www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

OPTIMIZING LOCATION OF TOWER CRANES ON CONSTRUCTION SITES THROUGH GIS AND BIM INTEGRATION

SUBMITTED: March 2012
REVISED: August 2012
PUBLISHED: September 2012 at http://www.itcon.org/2012/23
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SUMMARY: *Tower cranes, on today's typical building construction sites, are the centerpiece of production, hoisting and transporting of a variety of loads. Occasionally tower cranes operate with overlapping work zones and often under time, cost and labor constraints. Identifying optimal number and location of tower cranes is an important issue that can reduce conflicts between groups of tower cranes. Geographic information systems (GIS) facilitate the analysis of large amounts of spatial data used in the process of location optimization for tower cranes. In addition, integrating analysis results from GIS with 3D visual models enables managers to visualize the potential conflicts with tower cranes in great detail. Building Information Modeling (BIM) helps managers to visualize buildings before implementation takes place through a digitally constructed virtual model. Hence, in this paper, the integrated GIS-BIM model starts with the identification of feasible locations for defined tower cranes. The method presented is based on previous works using "geometric closeness" and coverage of all demand and supply points as key criteria for locating a group of tower cranes[*)]. Once the geometry of the construction site is generated by the BIM tool, the model determines the proper combination of tower cranes in order to optimize location. The output of the GIS model includes one or more feasible areas that cover all demand and supply points, which is then linked to the BIM tool and generates 3D models to visualize the optimum location of tower cranes. As a result, potential conflicts are detected in different 3D views in order to identify optimal location of tower cranes. To address the feasibility of a GIS-BIM integrated model for layout of tower cranes, an actual case example is introduced.*

KEYWORDS: *Tower Crane, GIS, BIM, Interoperability, Spatial Analysis, 3D Visualization*

REFERENCE: *Javier Irizarry, Ebrahim P Karan (2012). Optimizing location of tower cranes on construction sites through GIS and BIM integration, Journal of Information Technology in Construction (ITcon), Vol. 17, pg. 351-366, http://www.itcon.org/2012/23*

1. INTRODUCTION

Tower cranes are considered as the centerpiece of construction equipment in building projects. They play a key role in transporting a variety of materials vertically and horizontally. The efficiency of tower cranes largely depends on their type, number and location. As the number of work tasks and the demand for tower cranes increase, planners may experience difficulties in making an appropriate decision about the optimum layout of tower cranes. A poor

[*)] Supply points are the locations where the object needs to be lifted (loading points) and demand points are the locations for unloading the object.

decision, however, is likely to have significant negative effects, which will lead to additional costs and possible delays (Al-Hussein et al. 2006).

On typical construction projects, the selection of the appropriate crane can have a significant influence on the cost, time and safety of construction operations (André and Sawhney 2001). Due to this role, many models have been developed over the past 20 years for solving tower crane problems, generally related to financial and operational efficiency. Some of the literature addresses safety issues associated with tower cranes (Shapira and Lyachin 2009; Shapira and Simcha 2009a), whereas others rely on improving the crane operation (Rosenfeld and Shapira 1998; Appleton et al. 2002; Ju and Choo 2005; Shapira et al. 2008), or involve cost forecasting models (Jung et al. 2006). Most crane location-related studies relied on the use of mathematical programming formulations. Some of these methods were designed to minimize the total crane transportation cost (Rodriguez-Ramos 1984 and Francis 1983; Furusaka and Gray 1984; Zhang et al. 1996). Researchers have also developed mathematical models in an attempt to decrease total crane transportation time. Choi and Harris (1991) introduced a model to optimize single tower crane location by calculating total transportation times incurred. Leung and Tam (1999) used multiple linear regression techniques to determine the optimal location of cranes in terms of minimizing the hoisting times. Others have used mathematical algorithms for different artificial intelligence techniques in order to optimize crane location. Li and Love (1998) and Philip et al. (1997) used genetic algorithms (GAs) to optimize a set of temporary facilities. Tam and Tong (2003) developed genetic algorithms and an artificial neural network model (GA-ANN) for predicting tower´crane operations and site layout. However, only limited attempts have been made to determine the optimal number and location of tower cranes based on a graphical programming environment. Notable efforts were made by Farrell and Hover (1989), who developed a database supported by a graphical user interface for selecting and locating cranes, and by Alkass et al. (1997), who developed a computer system capable of assisting the users in crane selection.

In many cases, decisions made on the selection and location of cranes govern the selection of other equipment (Shapira et al. 2007). In the interests of safety and efficient operation, Zhang et al. (1999) proposed a model to locate a crane group based on the concept that the workload for each crane should be balanced. In this approach the lowest possibility of conflict concept was applied to identify optimal location for cranes. Although these studies can handle issues related to tower crane problems such as locations and operation, there are limitations that need further research. One main limitation to be further investigated is the type and number of cranes that should be predetermined at the early stages. Also, for each supply point (S), only one demand point (D) can be applied in the model. In addition, many of the previous studies failed to consider the supply locations as an alternative to determining optimal crane locations.

The location and type of tower cranes are closely related to the shape, position and spatial characteristics of the loads and obstacles. This spatial data is mainly used in the process of location optimization for tower crane(s), which is possible to be analyzed in large amounts by geographic information systems (GIS). The optimal number of tower cranes is a function of their locations and the geometric layout of loads. On the other hand, GIS support the wide range of spatial data that can be used to support location problems. The advantage of GIS-based methods is that they directly use spatial aspects of the construction site and display output in a suitable form to the user (Sebt et al. 2008). For these reasons, GIS is found to be useful for such purposes. In addition, visualization techniques can be used to further enhance the functionality and integrity of GIS models. Zhong et al. (2004) and Bansal and Pal (2007; 2009) are among the studies that utilized the visualization capabilities of GIS. Zhong et al. (2004) presented a three-dimensional (3D) GIS model to show the construction of a concrete dam, Bansal and Pal (2007) applied GIS for building cost estimation and visualization, and Bansal and Pal (2009) developed a GIS based navigable 3D animation to review project schedules.

However, due to the limitation of GIS tools in automated drafting and lack of semantic information about building elements, one can utilize different visualization tools. Regarding the distance between the crane's cab and load location, finding an optimal place for the tower crane plays an important role in improving operator's view. To respond to this need, it is appropriate to model the operator's viewpoint through the use of Building Information Modeling (BIM). Furthermore, visual representation can be extended to monitor the crane's movements and to prevent the collision of tower cranes operating in a shared work zone. In reality, the number of structural elements (obstacles) increases with construction progress. Cranes must not only avoid collisions with these elements that have previously been installed but also need a collision-free path for each subsequent element to be installed (Kang and Miranda 2008). The snapshots generated by BIM are capable of appropriately representing the changing construction environment.

