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ARCSPAT: AN INTEGRATED BIM-GIS MODEL FOR SITE LAYOUT PLANNING

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Abstract: Site layout planning (SLP) is an essential step for having a productive, efficient and safe construction environment. A well-planned construction site helps in increasing the productivity and safety of construction operations and in reducing the overall cost and duration of construction projects. Due to the wide range of factors and variables and the complexity included in the process of site layout planning, most of the models discussed in the literature provided solutions to the site layout planning based on wide variations in their scopes, objectives, and approaches. As a result, authors were not able to find in the literature a complete solution to site layout problems. This paper proposes an initial development for a versatile, flexible, and practical integrated BIM-GIS model for SLP to help professionals make efficient decisions and apply their knowledge to solve the problems associated with the SLP's process. It will also, highlight the potential lead of the proposed model to a unified solution for various SLP issues that accommodates most of the solutions supplied by other models presented in the literature. The model may serve as a foundation to solve future problems through a more detailed research in this area. The proposed model consists of six modules who will assist site planners in planning construction sites that are safer, more efficient and near to free of conflicts, and that would reduce the project's overall cost.

1 INTRODUCTION

A condensed review of the literature on existing models related to site layout planning would reveal the variations in their solving approaches, considerations, assumptions, optimization techniques, variables, scope and definition to the site layout problems in order to generate a solution, which makes it difficult to compare between the different models (Sadeghpour & Andayesh, 2015). For instance, some models symbolize the geometric boundaries of site objects as points on the site, others, encapsulate them in circles or orthogonal shapes, such as rectangular, and some represent their actual shape. In general, despite their vast contributions to the field of site layout planning, most of the models presented in the literature lack some fundamental requirements for a comprehensive site layout planning tool for which the integration of BIM and GIS would be useful. Authors identified common obstacles in some of the SLP models presented in the literature and suggested that spatio-temporal analysis capabilities, site logistics and route planning, 4D visualization, intuitive and familiar environment to users and human involvement and interaction are essential features and requirements to be included in a comprehensive solution for the site layout planning issues (Alsaggaf & Jrade, 2017). They also, presented a framework for SLP model based on BIM-GIS integration and discussed the potential capability of the model in solving some of the issues related to the site layout planning. This paper presents a methodology that is based on the framework discussed in (Alsaggaf & Jrade, 2017) to develop a versatile, practical and flexible BIM-GIS integrated model for SLP called “ArcSPAT”, which can tackle different issues of SLP. It will also, highlight the potential of the proposed model to lead to a unified model for SLP that accommodates some solutions supplied by other models as presented in the literature and that may serve as a foundation to solve future problems through a more detailed research in this area. The presented model will function as a tool to assist in planning and designing a safer and near conflict-free construction site to support decisions made by users during the process of solving problems associated with SLP rather than making decisions on their behalf or let them depend only on their personal experience. The said model consists of six modules where the development methodology used is described in this paper.

