BENEFITS OF INTEGRATING BIM AND GIS IN CONSTRUCTION MANAGEMENT AND CONTROL

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Abstract: Generally, a tremendous amount of waste and debris are generated by the demolition of existing buildings. Construction managers and site engineers are encountering difficulties in accurately calculating the volume of these materials, which have big influence on the duration and cost of projects. This paper describes the methodology used in developing a model that integrates Building Information Modeling (BIM) and Geographic Information System (GIS) to facilitate demolition waste management and control for megaprojects. The suggested model aims at facilitating the processes of estimating the quantities of waste by calculating the travel distance between the site, storages, and landfills and related time, as well as computing the number of trucks required for loading and hauling the waste from and to multiple sites. The main goal of this study is to demonstrate how this integrated model will provide construction managers with a comprehensive tool that could substantially benefit them in comparison to solely utilizing BIM. This paper will demonstrate how the model works and explain how it has the edge over using BIM only. The suggested BIM-GIS model will contribute to more green and efficient construction management. A hypothetical case project is given to test the workability of the model.

1 INTRODUCTION

BIM and GIS are powerful platforms widely used in the construction industry due to their various individual features and capabilities; however, each platform lacks important features the other platform offers. For instance, GIS provides topological (georeferenced) data, which allows for 3D analysis, spatial analysis, and queries such as calculating the distance between two different points, calculating routes, and defining the optimal location (Irizarry and Karan, 2012). BIM, on the other hand, is incapable of such analysis, but it provides a detailed database of object-oriented parametric information for the building and represents it in a 3D model, a feature that GIS is lacking (El-Mekawy, 2010). Research efforts conducted on leveraging the integration between BIM and GIS in the construction management process are rather scarce in comparison with ones that are carried on utilizing BIM only. Thus, this paper attempts to highlight various areas in which such integration is useful for construction managers and practitioners. Furthermore, the paper will underline some of the advantages of using the BIM-GIS model in managing the waste generated from the demolition of an urban development (a megaproject), plus controlling and monitoring some of the processes involved.

2 LITERATURE REVIEW

Poon et al (2001) pointed out that demolition (D) waste is estimated to be 10% to 20% higher in weight than waste generated from new construction (C). Llatas (2011) emphasized that as requirements for C&D
waste quantification become more and more accurate, concise and detailed, it is believed that computer-
aided estimation has good development prospects. Wu et al (2014) argued that one advantage of giving a
detailed classification of construction waste is that the chances of recovery of waste may be increased.
As a result of the urgent need for such tools, efforts to use BIM technology in construction management
have increased. Cheng and Ma (2013) developed a model to improve C&D waste sorting and
quantification and estimation processes by leveraging BIM tools. Jalali (2007) considered that the
estimation results could provide fundamental data for practitioners to evaluate the true size of the waste
and hence, make the adequate decision for their minimization and sustainable management. Wu et al
(2014) believed that the waste generation rates derived from different projects can assist in providing
information for benchmarking the effectiveness of different management practices. The optimal
technologies and work procedure can be selected by comparing the waste generation rates. Furthermore,
studies on the integration of BIM and GIS in the construction management field are few in general.
Irizarry, et al. (2013) developed a BIM-GIS integrated model to improve the visual monitoring of
construction supply chain management. Liu and Issa (2012) emphasized on the importance of 3D
visualization for pipeline maintenance and how it overcomes the shorting in 2D illustration. El Meouche, et
al. (2013) investigated multiple approaches to integrating BIM and GIS but did not propose a model or a
solution to a particular construction management problem. Isikdag, et al. (2008) suggested a BIM-GIS
model for the support of the site selection and fire response management processes. Irizarry and Karan
(2012) utilized BIM-GIS integration to optimize the location of tower cranes on construction sites. Other
research work, such as (El-Mekawy, 2010); (Berlo and laat, 2011) and others, worked on the
interoperability issues between BIM and GIS; and how to unify both domains at the semantic level to
make communication and the data transfer between the two platforms easier and more efficient.
Borrmann (2010) developed a spatial query language for 3D building models using tools and concepts
from GIS on BIM. The query language is meant to enable inquiring about walls located in certain story, if
a certain room is equipped with heating system tools, determining the columns that intersect with a
certain slab, defining the fire extinguishers positioned within a given distance from a certain building
component such as a window or a column, etc.