In our research, GIS is used to develop a crane location model where closeness relationships are generated by means of spatial analysis functions. In order to achieve the lowest possibility of conflict, the present model incorporates a newly developed conflict measurement named *crane conflict criterion* (C3). The C3 demonstrates the amount of the intersection area between cranes. It should be noted that while in this paper the lowest possibility of conflicts is used as criterion of location optimization for cranes, it is also possible to use any other criteria that can be valued in terms of cost or time. In this regard, the objective function of the model should be set to obtain the minimum total crane cost. BIM is employed to develop building models and to visualize the results of the GIS model in a 3D virtual world. In this sense, BIM provides the model with the capability to simulate the operator's viewpoint in order to detect potential collisions between tower cranes and objects in the worksite environment.

2. INTEGRATION OF GIS AND BIM

While BIM systems focused on developing objects with the maximum level of detail in geometry, GIS are applied to analyze the objects, which already exist around us, in most abstract way. Therefore, to visualize existing topography and a new facility to be developed together we need more research on integrating the data models of BIM and GIS (Bansal 2011). Several studies have been conducted to explore the application of GIS technology in BIM environments and BIM models in the geospatial domain. For instance, Isikdag et al. (2008) investigated the application of BIM (IFC in particular) in a geospatial context in order to improve the transfer and representation of information between these two domains. Choi et al. (2008) also established a prototype system to demonstrate the feasibility of BIM models to support indoor GIS applications. Peña-Mora et al. (2010), on the other hand, recognized the need to integrate different IT technologies, such as GIS, RFID and digital building information, in one reliable platform for emergency response management.

However, aforementioned research efforts have focused on either BIM or GIS. Real integration of BIM and GIS is achieved by using the strengths from both the BIM and GIS world in the context of the other, which has been recently proposed (Elbeltagi and Dawood 2011; Zhang et al. 2009). Before an integration approach is developed, the advantages and differences between BIM and GIS should be considered. To develop a BIM-GIS model, it is essential to bring the benefits of both technologies together into a single comprehensive model. GIS builds upon existing information and objects; so, BIM should be used to create the building information. On the other hand, the lack of spatial analysis capabilities in BIM underlines the need for utilizing GIS. The major incompatibilities that exist between the technologies have been provided in Table 1. Integrating these two technologies depends on the assumption that there are applications from both domains, which can maximize the value of both (Laat and Berlo 2011).

TABLE 1: Incompatibilities between BIM and GIS

	GIS	BIM
Modeling Environment	Mainly focus on outdoor environment. An outdoor activity may need to be positioned in GIS.	Focused mainly on indoor environment. Outdoors applications are limited to the outside of buildings. 3D modeling of site utilities and terrain modeling are also available in BIM.
Reference System	Geospatial data is always georeferenced. Objects are defined in a physical world with global coordinate systems or map projections.	BIM objects have their own local coordinate systems and a reference to a global coordinate system, for example at the left corner of the building.
Details of Drafting	GIS builds upon existing information and objects. It covers a large area with less detail and in smaller scales.	Drafting capabilities of BIM are utilized to develop larger scales with higher level of details.
Application Area	GIS is focused on urban and city areas.	BIM is rooted in the building and its attributes.
3D Modeling	GIS capabilities are limited to simple 2D shapes. Experimentation with 3D in GIS is in an early stage.	BIM is unique in its ability to work in full 3D environment. BIM has a rich set of spatial features and attributes.

Enabling interoperability at the semantic level is an important issue for the link between BIM and GIS. The key to conducting interoperability at the semantic level is to make sure that the relationship between two different disciplines is maintained during data transfer. To solve this problem, Bishr (1998) suggested a mechanism that automatically transforms the relationship from one discipline to the other. Efforts to enhance interoperability within the AEC industry and GISs have been made during the last two decades. Among the most prominent of these models are the Geographic Markup Language, GML, and the Industry Foundation Classes, IFC (Halfawy 2008).

The Open Geospatial Consortium (OGC) introduced the GML for data interoperability in the geospatial community. GML allows complete data transfer between different databases and application software, which results in application schema (Peachavanish et al. 2006). In order to demonstrate and promote such standards, OGC initiated collaborative efforts (such as the interoperability program) in the 3D domain, which resulted in many opportunities and discovered issues related to CAD-GIS-BIM architecture (OGC 2007; OGC 2008). Another important effort is CityGML, an open data model and XML-based format for the storage and exchange of virtual 3D models. It is implemented as an application schema for the GML3 (OGC 2008). While recent attempts to integrate BIMs within CityGML models have value, there are some limitations to encompass a comprehensive BIM-GIS solution. For example, CityGML has been limited in use to exterior buildings and their surroundings.

The IFC is developed by buildingSMART (formerly the International Alliance for Interoperability or IAI) to support interoperability throughout the AEC community. By providing a standard language for exchanging construction data, the IFC has been established as a viable interoperability technology (Froese 2003). Although much of the IFC contents are specific to the building, buildingSMART has been working on extending the scope of IFCs to other civil engineering domains, such as GIS-based systems. In this context, the Industry Foundation Classes for Geographic Information Systems (IFG) has been developed for enabling the exchange of geographic information in GIS with the IFC schema (see http://www.ifcwiki.org/index.php/IFC_for_GIS). However, the prospect of achieving full-fledged semantic interoperability among users depends on the degree of agreements at both the application level and the tool level (Peachavanish et al. 2006). On the BIM side, the integration is made possible by providing accurate and detailed data, so GISs can acquire the needed real-time information in order to represent building components in the geospatial environment. On the other hand, GIS can perform different spatial operations, which is not yet possible in BIM technologies. For this reason, the model proposed here uses BIM capabilities to accurately provide geometric and semantic information about building elements and GIS to support the wide range of spatial analysis used in identifying optimal locations for tower cranes in terms of minimal amount of conflict. Thus, the time required for the input of detailed geometries of building materials and construction site conditions can be largely diminished.

This research aims at providing semantic interoperability at the application level. Integrating BIM and GIS at the application level can provide an effective way to identify optimal solutions for selecting and locating tower cranes. The advantages of this approach derive from its two main innovations: (1) implementing BIMs in geospatial environment, and (2) quantifying space conflicts between tower cranes and their surroundings in both domains.

3. OPTIMAL LOCATION OF TOWER CRANES

Having the characteristics of tower cranes and location of supply and demand points, it is possible to determine the number and optimize the locations of the tower cranes. The optimization process involves five primary steps:

1) Determining the geometric layout of supply (loading) and demand (unloading) points with their maximum load, and type of available tower cranes;
2) Generating feasible areas for locating the tower cranes;
3) Grouping tasks into separated classes based on closeness relationship;
4) Determining minimal number of tower cranes;
5) Optimizing location of tower cranes in order to minimize potential conflicts between tower cranes and other facilities. Each crane has its load chart that specifies lifting capacity. The maximum capacity is always obtained by the shortest crane's operating radius. The method presented for grouping tasks is based on prior work by Tam et al. (2001) and Zhang et al. (1999).

