Developing a Custom ESRI Facilities Data Model: Whole Building Management Exploring BIM Supported GIS Model

Katie M. Harris
Department of Resource Analysis, Saint Mary's University of Minnesota, Minneapolis, MN 55404

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Abstract

In the last decade, issues of critical infrastructure protection have received much attention from researchers worldwide. Geographic Information Systems (GIS) coupled with Building Information Modeling (BIM) makes it possible to create a 3D GIS data model that is intended to provide facility managers with improved modeling techniques to better manage the protection of infrastructure and assets, reducing risks and improving decision making. Building facilities are a part of society's daily life; whether it is a fire station or a community health center, the assessment and protection of infrastructure is critical to the wellbeing of the whole building management system. This case study focused on integrating Geographic Information Systems (GIS) and Building Information Modeling (BIM) by investigating the value GIS brings when integrating the two software programs.

Introduction

The average American between the ages of 20 and 65 works 40 hours per week; those figures equate to the average American spending nearly 10.3 years of their lives working. More than likely, this time working is spent inside of a building facility (LinkedIn, 2014). An employee's workplace environment is a key determinant of the quality of their work and their level of productivity. How well the workplace engages an employee impacts their desire to learn skills and their level of motivation to perform (Business Performance, 2014).

Facilities data is a growing trend within the GIS community. One of the largest costs for any organization is asset and facilities management (Fiorenza, 2013). With proper facilities management, organizations can reduce costs and manage space efficiently.

Facility management is an interdisciplinary field devoted to the coordination of space, infrastructure, people, and organizations, often associated with the administration of office blocks, arenas, schools, convention centers, shopping complexes, hospitals, hotels, etc. According to Rich and Davis (2010), Jack Dangermond stated, "Given the importance of facilities and their place in society, a revolution in facilities management is occurring." Geographic information systems (GIS) are designed specifically for managing and analyzing spatial relationships and offer many benefits to the facilities management community.

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Out of necessity, the facility management application industry has adopted architectural floor plans as the common denominator for viewing built environments. Use of floor plans help to create, organize, and label architectural building footprints and floor designs. These designs or floor plans are often created by computer aided design (CAD), which historically represented the only media available for understanding and interacting with buildings and their contents and associated workflows. The progression from hand-drawn floor plans to CAD drawings, and now building information models (BIM), is essentially a progression from single floor view to whole building representations (Rich and Davis, 2010).

Building Information Modeling (BIM)

Building Information Modeling (BIM) is an intelligent, model-based process providing insight to aid in planning, design, construction, and management of buildings and infrastructure (Figure 1). A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle, defined as existing from earliest conception to demolition (Zhang, Arayici, Wu, Abbott, and Aouad, 2009).

The BIM process began as a common name for a variety of activities in object-oriented computer-aided design (CAD) that support the representation of building elements in terms of their 3D geometric and non-geometric (functional) attributes and relationships. BIM gained widespread use after Lessarian argued in 2002 that it should be an industry-standard term (ISA Project Team Report, 2008).

According to Rodriguez (2015), benefits of deploying BIM to manage facility data include:

- potential to cut down on rework, such as re-keying information into models or making changes in the field
- improved productivity
- reduced conflicts and changes during construction
- clash detection

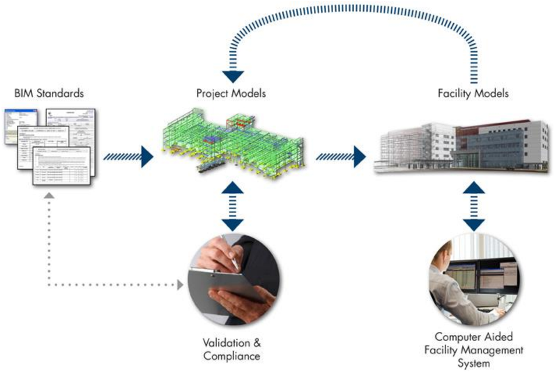

Figure 1. The BIM lifecycle mirrors that of a building, making it useful in every step of the facility's development. Graphic courtesy of Marchese and Rudderow (2013).

Geographic Information Systems (GIS)

Geographic Information Systems (GIS) is a tool used by individuals and organizations, schools, governments, and businesses seeking innovative ways to solve their problems. GIS stores information about the world as a collection of layers that can be linked together by a common locational component such as latitude and longitude, a postal zip code, census tract name, or road name. Geographic references promote the ability to more easily locate features on the earth's surface for analysis of patterns and trends.