It is evident, based on the above literature review, that the research work done on BIM-GIS integration in
recent years has not suggested a solution for demolition waste management for megaprojects (urban
development), even though it is an important area with much room for optimization of the current
practices and numerous issues to solve. It also can be concluded that there is an urgent need to use
computers and technology in construction management and to explore how this will benefit professionals.
This study will establish how integrating a spatial analysis capability, in GIS, is rather beneficial and will
add greatly to the typical construction management practice of just using BIM tools. Hence, the suggested
model aims to facilitate the processes of waste estimation, sorting, and removal, on an urban scale, by
leveraging the capabilities of both BIM and GIS and it provides this to the users in a single unified place.
The model includes two main modules, a management module and a monitoring and control module, as
shown in Figure 2. Each module has subdivisions, two of which are under the monitoring and control
module, which are work progress and sustainable demolition practice implementation. The management
module includes three subdivisions, which are waste estimation, waste sorting, and resources
management. Later in this document, each subdivision will be explained in detail to show how the module
works and what privileges it provides over using BIM only.

3 METHODOLOGY AND DEVELOPMENT

Data transition, query and analysis between BIM and GIS are further problematic due to interoperability
issues between both platforms at a semantic level, among other issues (El-Mekawy, 2010). Thus, this
paper is going to demonstrate a methodology, based on a literature review of Isikdag, et al. (2008) and El
Meouche, et al. (2013), for integration between the two platforms, leveraging the GIS analytical and query
tools to perform some tasks on the imported BIM file. The two programs used in this paper are ArcGIS
10.2.2 by ESRI (as a GIS tool) and Autodesk Revit 2015 (as a BIM tool). The methodology used to
develop the integrated BIM-GIS model process flow is shown in Figure 1. Section 3.2 illustrates the main
modules encompassed by the model and explains how it works, presenting the capabilities and
advantages of the model comparing to solely using BIM. A hypothetical case project, in Section 4, will be used to test the workability and capability of the proposed model.

![Model process flow diagram]

**Figure 1: Illustration of the BIM-GIS model process flow**

### 3.1 Model Development

First, the Revit file of the urban development is exported as an IFC2x3 file. The BIM file’s coordinates should match the real world coordinates of the city or the region where the urban development is located, to allow for the drafted buildings to be set in the right place after the importing process. Once the file is imported into the GIS, all the families (objects) included in the design will be categorized and put in groups (feature classes), based on the type of that class. For instance, all doors will be put together in one feature class named IFCDoors, and the same goes for windows, walls, floors, ceilings, etc. Some IFC components such as doors and windows contain a mix of materials: aluminum, steel, glass, wood, plastic, etc. As this paper is part of an ongoing research project, the current model does not automatically separate those materials or distinguish between their condition (reusable, recyclable, and total loss). After that, the imported BIM (IFC) file is georeferenced by allocating the proper projection system. If the urban development BIM (IFC) file is going to be imported on an already existing transportation network and topography layers (triangulated irregular network, known as TIN), it has to have the same projection system as them in order for all layers to work properly. It should be noted that using a multiuser Geodatabase (.gdb) file is preferable when dealing with cases such as urban development or megaprojects, as it allows what is called “versioning” which enables data to be shared and used by different users simultaneously and allows nullable fields in the attribute table associated with the geometric features imported into GIS (ESRI, 2009). Afterwards, the user defines the work zones. Depending on the nature and requirements of their work, these zones could be digitized (drafted) manually using a GIS sketch tool or also imported if they are already drafted in the BIM file. Each zone should be given a unique name to avoid the issues of conflict and to ease the analysis processes. The zone allocation could be based on a variety of characteristics defined by the main contractor. Next, two major fields should be created, within the GIS, in the attribute table of each component or feature class (door, window, etc.) in order to facilitate the waste estimation, sorting, categorizing, and quantification processes. These fields are: “condition”, with the following attributes, reusable (onsite and non-onsite), recyclable and total loss and, if applicable, “classification” (Inert or Non-inert). Accordingly, each building component should be categorized and allocated one unique attribute from the aforementioned attributes. The proposed BIM-GIS model should be successful in estimating the demolition waste generated, sorting the waste according to material condition (reusable, recyclable, and total loss), material type or element (steel, wood, concrete, glass, plastic etc.) and estimating the number of trucks needed for loading and removing the waste. The material condition attributes (reusable, recyclable, and total loss) are to be put manually in the model based on experience from previous projects and/or data collected on materials and building components. Those attributes could be updated later based on a field survey of the actual buildings. The attributes could be entered manually into the BIM (IFC) model and then exported to the GIS or entered into the GIS directly. It must be emphasized that the output data acquired is only as good and as reliable as the input data is.
3.2 Model Components (Modules)