In order to lift a load at supply point (S) with the weight w, a tower crane should be placed within a circle centered at S and with lifting radius R, where R is the minimum of the tower crane's jib length (Cr) and operating radius (r) obtained from the load chart. For example, assume that the crane's operating radius, r (in metric unit), can be calculated by the following equation: r=90-6w, where w is the load weight (tons). Also, assume that the jib length (Cr) is 60 m. Therefore, R is equal to min{60,90-6w}. It can be seen that the maximum capacity for this tower crane is less than 15 ton (for r=0), and for w=10 ton, R is 30 m. However, for w<5 ton, the corresponding R is 60 m. As illustrated in Fig. 1(a), to transport a load between (S) and demand point (D), the tower crane should be placed within the intersection of two circles describing operating areas for S and D. The size of this oval shaped area is determined by the crane's lifting capacity, the length of its jib, and the distance between S and D. This area is called feasible task area.

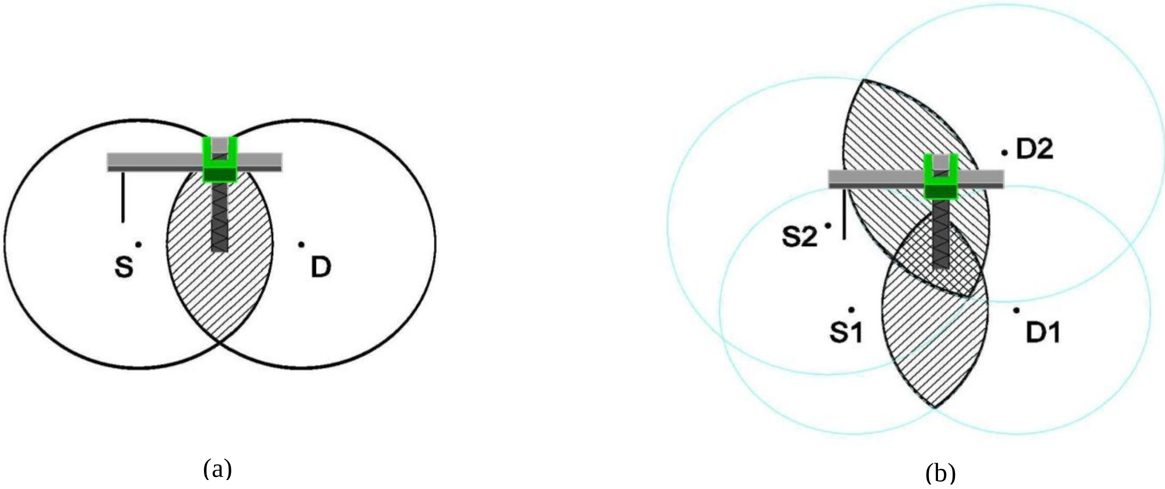

FIG 1: Feasible task area for supply (S) and demand (D) points (a) single task (b) multiple tasks

In the proposed model, it is possible to consider more than one demand point for each supply point. In this situation, supply points and related demand points have the same weight load and their feasible area may not necessarily result in an elliptical shape. In reality, there may be more than one feasible area within a construction site. A tower crane can handle two tasks, if it is located within the area of intersection between them (Fig. 1(b)). If there is no overlap between tasks, then a single tower crane is not enough to handle both tasks. The geometric closeness of tasks can be measured by the size of the overlapping area (the larger overlapping area, the greater closeness). For instance, area A in Fig. 2 is a feasible area of a task group consisting of three tasks, where Task 5 is said to be closer to the task group than Task 4 since the overlapping area between A and Task 5 (i.e. B) is larger than that between A and Task 4 (i.e. C). If a tower crane is located in B, it can handle three tasks in the group and Task 5, while a tower crane in C can handle Task 4 (instead of 5).

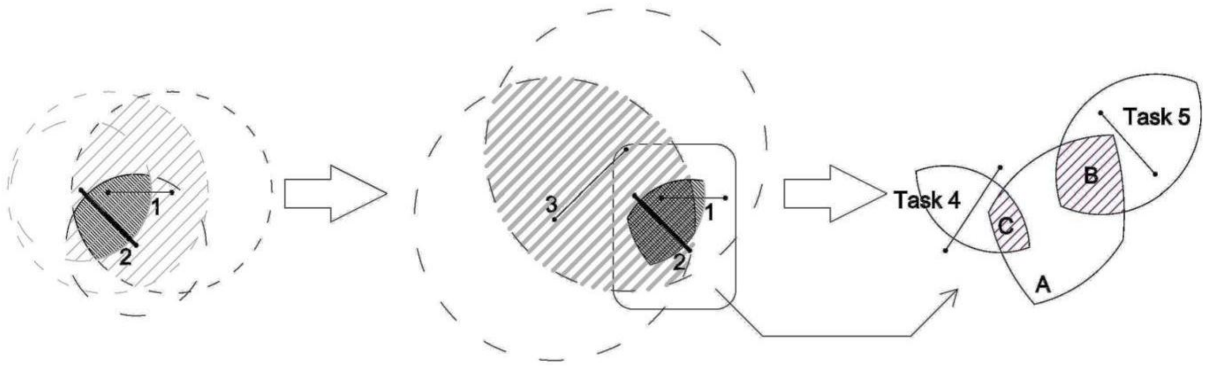

FIG. 2: Task closeness (adopted from Zhang et al. 1999)

The model starts by assigning initial tasks to different (crane) task groups. In order to reduce the computer running time, tasks furthest apart are given priority as initial tasks. This can be determined by minimal overlapping area between two task groups. Then the remaining furthest away task is added to the task group to develop a new feasible area. The process is continued for all remaining tasks until no tasks have an overlapping area within the present group. With regard to coverage of all demand and supply points, the model repeats these steps for unassigned tasks. The result consists of one or more feasible areas that represent the required number of tower cranes. In most cases, more than one alternative is feasible. In order to reduce total cost, the alternative with the minimal number of tower cranes is selected.

