ▢ **Technology** infrastructure requirements (8)
- ▢ Required construction **handover deliverables** (9)
- ▢ **Role and responsibilities** of each stakeholder regarding BIM processes (10)
- ▢ **When** and **how** the model must be used (i.e. applications for the model in each project phase) (11)
- ▢ We currently have **no** contractual agreements or requirements/guides regarding BIM (12)
- ▢ Other, please specify (13) ____

End of Block: BIM Requirements

Start of Block: Construction Deliverables

Q9 Excellent work! Now, we would like to understand more about how BIM is used for construction deliverables. This section relates to how BIM is used within your organization during the construction phase of the project to deliver an owner's needed data.

Q10 We **collect and/or check asset data** during construction with: (Select all that apply)

- ☐ **BIM360** spreadsheet (native inside BIM360) (1)
- ☐ **Excel** Spreadsheet (2)
- ☐ **Internal** Mobile Platform (3)
- ☐ We **do not** track asset data during construction (6)
- ☐ I don't know (5)
- ☐ Other, please specify (4) ____

Q11 What **format(s)** do you request for **handover deliverables**? (Select all that apply)

- ▢ **COBie** schema (20)
- ▢ **Internally** developed schema (21)
- ▢ **IFC** format (22)
- ▢ **BIM** model (23)
- ▢ **Navis** file (29)
- ▢ Spreadsheet (24)
- ▢ Paper (25)
- ▢ Electronic (26)
- ▢ **Visual** (360 degree photographs, 3D laser scans, etc) (27)
- ▢ Other, please specify (28) ____

Q12 What types of **BIM deliverables** are **mandated** by your organization at construction handover? (Select all that apply)

▢ **As-built** models provided by design team (9)

▢ **Record Models** from design team (14)

▢ As-built models **provided by construction** team (10)

▢ A populated **COBie** spreadsheet (11)

▢ A populated spreadsheet **(manually or via BIM360)** from contractor (12)

▢ **No specific** model deliverable has been mandated (8)

▢ Other, please specify (13) ____

End of Block: Construction Deliverables

Start of Block: Facilities Management

Q13 Great work! Now, we would like to understand more about how BIM is used for facilities management.

Q14 Facilities Management - This section relates to the FM stage; how data is collected, stored, and used within your organization.

Q15 What time intervals does your organization require **reviews of the model** for coordination and QA/QC from the designer? (This pertains to the owner's need to ensure clash detection takes place and that data deliverables are being considered.)

○ Based on design phases (58)

○ After the project is complete (61)

○ We have not implemented QA/QC review process (59)

Q16 Identify which of the following best describes your **quality control procedures** used to assess the accuracy and completeness of model-based deliverables? (Select all that apply)

- ▢ We have **designated staff member(s)** responsible for model management and QA/QC (2)
- ▢ **Interference checks** are performed to coordinate different stakeholders' models (4)
- ▢ **Element validation** is performed ensuring all model objects are defined accurately and consistently through all phases (5)
- ▢ We send deliverables to an **external auditor/consultant** to check the model (6)
- ▢ We **do not** have a formal QA/QC process for the models (1)
- ▢ Other, please specify (7) ____

Q17 Describe the **format most used** by your maintenance and FM staff to **reference building data needs**, post-construction: (Select all that apply)

- ▢ Revit (1)
- ▢ Hard copy (3)
- ▢ CAD drawings (4)
- ▢ IWMS or CAFM (9)
- ▢ Floor plans imported into computerized maintenance management system (CMMS) (7)
- ▢ Other, please specify (8) ____

Q18 How does your organization **use floor plans**, post-construction?

- ○ Direct product of the model (4)
- ○ Link to **IWMS** and/or **CAFM** (7)
- ○ Create floor plans with another software after provided the deliverables (5)
- ○ Other, please specify (6) ____

Q19 Which of the following best describes **how you will utilize the final BIM deliverable(s)**, post-construction. (Select all that apply)

- ▢ We utilize **3D geometric aspects** of the model with hyper-linked close-out documentation (58)
- ▢ We utilize the **model** and/or its **attribute data** to track asset management (59)
- ▢ We utilize the model's attribute data to track **space management** (60)
- ▢ We have integrated the model and/or its attribute data into an **IWMS/CMMS** (61)
- ▢ We have integrated the model with existing **civil infrastructure/GIS** (62)
- ▢ We currently **do not** use the model or its attribute data post construction (57)
- ▢ I am not sure (63)
- ▢ Other, please specify (64) ____

Q20 What have you experienced as the most common reason why the **collection of building documentation** (asset data and visual data) is not collected on a project? (Select all that apply)

- [ ] **Cost** of services, equipment, and/or resources **seem too high** (1)
- [ ] To ensure smooth **field operations** (2)
- [ ] To ensure on **time/schedule** delivery (3)
- [ ] To ensure expected **quality/accuracy** is achieved (4)
- [ ] Other, Please Specify (6) ____

Q21 How much time is spent after handover **organizing the BIM data** to make it usable for your organization?