Figure 2 provides a detailed explanation of the model's components and its associated modules. In each module, there are subdivisions that represent the main operations involved in the demolition-waste management and control that the BIM-GIS model is capable of processing efficiently and in a timely manner.

![Diagram of BIM-GIS Module](image)

Figure 2: Explanation for the modules (components) of the BIM-GIS model

4 CASE STUDY

The case study provided in this document is hypothetical and meant to confirm the workability of the presented BIM-GIS model and aims at validating it, considering its efficiency for the purpose of C&D waste management and control. It encompasses twelve simple and similar buildings that are equally distributed over three different work sites. Each building includes 4 windows, 4 doors, ceilings, walls, stairs and railings with an approximate area of 2,000 ft². Land use (residential, commercial, and industrial) is assigned to the work zones (work sites) instead of lots on which the buildings are. This is because it will be hard for the reviewers to tell the difference at such a scale (urban scale) when reading this document. Also, the low number and simple structure of the buildings is meant to be as this case study is meant to test the workability of the model, which can be done sufficiently with the provided data. A true waste treatment facility, close to the project area as shown by Google maps, was selected and drafted in GIS as the destination point to which the demolition waste is going to be transported. The model is used to estimate the demolition waste, sort the materials and calculate the number of trucks required to remove the waste generated.

![Imported BIM (IFC) urban development into Arcscene](image)

Figure 3: Imported BIM (IFC) urban development into Arcscene.
5 THE BIM-GIS MODEL VALIDATION

5.1 Management

5.1.1 Waste Estimation

The waste estimation process in this model could be conducted in various ways. First, the fields required for the demolition-waste estimation process (material condition, total waste per material and land use), are created. All the required parameters and measurements for all the materials available in the building already exist in the imported BIM (IFC) file. Accordingly, the volume for all the materials is calculated by utilizing Equation 1. Then all the condition attributes, reusable (onsite or on other site), recyclable or total loss, are assigned to every single material. These different condition data could be determined first, based on standards or experience and then calibrated during the process of the demolition for more precision. After the previous steps, the utilizer could easily retrieve the information about the estimated waste volume in any way required. For instance, the user could use the model to estimate the total waste of a certain building, work zone (as in this case study), or for the entire project. This could be done by the “select by location” function in ArcMap’s (GIS) main menu. Also, the waste could be calculated for a certain type or condition of the materials one wants to inquire about, such as concrete, wood, steel, glass, etc., or reusable (onsite or other site), recyclable, or total loss. This also could be done by first “select the location”, as previously mentioned, of the wanted materials and then by the “select by attribute” function available in the ArcMap’s main menu. Equation 3 is used in the model for estimating the total loss that will be calculated after estimating the total waste, reusable and recyclable waste volume generated as illustrated in Figure 4. Even though BIM is capable of inquiring about materials according to their conditions, the proposed BIM-GIS model is evidently advantageous in terms of estimating the waste for targeted location exploiting the spatial relationships between objects. The model could also estimate the waste generated from a certain building located within a certain radius or within a certain distance from a street or another building. Furthermore, the model can include the waste index values discussed in (Cheng and Ma, 2013), such as the Global Index method introduced by (Jalali, 2007) and the waste index presented in (Poon et al., 2001). Cheng and Ma (2013) explained the waste index as the amount (in unit of volume or weight) of construction waste generated per m$^2$ of Gross Floor Area (GFA) and the global index as a more detailed method that allocates certain changes or increased percentages to every kind of building material. For example, concrete, steel, wood, glass, cement, and masonry have a value of 1.1, 1.02, 1.05, 1.05, 1.1, and 1.1 respectively. This could be easily done by creating a field named “increase factor” and assigning the values to the building materials, then, calculating the material adjusted volumes by using Equation 2. The previous step could be applied to any adjusting factors needed to be calculated even if it is related to the land use or project type, such as private residential, public residential, or commercial buildings. GIS also enables associating the attributes of one layer such as “land use” with all the building components by using a feature called “Spatial join.” This is one of the multiple features that GIS boasts, which the BIM tool lacks and thus could not run such process with the same efficiency if at all. Finally, maps, using BIM-GIS model, could be produced for determining the locations of the components need to be demolished with associated attributes and estimation to provide the workers or practitioners with a target volume to consider while demolition of the building or part of it. Also, a detailed description for the component could be printed out using the layout tool in GIS. Figure 5 shows how the model can estimate the waste volume for single building component.