The model considers the least possibility of conflicts as a criterion for optimizing location of cranes. The possibility of conflicts is measured using the overlapping area of the tower cranes assigned to each group. A larger overlapping area between two or more cranes may result in longer presence of the cranes in this shared area and therefore there will be a higher risk of collision (Shapira and Simcha 2009b). Thus, the model searches for places with minimum overlapping area between cranes and their surrounding facilities. The negative effect of space conflicts on safety and productivity has been addressed and studied by several researchers in the past. Because the possibility of conflicts is directly related to the tower crane's work zone, the severity of conflicts is measured by the proposed spatial index. The model utilizes a measurement defined as crane conflict criterion (C3) to quantify the severity of conflicts between tower cranes and their surroundings. C3 can be calculated by the following equation:

$$C3=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(A_i\cap A_j\right)+\sum_{i=1}^{n}\sum_{j=1}^{n}\left(A_i\cap F_j\right)}{\sum_{i=1}^{n}A_i+\sum_{i=1}^{n}\sum_{j=1}^{n}\left(A_i\cap F_j\right)}$$

, where A_i is the crane's work zone and F_j is the area of facility j.

Therefore, $A_i \cap A_j$ refers to the amount of the intersection area between cranes and $A_i \cap F_j$ denotes the intersection area between cranes and surrounding facilities. Optimal locations are defined as locations with minimal C3. The final step is to represent the results with minimal C3 in a 3D virtual world. In this sense, BIM enables the 3D modeling of possible conflicts *before* locating real tower cranes in the field. As described above, geometric attributes and spatial relations among tower cranes play a large role in selecting and determining the optimal location of cranes. The process of finding the location is closely related to the spatial characteristics of the construction site (e.g. shape, size, topography) that can be derived from a BIM. However, such information from BIM cannot be manipulated easily by using mathematical techniques. This is probably the major reason why mathematical optimization in the literature was only successful for a single or very limited number of cranes. On the other hand, GIS have already been successfully used to solve construction layout problems. Using the spatial analysis functionality provided by GIS, such as overlay operation, proximity and neighborhood functions, GIS facilitate the analysis of large amounts of spatial data used in the process of location optimization for tower crane(s). It improves construction and space planning by integrating spatial (e.g. crane's operating radius) and non-spatial information (e.g. crane's lifting capacity) in a single environment.

To illustrate and explain these steps in detail, an actual case study is used and described in the following section. The case study approach was chosen because it enables the most effective evaluation of how the model can be used. The case study shown below can be considered as a large and complex project, including five tower cranes and the wide range of component information associated with the building. However, the principal concept of the developed model can be used also for small and medium-size projects, in addition to large-size projects.

4. CASE STUDY

The methodology outlined above was employed to determine the needed tower cranes and their optimal locations for a commercial building project. The project is a commercial complex located in Tehran, Iran, consisting of 6-story shopping mall, entertainment complex, underground parking, and recreational facilities with a site area of 8 acres (32000 m2) and a total gross floor area of 128,200 m2. The location in an urban area with limited workspace and its proximity to congested throughways are factors that require the contractor to utilize tower cranes. In order to demonstrate the model's capabilities, three different types of tower cranes (as listed in Table 2) are taken into account when identifying the optimal locations. Although the crane's prices are not included in the table, the model is capable of considering different combinations of tower cranes to minimize the total cost. In this case, after grouping the tasks based on different types of cranes, the process starts with assigning a tower crane to a task group and generates the remaining task groups based on different types of cranes. The process is repeated for all tower cranes, until the best crane combination that has the minimal cost is reached. In many practical cases, the type and number of tower cranes are fixed, and the contractor attempts to find the optimum or nearoptimum location for each supply point on the construction site. The same procedure can be applied to deal with the cases involving supply points as dependent variables (i.e. calculate C3 or total cost of different layouts instead of tower cranes).

TABLE 2: Characteristics of tower cranes for the case study

	jib length (m)	height (m)	footprint (m^2)	radius-load equation[1] ($r = a - b \times w$) r = operating radius (m), w = weight of load (ton).
Crane 1	70	63	36	a = 85, b = 7.5
Crane 2	55	56	36	a = 56, b = 4.7
Crane 3	50	45	25	a = 60, b = 13

[1]obtained from the crane's load chart

Fig. 3 describes the architecture of data exchange between GIS and BIM for optimizing location of tower cranes. The procedure involves the following steps:

Step 1: Create BIM model. The building's spatial geometry is defined at this stage, and the weight of each load is determined based on the material being used. The locations of supply and demand points are represented by the centroid of an area where the material components are assigned. In order to provide accurate analysis, it is best to use as small of an area as possible. This approach makes the points closer to their real locations. For instance, suppose that there are three points (supply or demand points), which are represented by the centroid of an area. Using more (e.g. three) areas for representing these points will obviously result in more accurate locations than those from one area. One hundred and fifty points have been used as supply and demand points in the case study. In order to support and facilitate interoperability with the GIS application, the model has been developed based on the IFC standard. There are many available commercial BIM software applications (e.g. Autodesk® Revit, Graphisoft's Archicad, Vico Software, Bentley's Micro Station, etc.) that support the IFC standard. In this study, Autodesk® Revit Architecture 2012 was used to accomplish this step. The BIM module automatically measures density (mass) and areas so that the required information could be provided as soon as it was modeled into Revit Architecture and then exported to a central database (e.g. MS Acess). In particular, the information acquired from the BIM are the locations of supply and demand points, the geometry of temporary and permanent facilities, and the available places for locating tower cranes on the construction site. Fig. 4 shows the top view of the case study with the location of the facility to be constructed.

Step 2: Calculate the lifting radius (R) for each load. As mentioned earlier, R is the minimum of a tower crane's jib length (Cr) and operating radius (r) obtained from its load chart. To lift a load of 2 tons, for instance, the lifting radius (R) is 70, 46.6 and 34 m for crane 1, crane 2 and crane 3, respectively. In this step, the weights assigned to each of the supply or demand points should be limited to the maximum load for every lift. In the case study, the maximum weight of lifts was 3 tons. The products of this step are points annotated with their lifting radius (R), which are stored as single {X, Y} coordinate pairs.

Step 3: Generate feasible task areas. Using the lifting radius quantities calculated from step 2, the feasible area of crane location for every point can be generated. This area is a circle centered at the supply or demand point with a radius of (R). The ArcGIS application was used to perform the spatial analysis needed in the process of location optimization for tower crane(s). Creating feasible areas to a specific distance (R) around the points can be performed using a buffer (analysis). In this case, points are an input feature and the buffer distances are dependent on the R values. The intersection of the circles belonging to the same task creates the feasible task area. The intersect tool available in ArcGIS can be applied to calculate the geometric intersection of feasible areas within the same task group. The shape of the feasible task area depends on the location of task points relative to each other and the type of crane being used. Also, the area of the permanent facility (i.e. the building project) and areas outside of the site boundary must be subtracted from task areas, because it is not possible to locate tower cranes in those regions. This can be done by erase analysis function design in ArcGIS. The GIS data produced in this step are a new set of polygons having attributes of the task's name and type of tower crane. In addition, all required spatial attributes such as area and perimeter are automatically generated when the polygon data is generated. It is expected that the feasible task areas for crane 1 are larger than that for crane 2, and crane 2 has the larger feasible task areas than those for crane 3. It could be seen in Fig. 5, for example, that the area corresponding to crane 1 encompasses the area corresponding to crane 2, and the feasible task area for crane 3 is surrounded by that for crane 2. Overall, there are 50 feasible task areas that have been employed in the case study.