GIS is one technology that has many practical uses for facility managers. Facility managers can use GIS for space management, visualization and planning, emergency and disaster planning and response as well as many other applications (Rich and Davis, 2010).

According to Artz (2009), the benefits of deploying GIS to manage facility data include:

- cost savings resulting from greater efficiency
- better decision making
- improved communication
- better geographic information recordkeeping
- managing geographically

Study Objectives

A facility model was designed and created using an ESRI facility model template; the object of this study being to test implementation of the designed model. To show value achieved after implementation, three metrics were chosen: 3D capability, spatial reference, and attribute storage. Metrics were selected for comparison and study due to needs identified by the government facility selected for this case study application. As such, metrics defined herein may not be directly applicable to all instances of BIM and GIS integration.

Analyzing integrated GIS and BIM software consisted of questions to determine the effectiveness of implementing an integrated GIS and BIM software platform model. Effectiveness of integrated software was examined using a survey distributed to government facility employees, who were part of the case study. Employee participants in the survey were regular software users. The survey was distributed to these end-users to evaluate and measure attitudes towards the new software GIS and BIM model. Consequently, all data and input selected for the study are bound to reflect only that of the government case study for which it is directly applicable.

Case Study and Study Area

The case study consisted of a local government campus of buildings. Government officials were an active stakeholder and were aware the study was implemented; officials also agreed to provide data and access to facilities in order to help make this study possible.

The campus and facilities research consisted of four buildings interconnected by either a walkway or hallway. Each building is grouped together by work-specific related tasks; therefore, each building has varied levels of security. Two of the four buildings have a high level of security while the remaining two buildings have minimal security present in the main entrance areas of the building. Three out of the four buildings were used in this study (Figure 2). The building not included in this study has a very high level of security and access to the data was not made available.

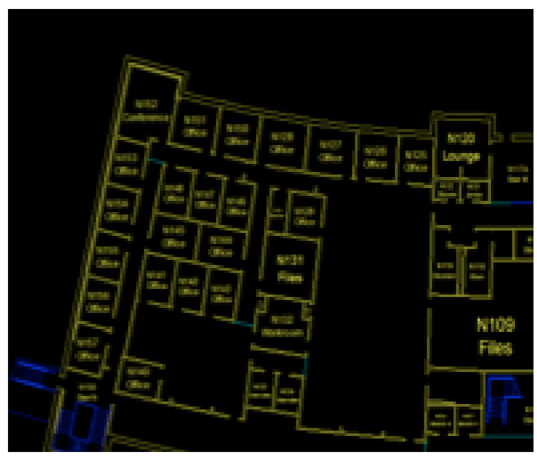

Figure 2. CAD graphic – section of main level building 1 of 4. Due to data privacy, a complete floor plan could not be displayed.

Out of the three buildings being used in the study, one has a basement and another has a boiler room located in the lower level of the building. All three buildings have a main level, upper level, and a penthouse, which is located on the roof. The buildings are comprised of a range of approximately 1,500-42,000 square feet (sq ft) on each level and consist of office space, meeting rooms, heating/ventilation spaces, and welcome spaces.

Data Model Design Background

Pre-Existing Data

Data described here reflects considerations used to design and establish the facilities model prior to implementation. Pre-existing CAD data was imported into GIS and spatially referenced. Much of the pre-existing data consisted of CAD building floor plans and locations of assets, which included cameras and fire alarms.

In addition, data existed to generate a 3D facility model, including but not limited to building polygons, exterior land, and water polygons. This data was used to generate a facilities template model for which this implementation analysis is based upon.

Data

The facilities data model required a template. The template used included an ESRI facilities data model template. The ESRI facilities data model was chosen due to the ability to add and maintain facility data with ease.

Exterior land and water polygons were incorporated into the ESRI data model to show and manage the landscape – an aspect of facility management.

Facility Model Design Background

Facility building CAD files were exported as .DWG files into a GIS database and georeferenced. This process was completed for each floor level of each building included in the study area. Buildings with multiple floors were superimposed on top of one another to create a multi-floor facility. Data was brought into GIS due to its spatial reference and recordkeeping capabilities.

Using GIS along with CAD data provides a spatial dimension for building management and analytical processes. Combining the power of GIS and CAD allows questions to be asked such as:

- Where are my assets located and how can I most efficiently place and maintain them?
- Where are the best locations for groups of people who do complementary tasks (Stockton, 2013)?