Figure 4: Waste volume calculations generated by the BIM-GIS model.

Figure 5: Calculation of the waste volume for a single component (doors) in three different zones.
5.1.2 Waste Sorting

The BIM-GIS model helps in performing a variety of data manipulation, enquiry and analysis. The model allows users to run customizable sorting for the demolition-waste generated by placing it under three main categories; these are: by condition, material type and component. Each category is then subdivided into different attributes depending on the category as shown in Figure 6.

Each component in the building should get one unique attribute from the attributes given in this subcategory; these are: reusable (onsite or other site) and recyclable. Total loss could be subdivided into inert and non-inert material if needed. As stated by (Zhang et al., 2012) common inert materials include but are not limited to: “reinforced concrete, asphalt, cement plaster, mortar, aggregate sand, bricks, rocks, rubbles, and soil.” Common non-inert materials include but are not limited to: “wood, metal, plastic, and other organic materials.” Each sorting attribute, recyclable for instance, could then be exported using the GIS export option into a new separate layer (feature class) that could be used separately for further analysis and statistics. The model offers users with an abundance of analysis and statistics capabilities that are only possible by integrating BIM with GIS. Thanks to its feature of relating space (location) to geometry, the user can run analyses or ask questions such as “how much is the volume of recyclable materials generated in this zone?” and compare them to the other zones. This could help in identifying or studying the type of buildings that generate more recyclable, reusable or total loss materials and sorting them according to different attributes such as the age of the building, the structural system, etc. (This type of query is not part of this paper; therefore, its results were not included).

The BIM-GIS model also helps users to perform statistics on the types of materials in the demolition-waste estimate. For instance, the user can inquire about the amount of steel that would be generated in a particular building or zone. This sort of analysis and estimation is beneficial for the workers to help them plan and prepare their demolition operation. Also, by using the export feature class option within ArcMap, the users could isolate any material of interest in a separate layer to further analyze and perform more statistics and analysis as needed. By adding the cost of the different waste materials generated, the user could estimate how much money, as return on investment in some cases, could be gained in this case. This, again, can be estimated on the different project’s scales previously discussed.

The model will provide subcontractors with necessary information such as the number of doors or windows in the building or area that needs to be demolished. Also it enables the operator to run such statistics in different levels or scales. The user can inquire for information about multiple buildings, a certain work zone, for the whole project area or even according to land use. This feature is unavailable for BIM users, as spatial data analysis, which BIM lacks, is required in order to get this type of information.
Furthermore, detailed specifications and drawings can be printed out for the workers to recognize the specified components along with maps showing exactly where they are in the building.