2 LITERATURE REVIEW

Site layout planning (SLP) is an important step in any construction project. It takes place after finishing the detailed drawings and documentations of a project and before the construction process starts. The main purpose of SLP is to manage the available spaces on a construction site and to select the most appropriate location for placing temporary facilities (TF) needed to complete a project by considering all constraints that exist between the different TFs and their relationships to permanent facilities (PFs). Published studies have emphasized the significance of site layout planning to achieving a more productive, safe, cost efficient construction environment (Razavialavi & Abourizk, 2017; Hegazy and Elbeltagi, 1999; Tommelein, et al., 1992b). Site layout planning could tremendously increase the effectiveness of the different site activities and reduce the overall cost associated with it (Dawood & Marasini, 2001). In the past, several studies have been conducted to find a solution that would help practitioners with the site layout planning process; however, the authors did not find a study that offered a complete solution for SLP problems. Models presented in the literature to solve the site layout planning issues are rather scattered in scope, methodology, definitions to the issues associated with the site layout planning (Sadeghpour & Andayesh, 2015), and, in some cases, are less user friendly and need special training and specific knowledge. Accordingly, the resulting models are independent in nature, which has impeded efforts to build on existing models to reach a comprehensive solution to site layout planning problems. Alsaggaf & Jrade, (2017) identified five common areas that were either neglected or need some improvements in the SLP models presented in the literature, which are essential to be addressed into a comprehensive SLP model as follows: 1) technical complications associated with the optimization techniques; (2) lack of spatiotemporal functionalities and capabilities; (3) absence of site logistics, accessibility and route planning; (4) ineffective 4D visualization and (5) insufficient human involvement and interaction. Taking those into consideration, the authors proposed a framework for a SLP model based on the integration of BIM and GIS and evaluated the potential of the model in solving some issues related to the site layout planning. Although many of the models discussed in the literature have the advantage of suggesting a suitable place or even locating temporary facilities (TFs) onsite based on user’s pre-defined constraints, they mainly lack sufficient human input (Alsaggaf & Jrade, 2017). Generally, users prefer a tool that guides (supports) them with making right SLP decisions and checks their decisions for conflicts and for factors that might get neglected during the planning process, rather than a tool that makes the decisions for them. In recent years, integrating BIM and GIS had gotten the attention of both professionals and researchers. Even though, studies that use the integration of BIM and GIS in the different processes of the AEC industry have been few, however, it has been increasing in the past few years (Ma & Ren, 2017). In the literature, there are various applications for the integration of BIM and GIS including site layout planning and site selection, safety, asset management, location-based services (LBS) and navigation, urban environment analysis, and 3D Cadastre (Li et al., 2017). In site layout planning, having a comprehensive view of the construction site is essential to site planners. In planning the construction of a facility, the location and site on which it is being constructed cannot be neglected. This is where BIM-GIS integration becomes important because, on one hand, BIM can provide a detailed virtual 3D model that could facilitate the decision making and the analysis process for practitioners (Li et al., 2009). While on the other hand, GIS provides users with spatial analytical and assessment capabilities (Sebt et al., 2008). Karan & Irizarry (2015) claimed that many of the preconstruction activities (e.g., site layout planning) do not fully take advantage of the benefits that BIM provides to the design and construction practice, primarily because of the diversity of spatial relationships between topographic and temporary objects in a BIM environment, and since BIM tools do not support the geospatial analysis needed in the process of locating temporary facilitates, GIS can be leveraged throughout the preconstruction phase of a project. For example, GIS can be used in detecting the conflict in material layout and evaluating the accessibility degree rate onsite (Su et al., 2012). Irizarry and Karan (2012) used BIM-GIS integration to optimize the numbers and locations of tower cranes based on cranes positions and the distribution of supply and demand points on the construction site. Isikdag et al. (2008) suggested a BIM-GIS model to support the site selection and fire response management processes. Bansal (2011b) developed and implemented an integrated model, combining GIS and 4D modeling that enables space planning, time-space conflict identification, and conflict resolution prior to the construction. He leveraged the GIS functionalities to model topology and to conduct geospatial analysis on site. He also used BIM features to link the 3D model with the execution schedule to enable users identify time-space conflicts. Alsaggaf & Jrade (2017) presented a framework for a SLP model based on BIM-GIS integration and discussed the potential of the model in solving the issues related to the site layout planning. BIM and GIS integration allows for more comprehensive view of safety in construction (Zhou et al., 2012). A BIM-GIS model was presented in a study by Isikdag et al. (2008) showed that it can manage the process of fire response by considering functional data such as floor plans and stories and geometric data. In a similar effort, Tashakkori et al., (2015) proposed an Indoor Emergency Spatial Model (IESM) that combines BIM and GIS to facilitate indoor navigation by enhancing the travel time and decision-making process for first responders in case of a disaster. Moreover, BIM-GIS integration is leveraged to analyze the safety of routes, provide a clear depiction of neighborhood walkability for an elementary school and evaluate the outdoor walking environment in the U.S. (Kim et al., 2016). In addition, combining surface and sub-surface information would make clear the risk management for surface and sub-surface facilities, plus facilitating the planning and design processes (Hack, 2010). Thus, a framework presented in a study by Tegtmeier et al. (2014) showed that integrated BIM and geospatial models, help to model the surface and sub-surface of facilities (e.g., buildings and geology). Normally, asset management involves certain types of processes in regard to operation, maintenance, and renovation. Zhang et al. (2009) identified the benefits of BIM-GIS integration in large scale asset management and highlighted that more integration between the two contexts should be encouraged. Park et al. (2014) developed a BIM-GIS-based system for the best route selection of national roads, which can be applicable to the preliminary feasibility study and alternative route analysis as well. That system took into consideration respectively land acquisition cost, construction cost, and operations and maintenance cost. Irizarry et al. (2013) developed a BIM-GIS integrated model to improve the visual monitoring of construction supply chain management, since sustainable chain management is key for the process of asset management work order. Elbeltagi and Dawood (2011) introduced a BIM-GIS-based visualization system to facilitate tracking and monitoring repetitive construction progress for evaluating and visualizing construction performance with respect to time. Ryschka et al., (2016) described Location Based Services (LBS) as services that depend on and are enhanced by the positional information of the mobile device. Navigating to a target facility dynamically and in a timely fashion on a GIS platform has been made possible with modern-day technologies, and including architectural and engineering information such as floor plans and utilities (e.g., water and electricity supply) would lead to more effective decisions (Lapierre & Cote, 2008). A smart indoor solution was proposed by Shayeganfar et al. (2008) that integrates BIM with the environment and user constraints through Semantic Web Technologies in order to facilitate indoor navigation in a timely manner for users and to ease the maintenance and management for the administrators. The role of BIM and GIS, along with other ICTs, has been identified for its potential implementations for smart city development, such as urban environment analysis, with the goal to enhance sustainable resources and infrastructure management (Neirotti et al. 2014). A methodology based on BIM-GIS integration presented by Bansal & Pal (2009) was used to visualize direct sunlight in order to calculate the amount of sunlight that falls on each surface of a facility. An integrated 3D city system was used to estimate, on an urban scale, the required energy and the effect of various levels of building on the energy demand (Strzalka et al., 2010). A conceptual GIS-BIM framework for an algae power generation model, with the goal to decrease energy use at the level of an urban neighborhood, was discussed in a study by Castro-Lacouture et al., (2014) while Di Giulio et al. (2015) developed a prototype semantic BIM-GIS model, to analyze the design, construction and O&M data of healthcare district buildings, using optimized Semantics-driven design procedures and interoperable tools. Recently, applying the integration of BIM and GIS into the 3D cadastre field has become of significance. According to Frédéricque et al. (2011), inaccuracy and complexity are likely to happen in the traditional practice, specifically when superstructure and infrastructure building components are taken into consideration and implementing a BIM model can be useful as it provides extensive information about facilities; nevertheless, data could be simplified for the purpose of 3D cadastre. More literature about BIM-GIS applications in the AEC industry can be found in Ma & Ren, (2017); Li et al., (2017). It is evident how integrating BIM and GIS can be leveraged to provide solutions to various AEC industry related problems including SLP. SLP is a spatio-temporal problem in nature, thus, it is logical that integrating BIM and GIS is beneficial for professionals to effectively plan the construction site in a more comprehensive manner since BIM provides a detailed 3D model that allows for more informed decisions while GIS provides spatio-temporal analysis.