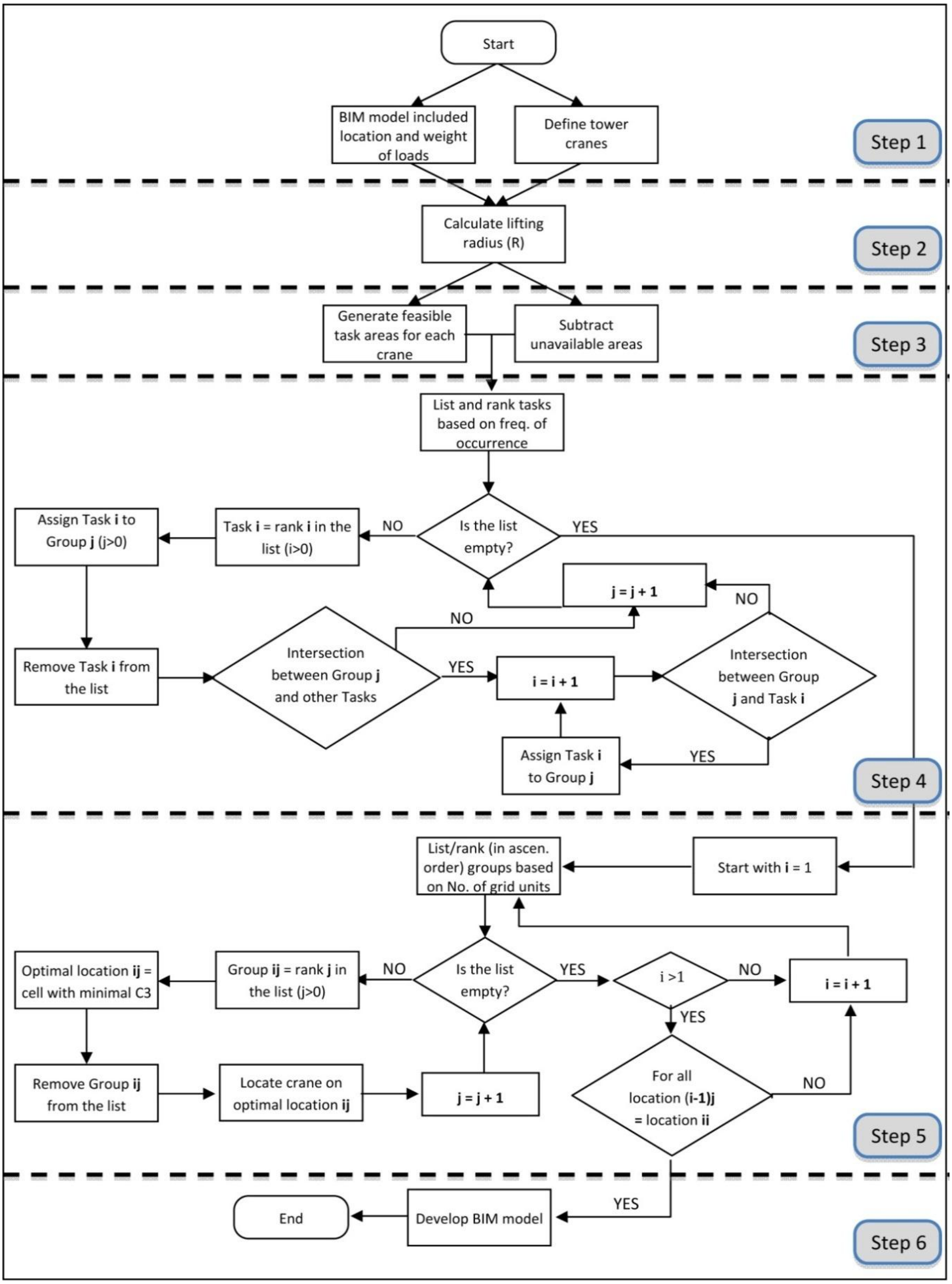

FIG. 3: Flowchart of GIS-BIM optimization location model

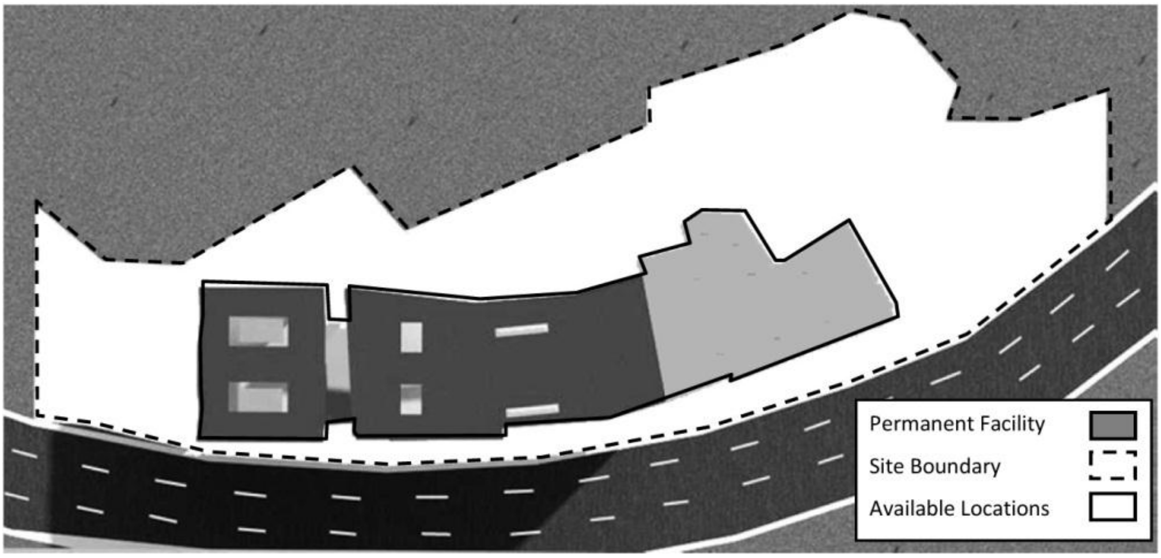

FIG. 4: Case study site layout

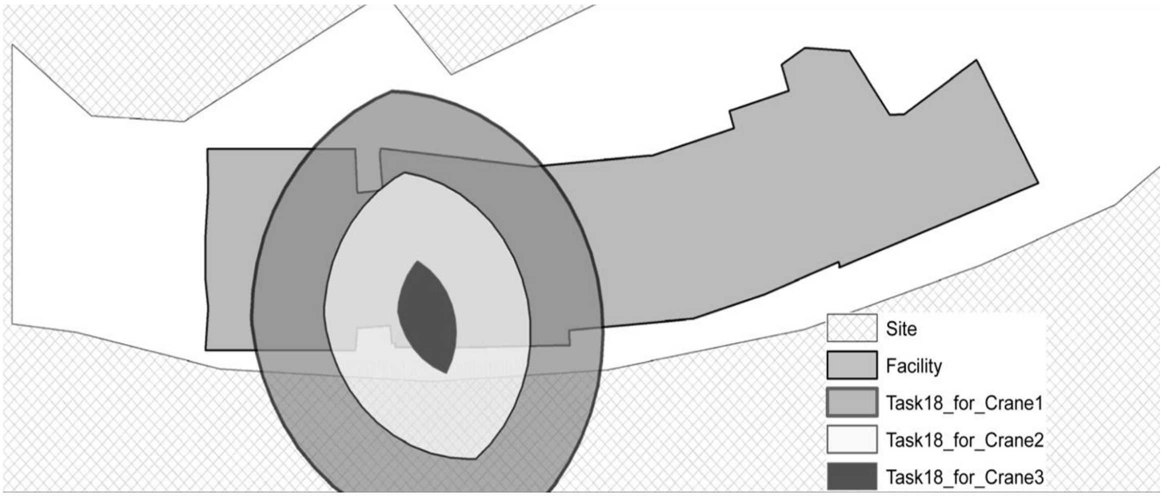

FIG. 5: Feasible task areas for a typical task (i.e. task 18) based on different cranes

Step 4: Group tasks. Based on geometric closeness, the feasible task areas created in step 3 are joined together into groups. In most cases, each task area overlaps with other feasible task areas. In general, having fewer overlapping areas limits the number of alternatives for grouping the tasks. For instance, if a task area overlaps with four other tasks, there are four possible alternatives for grouping purposes. In addition, the maximum number of tasks that can be grouped with the task area is limited to four (see Fig. 2). On the other hand, when there is no overlap, a tower crane should be assigned to the task area and, because there is no overlap, none of the other task areas can be handled by the assigned tower crane. In order to achieve the minimum number of groups (which represents the required number of tower cranes), the model starts with tasks furthest apart as initial tasks, that is, tasks with the least frequency of occurrence in the possible combinations of groups. The proposed algorithm determines the minimum number of tower cranes using the concept of searching by elimination. As mentioned, in order to facilitate the process of searching, it is better to start with tasks furthest apart (i.e. tasks overlap with fewer task areas). As the algorithm considers all possible combinations of task groups and there are fewer possible combinations for the tasks furthest apart than other tasks, the number of calculations is considerably reduced.

The grouping process proceeds with the next furthest away task and if it has an intersection with the initial task, it can be added to the task group. The procedure is continued for all tasks until no task that has an overlapping area within the present group remains. In ArcGIS, attribute data are stored in a Microsoft Access database as separate tables. Then, the Structured Query Language (SQL) is used to conduct the grouping step. In the case study, there were a total of 120 possible combinations of groups for crane 1, and the model started with “Task 18” as the initial task. It should be noted that “Task 18”, with the least frequency of occurrence, was available in 8 combinations of groups. After completing the grouping process for “Task 18”, the group contained 18 different tasks. Table 3 summarizes the results of this step. As can be seen, with regard to coverage of all demand and supply points, three cranes type “crane 1” are needed, although seven cranes type “crane 2” or eleven cranes type “crane 3” are needed to handle all tasks.

TABLE 3: Required number of tower cranes for the case study

Crane type	Possible combinations of groups	Required number of tower cranes	Average number of tasks within groups
Crane 1	120	3	17
Crane 2	215	7	7
Crane 3	118	11	5