Network Analyst

ArcGIS Network Analyst was incorporated into model design to provide network-based spatial analysis tools for solving complex routing problems. It uses a configurable transportation network data model, allowing organizations to accurately represent their unique network requirements. A building centerline was digitized throughout the facility in order to achieve functionality of the ArcGIS Network Analyst tool. This was used inside the campus of buildings establishing a routable network utilizing hallways, stairs, and elevators. Routing scenarios permit the ability to perform “what if” and timing scenarios.

- How can one get from point A to point B using the quick route?
- If the use of elevators were not an option, how would you navigate through the building?
- What are accessible routes that are wheelchair friendly?

Methods

Model Implementation

ArcGIS for Facilities is an ESRI initiative to build focused GIS solutions for the facilities domain, enabling users to get up and running quickly and to be able to do their work more efficiently (ESRI, 2012).

This model is meant to streamline data collection, maintenance, and use of assets. ESRI's facility data model template was used to create interior and exterior building lines to represent a 2D facility model. The template included processing tools. These tools were utilized to create interior spaces and load interior spaces.

Three-dimensional (3D) modeling was a goal set by the government agency to enhance visibility analysis prior to model design. 3D modeling aids in future expansion of the campus and visualization of how a proposed building will interact with the existing environment before it is built. The 3D views were achieved using ArcScene. In order to utilize 3D functionality of the data, an accurate z-value was required. A z-value typically consists of a vertical measurement or other value representing an additional attribute such as elevation. This differs from typical x,y horizontal positional location values; z-values were added to floor lines using ArcGIS. The ceiling height of the building was calculated to 15 feet throughout the campus; this was an important factor in adding elevation to the 3D model.

Analysis

Three metrics were chosen based on the unique needs of the government agency. AED's, fire alarms, and elevators were chosen to highlight functionality before and after creation of the model.

The government facility was interested in 3D capability, spatial reference, and attribute storage because of the visual analysis aspect 3D provides as well as the accuracy of the data when spatial reference and attribute storage are combined.

3D Capability

GIS is traditionally two-dimensional (2D) but has 3D capabilities in ArcScene, while BIM works in the 3D realm. 3D modeling is just one aspect of BIM that has dominated the limelight (Zhang *et al.*, 2009). 3D enrichments within the model were evaluated based on capability and enhancements that can be achieved.

With the help of GIS, ArcScene 3D, and ArcGIS Network Analyst routing, questions can be asked such as:

- Where are company assets located?
- How can hypothetical scenarios be modeled?
- How can planned routes for the facility be modeled?

According to Rabia and Farooq (2009), 4D and 5D models can be created in GIS by incorporating time and cost constraints, aiding in complete optimization. Using GIS increases the coordination among various disciplines involved in construction and also the communication.

Spatial Reference

Both GIS and BIM create a digital representation of the real world. GIS handles data in the macro level of the real world, working with "outside" data, while BIM handles data in the micro level, working with mainly "indoor" data of the real world. GIS uses geographic coordinate systems and world map projections while BIM coordinates are relative to the object being modeled and are not usually relative to any particular place on earth (Zhang *et al.*, 2009). Spatial reference within the model was evaluated based on functionality and the type of data GIS and BIM respectively can handle, summarized with the following question:

- How can whole facility management be modeled?

Attribute Storage

The magic of GIS is that geometry and attribute information are married to each other, thus providing a more complete set of information solutions for decision support. Therefore, in order to deliver sustained value, a facilities GIS must be able to automate the process of moving information back and forth across many formats and system boundaries (Smith, Dempsey, Cheuvront, and Rich, 2015). Ideally, data maintained in CAD, BIM, or other systems is automatically harvested into GIS, which provides the map-centric information display and the platform for integration with other enterprise information systems. But this is not necessarily a one-way process. Operational data maintained in a GIS can also be used to update CAD or BIM files with information that is maintained in GIS and other systems when it is helpful to design and construct processes (Smith *et al.*, 2015).

BIM tools support a much deeper and richer information model and are therefore capable of delivering much more useful information about the overall facility than is necessary for operations and maintenance. Furthermore, the object-oriented nature of BIM ensures that this information is properly formatted and topologically correct, a big advantage over CAD which does not enforce this kind of information structure discipline (Smith *et al.*, 2015). BIM's real strength and power lies in the knowledge database, which can be used in conjunction with other software to deliver quick and reliable information in areas of sustainability, estimating, structural analysis, demolition and reconstruction (Zhang *et al.*, 2009).