3 COMPONENTS OF THE PROPOSED BIM-GIS MODEL FOR SLP

The main objective of this paper is to propose the initial development of a versatile, flexible, and practical BIM-GIS model for SLP that functions as a tool to assist in planning and designing a safer and near conflict-free construction site. The said model is based on the framework presented in Alsaggaf & Jrade (2017). The idea behind the proposed model is to support decisions made by users during the process of solving problems associated with the SLP, rather than having the model make decisions on the users' behalf or let them rely only on their personal experience. The BIM-GIS model is designed in a modular format incorporating six modules as follows: 1) a 3D modeling module, which links both BIM and GIS tools; 2) a route planning module that estimates the number of trucks (RPH) for loading and hauling; 3) an execution schedule time entry (SETE) module that facilitates the daunting and time-consuming process of creating a 4D model; 4) a 4D modeling module that simulates the construction progress and helps in placing the TFs on the right locations on site ; 5) a temporary facilities library (TFL) module, which is developed to facilitate the selection of TFs to model and plan the construction site; and 6) a dynamic conflict detection (DCD) module that uses a detection tool to forecast potential conflicts and clashes on a construction site by notifying users about detected conflicts through an automatically generated report holding detailed information. Due to the length restriction of this paper, module 2, which is based on a methodology presented in Al-saggaf & Jrade (2015), will be excluded. A hypothetical case project will be used to test and validate the workability, functionalities, and performance of the different modules included in the proposed integrated BIM-GIS model for SLP. A 3D BIM model was created by the authors for 3 different buildings including a building under construction, which is an eight-storey residential apartment building and two other buildings surrounding it. The case project was selected to be in the city of Ottawa, Canada and all the information regarding the transportation network, land distribution, and land use for the selected project area was obtained in forms of shape file (.shp) format (that is owned by the city of Ottawa) from Carleton University. A total number of 12 temporary facilities will be used in the case project. Additional site objects, categorized as permanent facilities, such as trees, are included in the case project. The case project will be sufficient for the purpose of testing and to demonstrate the workability, functionality, and performance of the different modules included in proposed model.