Step 5: Calculate C3 for all feasible areas. The optimization objective for locating cranes in this study was to minimize the possibility of conflicts between the tower cranes and their surroundings. Because the areas of the groups created in step 4 are greater than the footprint area of the tower cranes, orthogonal layout grids are generated. Therefore, each group is partitioned into congruent squares with the same area as the crane’s footprint. Optimal locations are defined as unit grids with minimal conflict criterion (C3). As the conflict index equation shows, the C3 for each crane is dependent upon the location of other cranes (As the location of surrounding cranes changes, the amount of the intersection area between cranes changes as well). Calculating C3 for all alternatives is accomplished using the python language module available in ArcGIS. This is an efficient method of executing iterative processes with the aid of the spatial operations of ArcGIS (e.g. intersect, split, overlay). For the three generated groups of “crane 1”, the number of grid units in the group 1, 2 and 3 are 4, 8 and 22, respectively. Therefore the number of the alternative to be examined is up to 4 X 8 X 22 = 704. To manage the process effectively, it should start with the group with the least number of grid units (i.e. group 1 in the case of crane 1). Then the C3 is calculated for each cell while keeping the location of cranes fixed on other groups (e.g. locate the crane on the centroid of the group area). In the case of “crane 1”, there are three task groups that necessitate the use of three tower cranes. The model starts with “group 1” where there are four possible locations in which tower cranes can be placed. In order to calculate C3 for these four possible options, two tower cranes need to be located within “group 2” and “group 3”. After calculating C3 for all grid units of the first group, the first crane is assigned to the cell with smallest C3 and the process is repeated for the remaining groups. Then, C3 can be calculated for all options available for “group 2”. By locating cranes on their optimal location, which resulted from the first stage, the entire process is repeated for all groups, until the minimal C3 occurs on the same cell. Fig. 6 shows the optimal locations of tower cranes based on their C3 quantity, where dark spots indicate locations with less chance of conflict.

FIG. 6: Optimal locations of tower crane type 1 based on conflict index (C3)

Step 6: Integrate with BIM model. In order to visualize the potential conflicts of the tower cranes in 3D space, the results of the GIS analysis are exported to a BIM application. The GIS data requirements for this step include: a GIS map of the places to locate tower cranes and the characteristics of tower cranes assigned to each place. Once tower cranes have been located on their optimal locations in the BIM model, the top view of the site must match the ones in the 2D GIS map. Also, the final locations should be checked to see if they can cover all supply and demand points. Three-dimensional modeling tools (such as mass objects) in Revit Architecture are used to define the geometric shape of the tower cranes. Once a tower crane and its operating area are modeled using a mass object, area and volumetric quantities regarding potential conflicts between tower cranes and their surroundings can be automatically calculated and reported. When the model is graphically presented, it is possible to detect the conflicts in the BIM environment. In order to resolve a conflict, one can change the location of tower cranes and, after exporting the new layout to GIS, calculate a new conflict index (i.e. C3). The plan and 3D view of the case study are shown in Fig. 7, in which tower cranes (in the case of "crane 1") are located in their optimal locations. In addition, BIM allows the user to simulate the operator's viewpoint prior to field implementtation.