Attribute storage within the model was evaluated based on ability to store attributes as well as how those attributes are stored.

Survey

A month after the facility model was implemented within the government facility; a survey was administered to government employee participants to assess attitudes toward the new model and its effectiveness of use.

The survey was distributed among government employees. These employees represented the survey sample. This survey utilized a purposive sample method as to sample all individuals who would be using the model. The survey participants included the facility manager, public works asset manager, and onsite GIS employees. Participants had a varying degree of technology backgrounds and experience with GIS and BIM. In general, the population was familiar with regular day-to-day operations of both GIS and BIM and could differentiate between their experiences of using an integrated GIS and BIM model.

The sample population for this survey was rather small, but applies to this specific case study and an expansion of the survey could not be applied beyond the control group.

Effectiveness was measured through an affective Likert scale. Likert (1932) developed the principle of measuring attitudes by asking people to respond to a series of statements about a topic, in terms of the extent to which they agree with them – consistent with tapping into the cognitive and affective components of attitudes (McLeod, 2008).

The survey consisted of eight statements:

- Using the merged GIS/BIM model in my job would enable me to accomplish tasks more quickly
- Using the merged GIS/BIM model would improve job performance
- I would find the merged GIS/BIM model useful in my job
- The merged GIS/BIM model was successful in performing the intended task
- I find the merged GIS/BIM model easy to use
- Exploring new features by trial and error with ease was attainable
- I find the learning to operate the merged GIS/BIM model was attainable
- Overall, you are satisfied with your experience using the merged GIS/BIM model

Questions were derived from Chin, Diehl, and Norman (1988) and Davis (1989). All questions were answered on a scale from 1-5:

1. Strongly Disagree
2. Disagree
3. Neither disagree nor agree
4. Agree
5. Strongly Agree

Survey responses were analyzed and visualized through bar graphs.

Results

This study was aimed at measuring impacts and attitudes toward integrating GIS and BIM software. Security and public safety components (AED's, fire alarms, and elevators) were selected to show functionally before and after the creation of a GIS integrated BIM model. To show the enhancements achieved with the creation of a facility model, three metrics were chosen: 3D capability, spatial reference, and attribute storage. A survey was also conducted with the government agency to measure attitudes and perceptions of using merged BIM and GIS.

3D Capability

3D capability was evaluated based on the enhancements brought to the model through hypothetical scenarios.

- locating public safety and security features within a desired distance
- planned evacuation routes can be modeled for a various scenarios (what if a stairwell or elevator closed)
- planned routes cans be modeled using network analysis and 3D views in ArcScene

Before integrating GIS and BIM, security and public safety features were static features on a CAD map, lacking asset information. After the integration, AED's and fire alarms were displayed similar to their 2D appearance. However, elevators were able to be displayed with a multi floor view (Figure 3).

Spatial Reference

Spatially referenced data was evaluated based on functionality and type of data. Exterior land and interior building design elements can be represented together using one platform based on real world coordinates. Before the integration, CAD floor plans were drawn to show indoor attributes and assets but were not spatially referenced to real world coordinates, whereas GIS building polygons were available in ArcGIS with spatial reference but lacked building information attributes and assets. By integrating the two software applications both “outside” and “inside” data can be modeled together in one place (Figure 4).

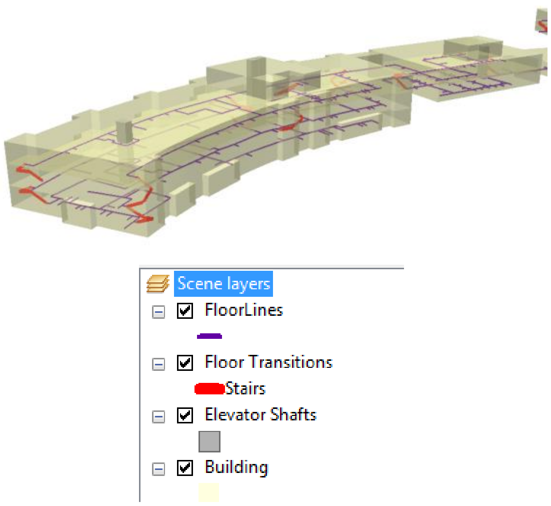

Figure 3. 3D ArcScene multi floor view of an elevator shaft.

Attribute Storage

Attribute storage was evaluated on ability to store attributes. Both GIS and BIM have the ability to store attributes.

- GIS stores attribute data in one of five different field types in a table or database (character, integer, floating, date, BLOB).
- BIM store attributes as parameters.