3.1 Module 1: 3D modelling

The developed BIM 3D model for the project should contain all the required information for the facility and should be reviewed by users before exporting the project file into IFC format (i.e., IFC 2X3), which will be imported into the GIS tool and transformed as a FileGeodatabase file format using the data interoperability extension in ArcMap. A plug-in is developed and linked to BIM tool (i.e., Revit) to help users seamlessly open the ArcMap from within BIM tool.

3.2 Module 3: Execution schedule time entry (ESTE)

To facilitate the process of creating a 4D model for users, a custom time-entry tool is developed utilizing the ModelBuilder tool in ArcGIS. A detailed construction execution schedule should already be available at this point of the project as SLP process starts after detailed drawings are ready and prior to the start of construction. Users can enter the scheduled time information for single or multiple layers (activities) (e.g., ifcColumn) in the 3D model and revise the schedule of the construction work flow using the 4D module. The advantage and importance of this module stems from the spatial analysis capabilities of GIS that most of the commercial scheduling tools (e.g., MS project, primavera, etc.) are lacking, which enables users to identify the required activities based on locational and attribute enquires. For example, users can instruct the module to select all the columns on the first and second floor with a specified width and length or based on a specified component number or the global unique identifier (GUID); or to choose objects within a range (e.g., TAG number 1234 to 1345). The Process flow of ESTE is illustrated in Figure 1. Users will, as well, use the module to enter the time information for the TFs.

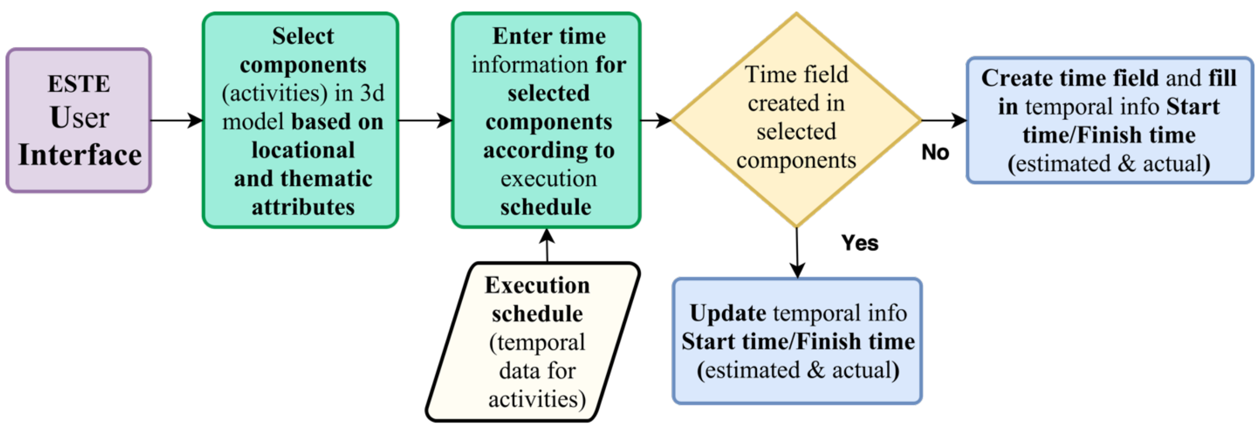

Figure 1: Process flow of Execution schedule temporal data entry (ESTE) module.