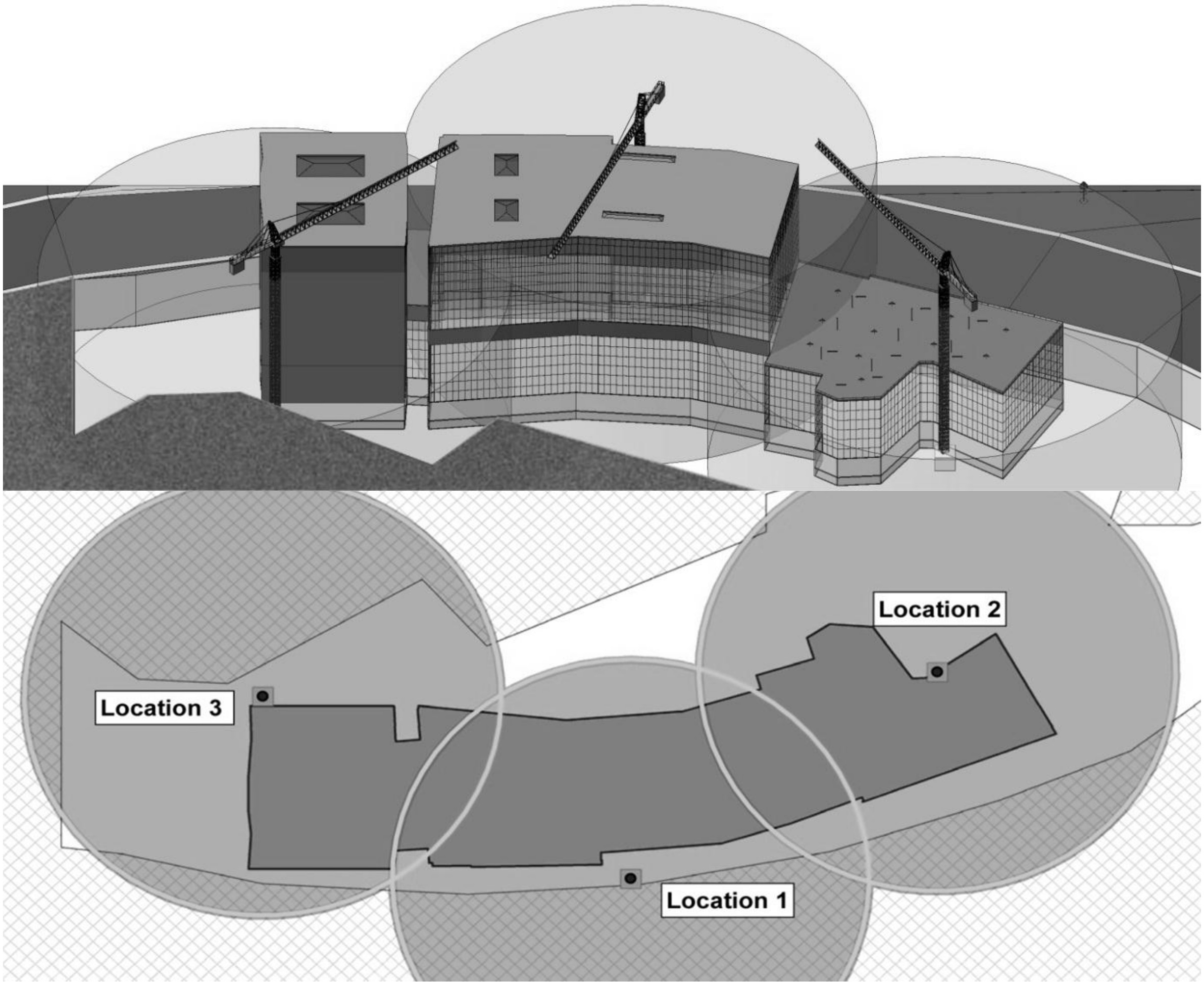

FIG. 7: 3D BIM (top) and plan (bottom) views for crane type 1

The results of the model were compared to the actual number and location of tower cranes of the case study project to verify and validate the approach. In the proposed model, "crane 2" was the same crane type as used in the project. The results for "crane 2" indicate that seven cranes are needed for transporting all loads (i.e. supply and demand points) defined in the study. In the case study project, however, the contractor planned to utilize only five cranes. In order to explain the cause of this difference, the locations of the tower cranes obtained by the model and those from the actual layout are compared (Fig. 8). In the case of five tower cranes, some supply and demand points are not included in the cranes operating area, which is contradictory to the assumption of providing overall coverage for all demand and supply points applied in the model. The use of a temporary ramp in the actual project, however, makes it possible for mobile cranes to provide access to the remaining locations. In addition, lower number of stories in the eastern zone of the building may obviate the need for more tower cranes (see Fig. 7). Excluding those areas from the GIS analysis results in the same number of cranes as in the actual case study project. At the time the proposed model was developed, construction in the case study project had been ongoing for about two months and 2 tower cranes were located on the site. Fig. 9 shows a general view of the construction site with the location of the installed tower cranes.