GIS offers advantages over traditional CAD and Computer Aided Facilities management systems due to the ability of GIS to perform complex geographical analysis and graphical navigation (Table 1). With the interconnectivity of the GIS to a facilities inventory database, personnel and equipment inventory can be georeferenced to the floor plans (Zhang *et al.*, 2009*).*

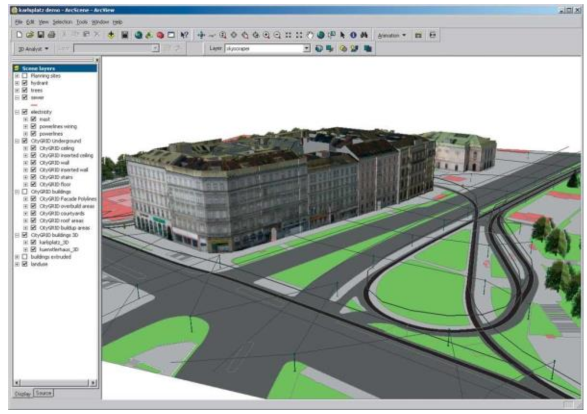

Figure 4. Sample ArcScene graphic displaying building and landscape modeling provided by Dorffner and Ludwig (2006). Due to data privacy, building and landscape images from this study could not be used.

Geospatial tools are increasingly being recognized as a smarter and better way of utilizing information technology for the re-engineering of asset management, with government organizations, and for generating productivity and efficiency gains (Zhang *et al.*, 2009). An advantage of GIS is the full GIS analysis functionality. Results demonstrated that the full suite of GIS tools was able to improve the day to day working responsibilities of the government staff.

The GIS-BIM framework defines a building and its physical objects, but also the geographic relationship of features around and part of the building and its objects (Smith *et al.*, 2015).

Survey Results

Government facility employees that were impacted by the creation of the model were asked to take a survey assessing the integrated GIS and BIM model. Results collected from the survey indicated a majority of affected government facility employees agreed the integration of GIS and BIM would be a useful tool at their

Table 1. Table showing functionality of GIS and BIM before and after integration of the two software programs.

	Before Merged GIS and BIM	After Merged GIS and BIM
Routing: "what if" and timing scenarios	– N/A	– Quickest way from point A to point B – Routing people to locations – Wheelchair accessibility
3D Capability: capability and enhancements	– 3D capability utilizing BIM	– Locating all security and public safety features within a desired distance – Planned evacuation routes can be modeled for "what if" scenarios – Planned routes can be modeled using network analysis & ArcScene
Spatial Reference: functionality and data types	– GIS: referenced "outside" data – BIM: referenced "inside" data	– Exterior land and interior building design elements can be represented together using one platform based on real world coordinates
Attribute Storage: ability to store attributes	– Both have ability to store attributes	– GIS stores attribute data 1 of 5 ways (text, numerical, date/time data, images – BIM stores attribute data as parameters. Parameters store information which can be scheduled, exported to other applications or viewed as properties.

disposal within their daily work tasks while improving job performance (Figure 5). Overall, 5 out of 6 employees agreed they were satisfied with performance.

Discussion

In today's technological world, being able to interpret data through varying platforms is an advantage. GIS and integrated BIM bring an added element of design and data analysis to a model and has the ability to be implemented for various other business and construction uses. According to Smith (2010), "We are never going to be able to have all stakeholders use one piece of software (nor should we expect that day to come). However, it is important that we use the best tools possible for a purpose and not make the software so complex that it does not work well for anyone."

Today's data integration and interoperability are the result of continuous research and development in the software industry, enhancing GIS technology over the last three decades in response to the market's need to connect growing amounts of data (Barron, Hardy, and Young, 2015). ESRI and GIS have been showing great advances in the field of 3D in order to help us understand and analyze the world around us. Results of this study show GIS adds a spatial reference element and improved geographical analysis and navigation to a BIM model.

