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BIM-GIS: Analysis and Integration for Contractors

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This paper introduces a set of analyses using location specific GIS data to inform certain preconstruction and construction activities performed by contractors. Five types of GIS assessments whose output provides information for project risk analyses, site logistics, site security, and safety are discussed. The results from these analyses show that the information obtained could be beneficial for contractor's decision making and construction planning. Additionally, a hypothetical project was created to provide context for the integration of BIM and GIS to support the operations and maintenance of mechanical equipment. A practical workflow is proposed that includes specific building information and steps in the process to import BIM project data into GIS software for visualization of a building asset location. As proof of concept, Air Handling Units (AHUs) data was input to the Revit® model element, which was then exported as a text file and imported to ArcMap™. The workflow can be applied to a single building or several buildings in a broader site like university campuses. This paper contributes to the literature with 1) its application of GIS data for preconstruction and construction analyses, and 2) a workflow that integrates BIM and GIS data using commercial off-the-shelf (COTS) software.

Key Words: BIM, GIS, BIM Workflow, Preconstruction, Construction Planning

Introduction

The demand for digitalization of the built environment to be used as data for smart buildings, smart infrastructure, and smart cities has increased around the globe. Liu et al. (2019) identified the data integration-oriented performance as a key characteristic of successful smart city initiatives. Building information modeling (BIM), geographic information systems (GIS), and the Internet of Things (IoT) are tools that can help in the development of smart cities indirectly by facilitating the construction of infrastructures (Heaton & Parlikad, 2019).

During the last decade, researchers have sought to discover a practical method to integrate GIS and BIM to support planning, design, construction, or facility management processes. Marzouk and Othman (2020) proposed a framework for BIM-GIS integration to anticipate utility infrastructure needs during the project planning phase. Barazzetti and Banfi (2017) looked for new solutions to integrate parametric modeling in BIM software and geospatial data for the design phase. Deng et al. (2019) proposed a framework to support construction supply chain management by integrating BIM and GIS. Similarly, Vacca et al. (2018) proposed a BIM-GIS integration workflow to manage large building stocks. In 2019, research by Rahman and Maulud approached BIM-GIS integration as a 3D evacuation requirement using a multi-patch geometry data format. In a comprehensive literature review, Liu et al. (2017) identified the many ways researchers in the built environment have integrated BIM and GIS data using 3D cadastre, location-based services and navigation, asset management, heritage management, site selection and layout plan, urban environment analysis, and safety. Ma and Ren (2017) completed an overview to demonstrate how BIM-GIS integration can be useful in different project phases such as planning, design, construction, operations and maintenance, and demolition. Differently, Tobias (2015) showed recent efforts to use BIM in the geospatial context and GIS analysis in the BIM environment. To propose a practical workflow to support facility management, Mirarchi et al. (2018) defined a platform for indoor positioning systems that enable end-users to send specific geospatial reports to a central virtual model. In an effort to integrate BIM and GIS data, Zhu et al. (2019) converted geometry information from the Industry Foundation Classes (IFC) data format into a shapefile using open-source technology. In the context of smart cities, the implementation of BIM has been limited primarily to the design phase in countries with a history of good performance in overcoming challenges specific to the data integration required by smart cities (Derakhshanfar, 2020). The need for new research and practical workflows to support BIM use for project planning, design, construction, facility operations, and maintenance has increased in recent years.

In this paper, some of the challenges construction professionals may experience in the context of a project for a facility or infrastructure that includes a set of owner requirements for handover of the BIM-GIS data for operations and preventative maintenance are addressed. The authors acknowledge that this context is a specific project type, however the transition to smart buildings and infrastructures is an emerging trend for which the construction industry has a significant role. Sections in this paper include discussions of GIS analyses using Esri ArcMap™ with census data for project risk analysis and its use for BIM handover to the owner for facility and infrastructure operations and maintenance. The use of ArcMap™ and spatial data provides important information about a project during the planning, design, and construction phases. A practical workflow is proposed based on a hypothetical project that includes the contractor's input of asset data to the project's BIM as required by the owner for operations and maintenance. After developing the BIM model, the text file with mechanical equipment data was exported, and then imported to ArcMap™. In doing so, the building and geographic information that is necessary for efficient operations and preventative maintenance were integrated. The data for the operations phase was then available as output from ArcMap™ for input to the project owner's Computerized Maintenance Management System (CMMS) or Asset Management System (AMS). Due to page limitations, the workflow and BIM data presented was limited to Air Handling Units (AHUs) as a proof of concept. The proposed workflow should be validated using other elements and facility assets from the BIM model in future research. Additionally, the workflow should be validated on a broader scale for more buildings located on a campus or an area within a city to establish ways that BIM data from several buildings could be visualized on a location map using GIS software.