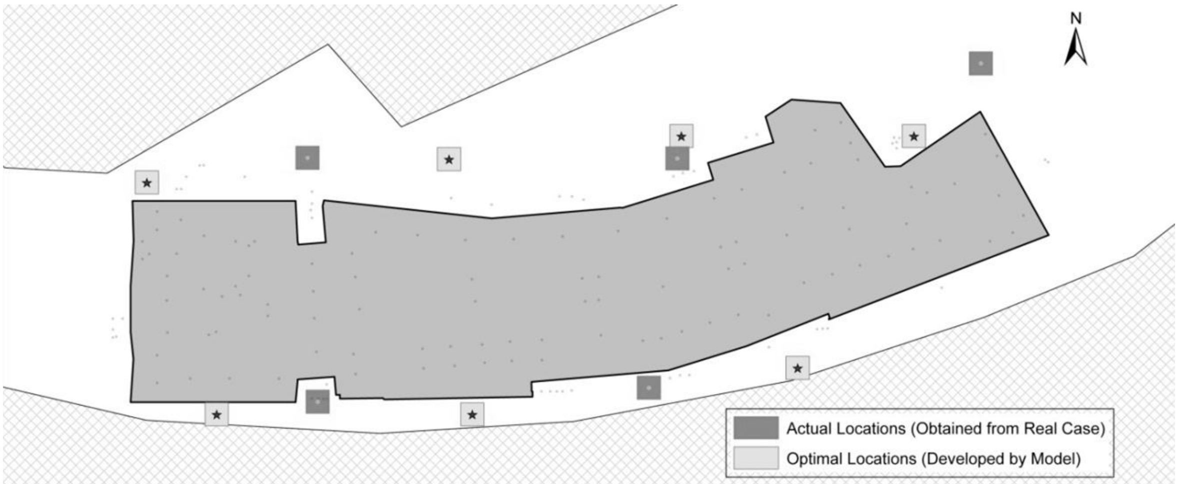

FIG. 8: Comparison of actual and optimal locations for tower cranes

FIG. 9: General view of the case study project under construction

The development of the GIS model seems to provide a better result for locating tower cranes on the construction site than that for the actual case. Using the same number of cranes, the locations generated by the model provide access to about 91% of supply and demand points, while only about 88% of those spots are included in the operating area for tower cranes located in the actual site. Also, the capacity of the proposed model in reducing the amount of conflicts between tower cranes can be assessed by considering the C3 model result values against real data. The average C3 of 0.40 resulting from the developed approach against the average C3 of 0.47 for actual locations reveals that the proposed model is capable of generating the locations with fewer amounts of conflicts between cranes (14% reduction of conflict index). Finally, a BIM model is applied to simulate the operator's viewpoint and to visualize crane movements in a shared work zone. Furthermore, 3D views can be produced at different phases of construction to appropriately represent the dynamic nature of the project. Using the BIM tool is an improvement over some of the previous research studies that focused mainly on 2D drawings. The integrated GIS-BIM model takes advantage of the interoperability capability made available by computers, enabling different types of tower cranes with several supply points to be considered before the start of the project.

There are various information exchange efforts such as the Construction Operations Building information exchange (COBie) and the OmniClass that address how 3D-shape information along with attributes can be used. Major BIM vendors are providing better tools to respond to the need for data exchange. The IFC is the only public, nonproprietary and well-developed data model for buildings and architecture that exists today (Eastman et al. 2011). In the proposed application, IFC was used as the data repository for addressing geometry, relations and attributes. However, the developed model suffers from a lack of interoperability between GIS and BIM. With an IFC file, it is not possible to save multiple georeferenced BIMs on a server and edit attributes and queries. One alternative for this is to use CityGML as a format of data exchange. However, it cannot be applied for building activities and therefore is not to be used for the proposed application. Although the use of commercially available tools in the model enables the user to exchange data between BIM and GIS domains, it still requires him or her to have knowledge about both systems and their functionalities. For example, after importing an IFC file to GIS, the user needs to know how BIM information is represented in the GIS model. Although entire BIM models can be shown, many of its attributes cannot be supported in GIS, mainly because of the complexity of minimal mutations inside a building. An alternative solution can be to use an external database for transferring attribute data between BIM and GIS. However, this approach is inefficient and lacks the needed semantic interoperability.

Thus, although the GIS-BIM integrated model works well for locating tower cranes on construction sites, there are areas that could be improved in the future. As the achieved results are encouraging, the authors are working to expand the application of the model through mobile computing systems. Using mobile computing devices and emerging visualization technologies, such as augmented reality, managers can conduct walk-through tours inside the construction site while looking at the augmented scenes with the optimal locations of tower cranes. In addition to enhancing the project personnel's perception of the future environment, the system can also be extended to identify potential hazards associated with construction activities. Furthermore, the use of a mobile computing system to improve the site layout of temporary facilities requires the integration of several key technologies; precise 3D models, precise GIS data, and mobile devices with GPS receivers, data connection, and light and proximity sensor. Various portable devices are available in the marketplace, which enable users to bring a BIM model to the field. Thus, the outcome GIS analysis can be extensively shared among BIM applications when those technologies come together. The authors are confident that the application of such technologies will in the future improve the efficiency and performance of the model.

5. CONCLUSION

This paper presented a new approach for integrating GIS and BIM that enables managers to visualize the 3D model of tower cranes in their optimal locations. Tower cranes are typically used on many building construction sites to lift a wide variety of materials vertically and horizontally. Identifying minimal number and optimal location of tower cranes, especially when they operate with overlapping work zones, can create a challenge for managers. This process comprises a variety of spatial data that can be presented in the 3D visualization model. Thus, there is a need for a new tool with spatial analysis and visualization capabilities within a single environment. Integrating GIS with BIM seems to be an appropriate approach to solve such problems.

The proposed method utilized the assumption of coverage of all demand and supply points to identify the minimal number of tower cranes. Feasible areas for locating the tower cranes were categorized under the criterion of minimized possibility of conflicts between tower cranes and their surroundings. Optimal locations are defined as locations with minimal amount of conflict. Considering the spatial nature of the analysis being done, GIS not only helps to visualize the method statement in a structured and standardized format, but also make it possible to link information from many different sources, in many different forms. Exporting the output of the GIS model to the BIM tool and generating 3D components provided the model with the capability to simulate the operator's viewpoint. Therefore, it is possible to detect the potential conflicts in different 3D views. The method also allows the consideration of more than one supply or demand points to determine optimal crane location(s). The developed model combines an optimization algorithm and GIS, which guarantees the optimal selection and on site location for any given set of tower cranes. Firstly, the proposed method supports different types of tower cranes, various layouts of supply and demand points, and any kind of construction site topography. Secondly, all possible combinations of task groups are considered. For the purpose of programming the necessary procedure, a location algorithm was developed on a mathematical basis.

A commercial building project was used to illustrate the general methodology and to validate the study. In order to demonstrate the practical capabilities, three different types of tower cranes were utilized as input to the proposed method. The locations derived by the model, compared to the actual locations, resulted in a reduction of the conflict index by about 16%. The results and the utilization of commercially available software in this study will enhance the functionality of the model to real construction projects. The implementation of the proposed model reveals the feasibility and practicality of using GIS for managers who have access to a BIM model with the full range of material information. This model can be applied as part of a site layout process and, using scheduling functionality provided by many BIM tools, allowing visualization of the sequential construction of the building from a crane operator's viewpoint. The practical application of the model will become even more useful in the future, as software applications support data standards and various information exchange efforts such as IFC. Integration of GIS and BIM, however, still comes with some limitations. The developed method suffers from a certain lack of interoperability between GIS and BIM. Although the use of commercially available tools in the model enables the user to exchange data between the BIM and GIS domains, it still requires him or her to have knowledge about both systems and their functionalities. In order to fully integrate GIS and BIM, future work should focus on providing more interoperability at the semantic level. The employment of mobile computing technologies is another potential area for future studies. This will extend the applicability of the model to real projects.

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