3.3 Module 4: 4D visualization

Using the time representation functionalities within the GIS tool (Timeslider tool bar), users can create a 4D simulation of the construction's progress. The time representation functionalities enable users to set different display outputs separately for the different layers. For instance, some layers could be selected to show the progress incrementally (e.g., layers for the structure under construction) meaning that even after the finish time of an activity is passed, it will still be displayed; other layers could be assigned to be represented only within the time for which they exist onsite (e.g., temporary facilities). Thus, they will be visible only for that period of time, which enables users to have a sense of the availability of space onsite. One of the advantages of the BIM-GIS integrated 4D module is that the layers displayed in a specific time period in the simulation are the only ones whose attributes will be shown in the attribute table. For instance, if a 3D model for a ten-story building is simulated and only four floors are completed during the first 5 months then, only the attributes for those floors will appear in the attribute table of the floor layer, which makes it easier for users to only identify and manipulate the layers of concern along with their data. Another advantage of the integrated model is that users can conduct spatial-temporal analysis such as “How many site objects will be covered by the tower crane’s jib radius at a specific date and time?”; “How far or how close is a certain TF (e.g., batch plant or parking lot) from the site office?”; and “What is the area of the finished floors after the first 9 weeks. Such information and capabilities are very useful for the site planners when virtually reviewing their 4D model. The presented 4D module is a result of the successful integration between BIM (Revit) and GIS (ArcMap) in a way that visualizes the construction progress of the project dynamically. The IFC 3D model provides a detailed 3D model that helps in visualizing the facility components dynamically; while ArcMap enables the visualization of construction progress over the time.

3.4 Module 5: Temporary facility library (TFL)

The TFL mainly consists of two parts which are: 1) a geodatabase (GDB) containing the actual physical (geometrical) representation and associated attributes for all types of the temporary facilities (TFs); and 2) an intuitive user interface with graphics and texts that facilitates the processes of selection and placement of TFs on map. The attributes maintained in the TF geodatabase will include, depending on the type of the TF, the length, width, height (thickness), area, safety distance, operational space required for the TF, the feature ID (FID), name of the TF, and the required functional information (e.g., minimum distance from, and or within distance) that will be used to help the DCD module apply the required spatio-temporal analysis considering the different constraints between the site objects when checking the site layout plan for potential conflicts. The TFs in the module will be put under three main categories, as per the categorization mentioned by Kumar & Cheng (2015), which are: Operational Temporary Facilities (OTF); Storage Temporary Facilities (STF); and Residential Temporary facilities (RTF). Users will select the main group (category such as OPTF, STF and RTF) of the TF they require; then they will be required to select the family of the TF needed (e.g., Cranes); after that users will be directed to select a sub-category of types of cranes (e.g., tower cranes, cranes, etc.); finally, users will be asked to select one from different options if available (e.g., the required size of the selected TF). Finally, users will select a point on the map to place the selected TF on and the centroid of the selected TF will be placed on that selected point on the map. All the TFs’ outputs created by the TFL will be stored in one layer named “Temporary facilities” except for tower cranes, since they need special analysis and calculations, they will be stored separately in a layer named “Tower Cranes”. Figure 2 illustrates the process flow of the temporary facilities library (TFL) module.

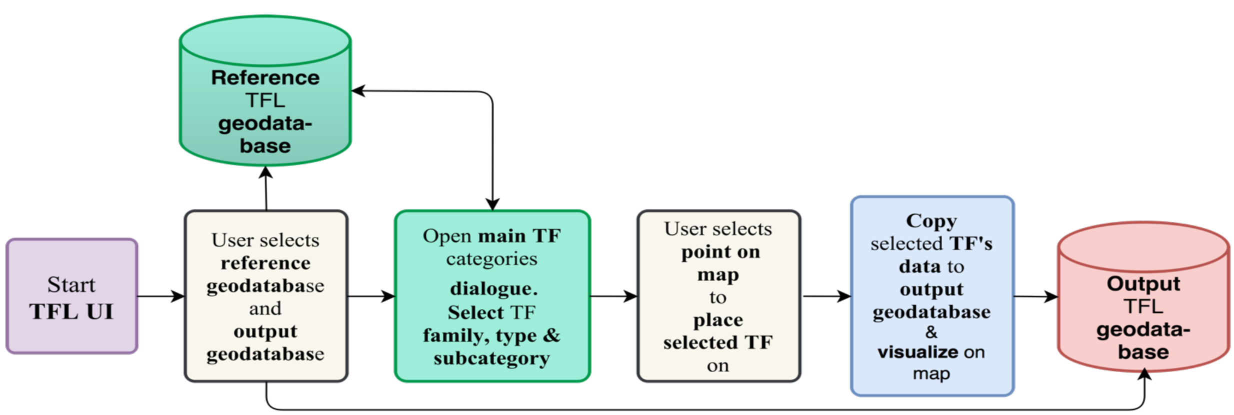

Figure 2: Process flow of the temporary facilities library (TFL).