According to buildingSMART Australasia, BIM and GIS should coexist and harmonize (as cited in Rabia and Farooq, 2009). With reduced professional risk, less waste, less rework, better time management, improved communication

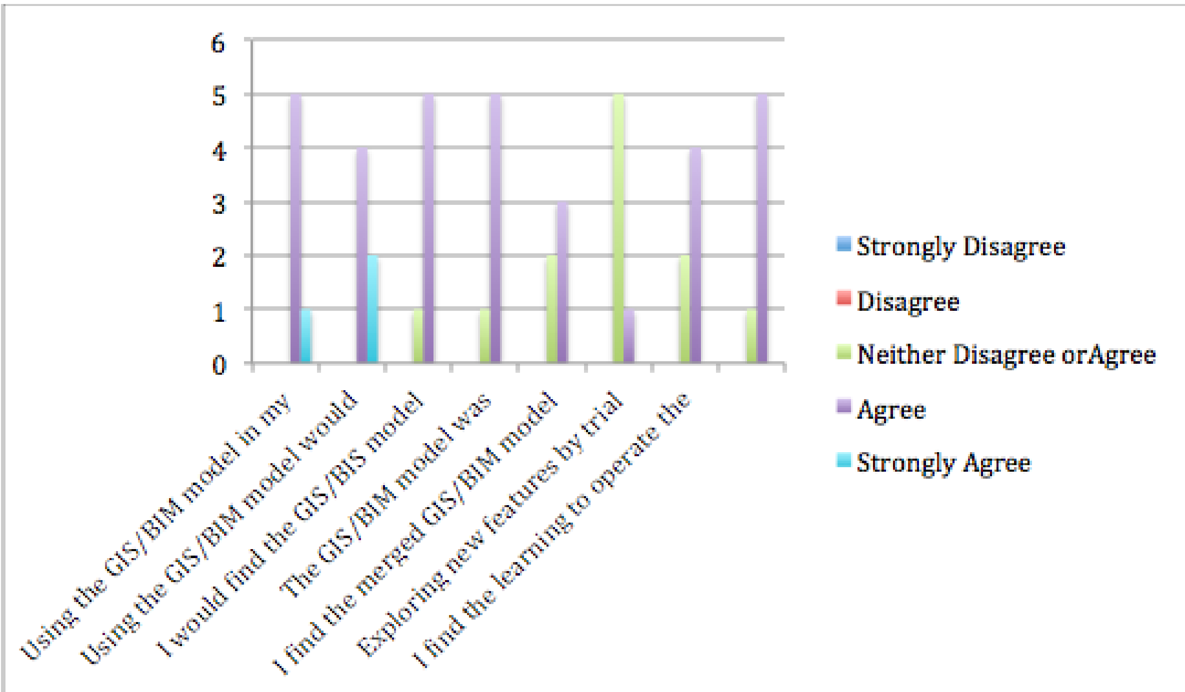

Figure 5. Survey results from the select employees at the Government facility.

and improved efficiency, the construction firms can use BIM and GIS to create new revenue streams and add to profitability.

The government should try to implement BIM supported by GIS in all big projects in an immediate basis to save billions and bring the workforce up to speed with new technology (Rabia and Farooq, 2009).

Recommendations for Future Work

In an ideal situation, future work would include a larger sample population to measure impacts and attitudes toward integrating GIS and BIM software. Unfortunately in the case of this project, expansion of the survey could not be applied beyond the control group.

This analysis has the potential to be used for various facility security and planning applications. In order to customize the model to suit other facilities, different criteria or datasets could be used in the analysis.

Conclusion

The purpose of this study was to measure impacts and attitudes toward integration of GIS and BIM to explore whole building management. After analysis, the combination of GIS and BIM has tremendous benefits.

GIS benefits can be well enjoyed by clients, contractors, consultants and stakeholders dealing with a project from its initial planning, to its implementation, to its scrap value. By implementing GIS in the construction field all disciplines profit in the areas of planning, design, implementation, facilities management, and maintenance (Rabia and Farooq, 2009). GIS applied to asset management cannot only facilitate data collection, processing, and display but can also integrate asset mapping with project management and budgeting tools so maintenance, inspections, and expenses can be accounted for in the same place. GIS tools help in predictive maintenance through assisting in the locating of problems and the scheduling of work as well as assisting in the locating and fixing of poorly performing assets (Zhang *et al.*, 2009).

The benefits of using information from a building model for facilities management are likewise compelling—fuelling the discussion surrounding building lifecycle management and nudging facilities management towards model-based processes. Rabia and Farooq (2009) listed the top benefits of BIM along with a few challenges. The benefits include easier coordination of various software and project personnel, improved productivity, improved communication and improved quality control. A few challenges of BIM are adequate training, senior management buy-in, cost of software, and cost of required hardware upgrades.

Geospatial information is important for effective large-scale asset management, as a large percentage of data used by the asset managers to answer their key questions are geographic. Geospatial location could be used as an approach to integrate various data sets.

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