Resource Management:

Cheng and Ma (2013) calculated the number of trucks, as many studies did, by dividing the volume of waste estimated by the truck capacity. The suggested model can instantly calculate the distance and travel time between the waste location and the target destination as well as the number of trucks required for the process of removing the waste as demonstrated in Figures 7 and 8. However, this is not accurate enough, as the distance between the waste location and its final destination ought to be taken into consideration in order to get the appropriate number of trucks based on trip frequency as shown in Equation 4. Some other pieces of information, along with the round trip time, should be included before using that equation, which are the truck loading time, unloading time, time needed to check the load, and wash-up time. These parameters, with the round-trip time, are part of the “Total round-trip time (min).” Using this approach, no trucks will be waiting for the other trucks to finish loading nor will there be any idle time waiting for trucks to come back and start the loading process. To test the workability of this method, we can take the volume of the recyclable materials shown in Figure 8 that have a volume of 785.68 m$^3$ as an example. The number of trucks is estimated to be 112 considering a 7m$^3$ truck capacity. This is a huge number, of course, considering the estimated volume. To calculate the number of trucks for the same volume of waste first, values of the different parameters included in the equation are assumed as: unloading time = 10min, loading time = 10min, checking time = 5min and washing time = 5min. The total in this case will be 30min and the travel time between the site and the recycling facility, as shown in Figure 7, is around 22min, which will make the approximate overall time to be 74min. Using Equation 4 the estimated number of truck will be 74/7=10.57 trucks, which is rounded up to 11 trucks. It is obvious that the difference between both numbers is substantially big, therefore the smaller number (11 trucks) is selected and this number can be adjusted based on the work productivity on site. The estimated number of trucks will increase as the trip time increases, which means that locating closer facilities is essential for this process, a spatial problem that the integrated model could solve instantly. This method (total round trip time) is used when the number of trucks does not exceed the number of loads estimated; therefore, both numbers have to be acquired and compared.

\[ [4]: \text{Total round-trip time (min) ÷ unloading time (min) = Number of trucks needed} \]

Figure 7: The route distance and time calculations generated by the BIM-GIS model.
5.2 Control and Monitoring

5.2.1 Work Progress and Application of Sustainable Demolition Practice Onsite:

The subcontractors’ progress and efficiency in applying the best practices in demolition and sustainable waste management could easily be monitored with the developed model. Once the total waste is estimated, a certain percentage (5-8%) could be considered to cover potential error, then whoever is responsible for record-keeping can easily identify if a percentage of waste (recyclable or reusable) generated is far less than estimated, and can track down the reasons that led to this shortage. This could, again, be performed on the different scales (building, block or zone, and the entire project) as discussed previously in this document. On the other hand, the workers should be notified of the amounts expected from them to maintain the minimum level of applying the sustainable practices in the task performed, as mentioned previously in the literature review. The developed model is a useful tool to perform the tasks required from them adequately. Also, the model provides a useful tool in terms of establishing and calibrating benchmarking for the different types of waste generated as it can record the rate of the waste generated based on material condition, type, and component and compare among the results.

6 CONCLUSION

A BIM-GIS model is demonstrated in this paper, providing outstanding capabilities for facilitating some of the most demanding and experience-dependent processes in planning, management and control during the demolition phase of megaprojects. These procedures involve waste-sorting, estimation, and estimating the number of trucks required for loading, hauling, and removing the demolition waste. The model was validated and proven to be beneficial when it was tested using a hypothetical, but realistic, case study and capable of performing all the aforementioned tasks successfully and sufficiently. The model has even been proven to be able to go far beyond the scope and tasks discussed in this paper, which will lead to more research and testing in order to improve the model in the future. The analytical comparison between the capabilities of the proposed BIM-GIS model, versus using BIM tools solely, ...
emphasizes the benefits of the combination of spatial data and the object-oriented data of buildings in the construction management field. This paper is part of an ongoing research that seeks to improve the current model in terms of applications in construction management in general and the demolition phase and urban planning, management and control in specific. In addition, future work will focus on increasing the automation and integration procedures between GIS and BIM to further facilitate the use of the model and to maximize its benefits. Finally, there is no doubt that integrating BIM and GIS will enrich the current construction management and control tools used in the industry by adding a vast variety of new functions, all performed in one single place.

References


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