3.5 Module 6: Dynamic conflict detection (DCD)

The process flow of the DCD module, which will check all the different objects on site against each other for potential time-space conflicts is illustrated in Figure 3.

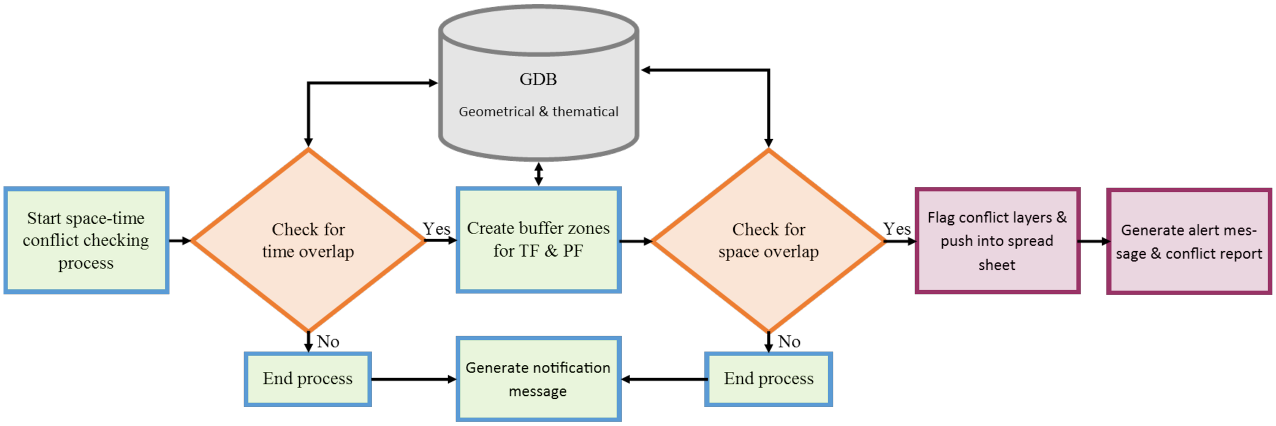

Figure 3: Process flow of the DCD module.

First, it will check if there is a time overlap, if yes, the module will check for spatial requirements (e.g., safety distance or operational space) in the attribute tables of the layers (feature classes) that have conflict. Then, the module will run the required spatial analysis for each site object depending on: 1) the type of the site object; 2) its function; and 3) if any especial spatial relationship between it and other site objects exists. For example, for some site objects (e.g., laydown areas), the module will check for conflicts in 2D; whereas, for other site objects (i.e., Tower cranes) it will check for conflicts in 3D. If there is no space or distance requirement in the attribute tables, the module will consider only the exterior boundary of the site objects in conflict. Second, it will check for a space overlap. In case of any overlap in time and space concurrently and/or constraint violation, an alert message will be generated notifying users of the number of detected conflicts, as shown in Figure 4, and all the information for the layers in conflict will be written into a spreadsheet and saved for users for checking and documentation purposes. The information in the spreadsheet includes the XY coordinates of the centroids of the layers in conflict along with the duration of conflict, its start time and finish time, names of the TFs in conflict, and FID number. The advantage of using GIS is that not only all the feature classes in conflict will be highlighted on the screen, but when users open the attribute table only the attributes for the features in conflict will be selected and highlighted in that table. This saves time and effort for users while identifying and conducting the required adjustments for the layers (e.g., TFs) in conflict. Users will check the site layout for any potential conflicts using the DCD module, adjust the layout accordingly, and run the conflict detection module again. These steps will be repeated until no more conflicts are detected. In addition, the visualization and data manipulation capabilities of GIS make it easier for users to see the areas of conflict and adjust the facilities of concern with ease in accordance to what is displayed on the screen and what is found in the generated report. Finally, users can print the final layout.