Methodology

For a comprehensive demonstration of the proposed workflow, a real-world project site in a mixed-use entertainment development consisting of retail, housing and office space located adjacent to Interstate 35 in Norman, Oklahoma was used. Bordering the development to the east is a Regional

Business Airport servicing general aviation aircraft, including business jets. A strip mall core and shell building was designed using Autodesk® Revit®. The model includes a lobby at the main entrance with retail spaces on the first level. The model also includes a partial second level and open-air terrace over the entrance lobby. The total area of the model is 28,125 square feet with four roof-top AHUs, each with a capacity of 12,500 CFM. The project site, main transportation corridors around the project site, and the designed model, are shown in Figure 1.

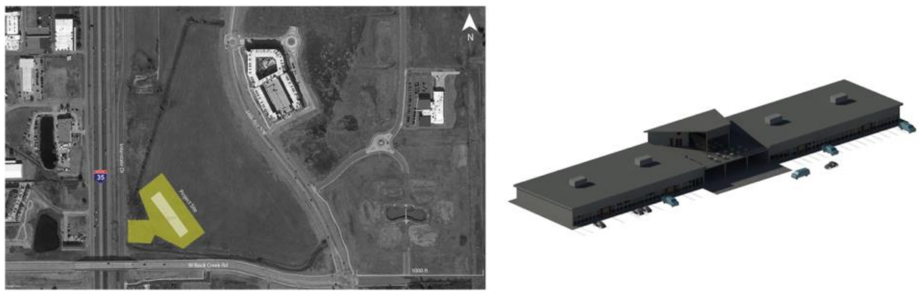


Figure 1. The project site, transportation corridors, and designed model

To study the problem of integrating BIM and GIS data for construction, an applied research approach was used to establish a proof of concept as a first step for future research. Real-world GIS data for the site location, 3D modeling software, geospatial processing software, and the researchers' observations during data transfer were used to establish the proposed workflow. Although limited in scope, the focus of this study was on 1) GIS data analyses relevant to contractors and 2) GIS data integration with construction BIM. The GIS data sets selected for the analyses have direct application during the preconstruction and construction phases of a project. The proximity analysis and emergency response units' analysis are both useful for inputs to risk analysis and site logistics. Whereas the socioeconomic data analysis is useful during preconstruction for feasibility analysis. The census data analysis, combined with historical aerial photos, provide context of the site surroundings and are useful for risk analysis, site logistics, site security, and safety planning. Five types of GIS assessments, including proximity analysis, emergency response units' analysis, socioeconomic data analysis, historical aerial photos analysis, and census data analysis, were chosen to demonstrate their application for typical contractor activities in the context of a construction project. The details related to each analysis and proposed workflow are mentioned in next sections.

Proximity analysis

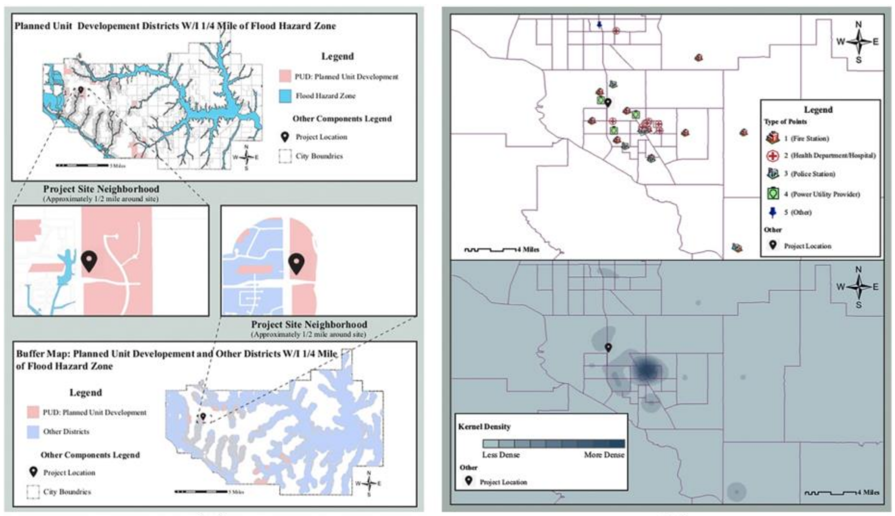
In this section, the process for proximity analysis is discussed in detail to support a broader understanding of its application for contractor's use. To create the maps shown in Figure 2(a), the Planned Unit Development (PUD) District map and the Special Flood Hazard Area (SFHA) map for the development were identified as two sources of information to analyze based on the proximity to the strip mall project. One of the most important features to consider in the design and pre-construction phase is the flood hazard.