- ○ Less than 3 weeks (It already comes in usable format) (54)
- ○ 1-3 months (55)
- ○ 4-6 months (56)
- ○ 6 months + (57)
- ○ We don't do anything with the data (58)

Q22 Rate the importance of the following **uses for BIM** in the Operations Phase of a building project:

	Extremely Important (5)	Very Important (3)	Somewhat Important (2)	Not Important (1)	I am not sure (4)
Maintenance **scheduling** (1)	○	○	○	○	○
Building systems **analysis** (2)	○	○	○	○	○
Asset management (3)	○	○	○	○	○
Space **management and tracking** (4)	○	○	○	○	○
Disaster **planning** (5)	○	○	○	○	○
Warranty Information (9)	○	○	○	○	○
GPS/ GIS **integration** (6)	○	○	○	○	○
Ease of **transfer** to IWMS/CMMS (7)	○	○	○	○	○
Use of BIM models as an **information "container"** (8)	○	○	○	○	○

End of Block: Facilities Management

Start of Block: Visualization and Asset Management

Q23 Excellent work! Almost done! Now, we want to understand how visualization and asset management is conducted within your organization.

Q24 Visualization and Asset Management - This section relates to the use of visual data and how it may be used within your organization. In this context, Visual Data pertains to the use of building data in visual format, such as BIM, photos and/or augmented capture solutions.

Q25 Which of the following **visual data** is **useful to maintenance and operations staff**? (Select all that apply)

- ☐ Photographs (1)
- ☐ 360 degree photographs (6)
- ☐ 3D Laser scans (7)
- ☐ Augmented/Virtual Reality (8)
- ☐ We do not collect visual data (9)

Q26 Which of the following sources of **visual data are requested by your organization** and from whom are they typically collected from?

	Photographs (1)	360 degree photographs (2)	Laser scans (3)	Augmented/Virtual Reality (4)	Does not collect visual data (6)
From Design Team (1)	☐	☐	☐	☐	☐
From the Construction team (2)	☐	☐	☐	☐	☐
Outside contract (3)	☐	☐	☐	☐	☐
We collect it ourselves internally (4)	☐	☐	☐	☐	☐

Q27 Does your organization use a **nomenclature** (like: bldg_Plbg_Pump_01_02) or similar to name assets?

- Yes, a consultant developed it for us (110)
- Yes, we developed one internally (111)
- No, we do not have a naming convention (112)
- Our IWMS/CMMS automatically assigns an asset number (114)
- Not Sure (113)
- Other, please specify (115) ____

Q28 Where does your organization name (or assign nomenclature to) assets?

- In the BIM file (1)
- In a digital folder (2)
- In IWMS and/or CAFM (3)
- Other, please specify (4) ____

End of Block: Visualization and Asset Management

Start of Block: Demographics

Q29 Great work! Now, we want to understand more about your organization.

Q30 Which of the following **best describes** your organization?

- ☐ Private/Closely Held (1)
- ☐ Quasi-Public (2)
- ☐ Municipal (3)
- ☐ State (4)
- ☐ College/University (5)
- ☐ Public Stock Corporation (6)
- ☐ Federal (7)
- ☐ Other, please specify (8) ____

Q31 Which of the following **describe(s) your role** within your organization? (Select all that apply)

- ☐ Construction procurement (80)
- ☐ Construction administration (82)
- ☐ Space management requirements (83)
- ☐ Operations and maintenance (84)
- ☐ Planning and documentation operations (85)
- ☐ A defined BIM role (86)
- ☐ Other, please specify (87) ____

End of Block: Demographics

Start of Block: Thank you for your time

Q32 If you have any **further comments** you would like to share, please use the space provided.

____

Q33 We will be creating a summary document of our results. In order **to receive the results** of survey findings, please provide your email address in the space provided:

____

Q34 Thank you for your participation! If you wish to contact UNCC about this survey, you may contact Dr.Glenda Mayo (Glenda.Mayo@uncc.edu) or Jesse Mallard (jmallard@uncc.edu). Please click the button below to submit.

End of Block: Thank you for your time