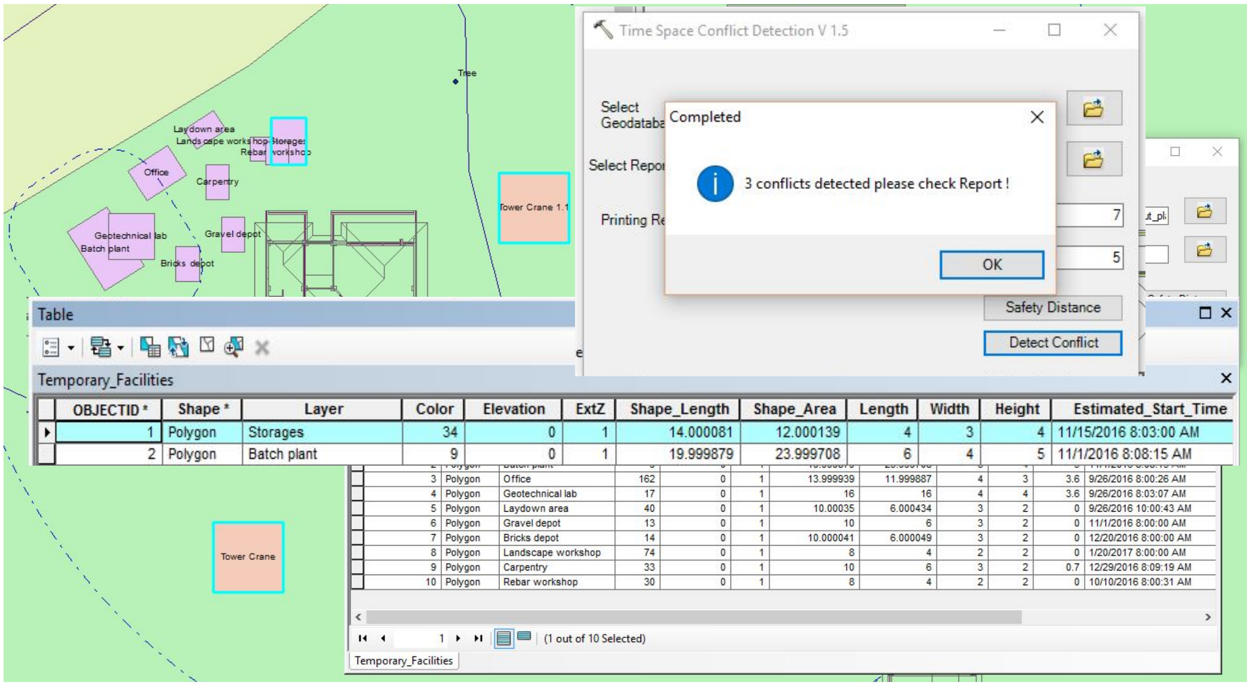

Figure 4: The DCD module detecting conflicts and generating an alert message.

4 DISCUSSION

The proposed BIM-GIS integrated model holds a promising potential for solving most of the different issues associated with SLP process. Figure 4 shows how the model is able to detect the conflict between the two tower cranes as they are very close to each other. Also, a conflict is detected between the storage and rebar workshop because there is a space intersection between them while, simultaneously, there is a time overlap between the time period they exist. The DCD module highlights the storage in conflict in the attribute table of the temporary facilities as shown in Figure 4 onsite. However, no conflict is detected between the geotechnical lab and batch plant as they do not exist at the same time period onsite. Moreover, the office interferes with the safety distance required for the batch plant, thus a conflict is detected between them. The proposed model includes SLP solutions presented previously in some models found in the literature, and also is to be extended to include new functionalities. The authors are currently in the development phase of other modules of the suggested integrated model and the initial results are encouraging. Especial constraints for height (3D) conflicts for tower cranes are not discussed in this paper due to the limited number of pages. Also, Module 2: (route planning and hauling or RPH) is not presented for the same reason.

5 CONCLUSIONS

Site layout planning (SLP) is vital for achieving an efficient and safe construction environment. Previously developed models vary in their scopes, objectives and approaches by providing enough solutions to the existing problems due to the complexity that is included in the SLP process. Five common areas are identified that were either ignored or require enhancements in some of the models discussed in the literature related to SLP. Studies have emphasized the importance of Integrating Building information modeling (BIM) and Geographic information system (GIS) for different AEC industry applications including SLP. A framework to develop a model for SLP that integrates BIM and GIS is presented. A hypothetical case project was used to test the developed SLP model. The integrated BIM-GIS model for SLP, which encompasses six modules, will assist practitioners in planning and designing a safer and near conflict-free construction site in an intuitive and efficient manner. The development of the model in a modular format is to provide comprehensive, flexible, and practical solutions to the parts that are not covered in similar studies and to act as additions to the existing ones.

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