According to Federal Emergency Management Agency (FEMA) and National Research Council (NRC), there are several benefits to flood hazard zone analysis. The benefits specific to design and construction of a facility include:

- Identification of higher-risk areas within and around the project site,
- Identification of evacuation needs and routes,

- Mitigation of business interruptions,
- Facilitation of efficient allocation in planning and response for emergency services,
- Increased ecological diversity.

The societal impact of these benefits includes reductions in loss of: life, property, and business. Additionally, the preservation of a floodplains' natural function is a benefit with societal impact (NRC, 2009). In addition to the benefits and impacts, the flood hazard zone analysis assists contractors gain a better understanding of the hazards they may face during construction of the project and contribute to the preparation of a more precise risk management plan. To clarify, the contractor could better anticipate the risk of hazards and prepare a strategy to respond to this risk.



(a) (b)

Figure 2. (a) Proximity analysis. (b) Point map and Kernel density map

To analyze the PUD and SFHA proximity to the project's location, districts within ¼ mile of the flood hazard zone were identified using ArcMap™. A ¼ mile was selected because it is considered a reasonable distance for analysis of areas around the site which are at higher risk. Figure 2(a) shows the districts around the project site that are located within ¼ mile of the flood hazard zone with pink color. One result from the analysis was that the selected project site is located within ¼ mile of the SFHA, therefore, the site is at risk for flooding. To better understand the potential hazard, a buffer map of the PUD and other districts within ¼ mile of the flood zone was created. The neighborhood scale map reveals that the majority of the project site is within this flood zone area. Although the flood route near the project site is narrow and could mitigate the risk of a catastrophe, the recommendation is to be prepared with a risk management plan and appropriate insurance to cover potential damages due to flooding on the site.

Emergency response units' analysis

There is little doubt that timely and anticipated response to disasters plays an imperative role in saving lives. Therefore, identifying the emergency response units around the project site is crucial. It is helpful for project stakeholders to have a good plan for emergency response through their risk management plan from the initial stages of a project. With a plan in place, emergency responders will be prepared to follow a documented workflow or instructions for prompt response.

Identification of the information that emergency responders will need is essential. For example, firefighters need to know where explosive and hazardous material are stored on a project site and the type of fire extinguishing system used in temporary buildings. They will also need information about the access points for entry to the buildings and the locations of safe zones within the building. By having this information, firefighters could develop a strategy for their response to fire and the different types of materials fueling a fire. To support this need, contractors should identify a person or assemble a team to categorize and provide the critical information needed by firefighters. The BIM-GIS integration for this analysis begins with the export of the KML file from Google Earth, which is then converted to a database for ArcMap™ to create a point map.

For the hypothetical project, a numbering system was used to categorize the emergency response units (1 = fire station, 2 = health department or hospital, 3 = police station, 4 = power utility provider, and 5 = other emergency response units). Also, a Kernel density analysis was employed to illustrate the spatial dispersion of these points. Figure 2(b) shows the location of emergency response units near the project location in the point map and in which area the dispersion is denser or more scattered in the Kernel density map. This type of dispersion analysis could assist project managers decide for which emergency response units they need to provide information to about the project.

Socioeconomic data analysis

The next analysis completed for the project used three bivariate choropleth maps for Cleveland County, in the state of Oklahoma, that were created to analyze the socioeconomic data (Figure 3). The data described in this section is the real-world data for the hypothetical project. By analyzing the community in which the project is situated, the owner and contractor could consider many factors during the pre-construction phase. For example, if an entertainment facility is planned, the data would be useful to evaluate if the proposed project would be profitable or if revisions are needed to increase profitability.

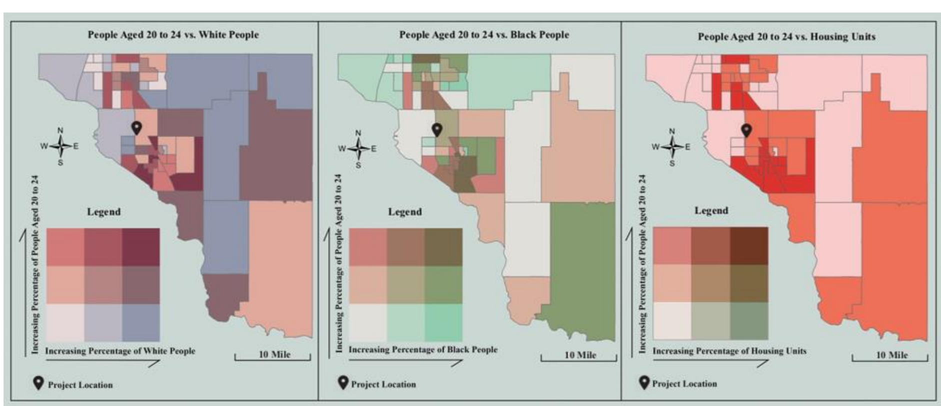


Figure 3. Bivariate choropleth maps

U.S. census data from the 2018 American Community Survey was used to analyze county residents age 20 to 24. This age range constitutes roughly 11% (30,363) of the total population (276,733) in the county. White and Black/African American county residents, along with existing housing units, were chosen to create different bivariate choropleth maps for this age range. The white population makes up approximately 78% (215,798) of the county's total population, and only 5% (12,860) of the population is black. As described earlier, the hypothetical project is a strip mall with space for several retail stores. By analyzing the two maps (people aged 20 to 24 vs. white and black people), the racial context of this age range in each tract around the project location could be identified. It also shows if the percentage of the two groups in different census tracts is increasing or decreasing. In the third map (people aged 20 to 24 vs. housing units), represents areas in which the construction of housing units has increased, which has led to more people moving into the neighborhoods located near the strip mall. It also demonstrates in which census tracts both variables are growing and which age groups are more likely to access to the strip mall. In a nutshell, this spatial data visualization would help the project decision-makers plan, design, and build their project based on the socioeconomic factors that may affect the project. This analysis is another example of a GIS data application for contractors.

Historical aerial photos and census data analysis

To illustrate the historical aspect of the project, historical aerial photos and Google Earth were used to reflect the transformation of land use patterns in the area surrounding the project location over a period of 61 years. The side-by-side photos in Figure 4 indicate the many changes in land-use patterns near the project. Three different patches around the project site were selected to demonstrate this transformation. The highlighted red patch shows the change from wasteland near the airport to the commercial land use pattern to support the area's commercial demands generated by the airport. The highlighted blue patch shows changes from a natural habitat to a more advantageous place for human activities to support the denser population. By comparing these two pictures, one can see that some natural habitats like natural corridors (waterways) have changed to create more residential land use pattern. The agricultural land use patterns in the highlighted yellow patch have also transformed into commercial land-use patterns.

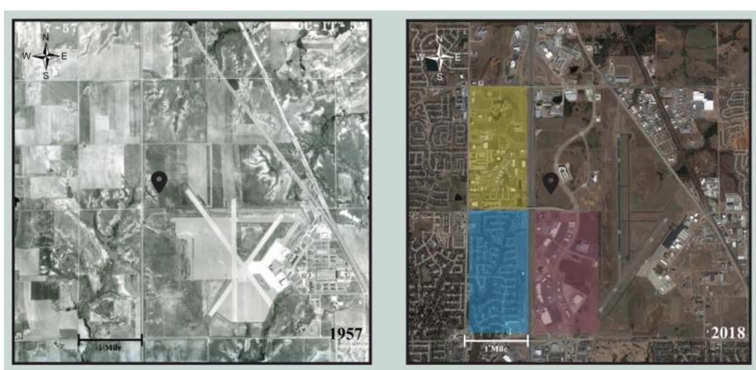


Figure 4. Comparison of land use in the project neighborhood in 1957 and 2018

To show another historical aspect of the project, the U.S. Census Bureau data was used to identify other changes over time. The data related to the number of housing units and the total population in the census tract of the project location for three different years were used for this analysis. The bar chart in Figure 5 shows an increase in the number of housing units by 29.28% between 2010 and 2018. An increase of 48.39% in the total population can also be seen from the analysis. However, the growth rate of housing units decreased between 2014 and 2018 compared to four years earlier, which indicates the opportunity for more housing units, and consequently, more population in the area. This type of analysis could be useful in the preconstruction phase of a project when the owner is most likely to request a feasibility study before design and construction.

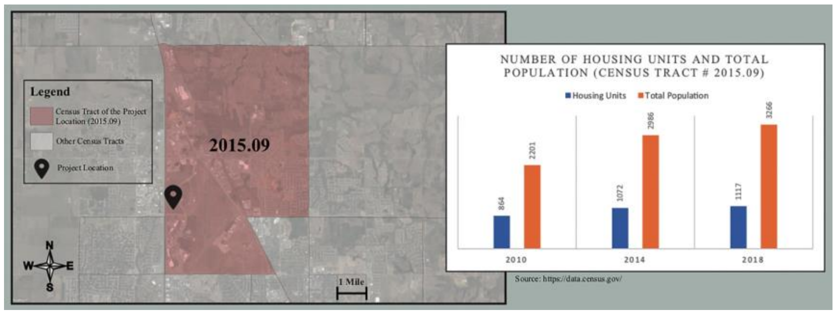


Figure 5. Change in the number of housing units and total population

Proposed Workflow

In addition to the five site specific analyses using GIS data discussed in the previous sections, the hypothetical project was used to test the integration of BIM and GIS data for operations and maintenance of the air handling units specified for the facility. As proof of concept, data about the AHUs for operations and maintenance was first input to the property field for the model element in Revit®. It was then exported from the model as a text file for import to ArcMap™.

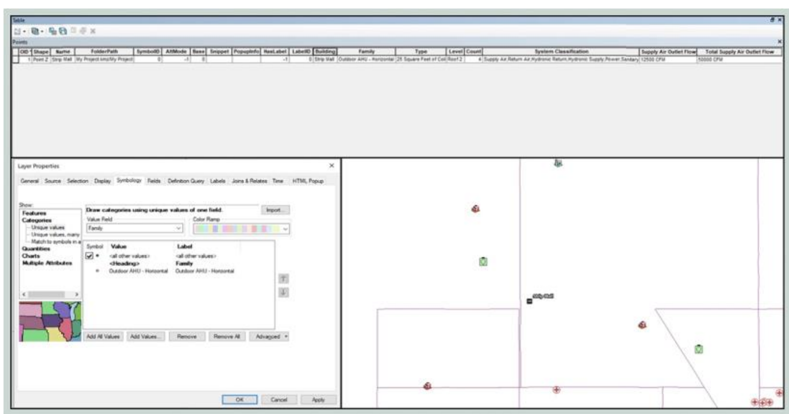


Figure 6. Attribute table, layer properties, and point map

To accomplish the integration, the following BIM workflow is proposed:

1. Input the relevant asset (e.g. AHU) data to the model element's property field in Revit® or other modeling software being used,
2. Export the schedule of air handling units as a text file,
3. Copy the required data to an Excel™ worksheet and organize it for import,
4. Save the file as a comma-delimited file (.csv),
5. Open ArcMap™ and join the .csv file to the desired layer (e.g. point layer) with at least one identical column in the Excel spreadsheet and the layer attribute table,

6. After joining the file, rename one of these columns to avoid confusion. In this case, the ‘Name’ column from the Excel™ file was renamed to the ‘Building’ column as shown in Figure 6,
7. Open the layer properties and add the values desired for visualization on the map under the Symbology tab as shown in Figure 6,
8. Export the map in the desired file type required to be used for different purposes, such as preventative maintenance.

Conclusion

In this paper, five analyses using GIS data, census data, and ArcMap™ were completed, and a workflow for the integration of BIM data with GIS data demonstrated. These analyses provide contractors with a set of results from project specific GIS data to be included with the project BIM and documentation handover for operations and preventative maintenance. Contractors can also use these analyses to prepare a comprehensive risk analysis plan, site logistics, site security, and safety plan for use across different phases of a project. In comparison with the previous studies discussed in the introduction section, the analyses completed in this study not only shows how GIS data can be used to inform a project BIM, but also introduces types of results and the usefulness of these results for contractors making critical decisions during the preconstruction and construction phases of a project.

In addition to the analyses, a practical workflow was defined using BIM and asset data for use by facility operators. This workflow offers contractors a step-by-step process to integrate building, infrastructure, and geographic data using BIM software, Esri ArcMap™, and census data. It is worth mentioning that the BIM data used in this workflow is limited to AHUs as proof of concept. Thus, the application of this workflow for other BIM components should be validated in future work. Furthermore, the proposed workflow has excellent potential to be used on a broader scale for more buildings like university campuses and similar facilities. Finally, the illustration of BIM and GIS integration using different analyses in this paper highlights a path for contractors to follow towards increasing the number of smart buildings, smart infrastructure, and smart cities. This paper makes two contributions to the BIM and GIS literature. First, this paper introduced five different GIS assessments that contractors can use to make decisions based on results from project specific location data analyses. Second, the paper demonstrated a workflow to integrate BIM data with GIS data. While the scope of analyses and workflow discussed in this paper is limited to a proof of concept, the BIM platform is a commercial off-the-shelf software (COTS) and the data sets are widely available for use by contractors, designers, and project owners.

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