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# A FRAMEWORK FOR AN INTEGRATED BIM-GIS DECISION SUPPORT MODEL FOR SITE LAYOUT PLANNING

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## ABSTRACT

Site layout planning (SLP) is an essential step for an efficient and safe construction environment. A well-designed construction site helps in increasing the productivity and safety of construction operations and in reducing the project's cost and duration. The main purpose of SLP is to manage available spaces on the construction site and to select appropriate locations for the temporary facilities (TF) by considering all the constraints between TFs and PFs (permanent facilities). 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. This paper proposes a framework to develop a model for site layout planning that integrates Building information modeling (BIM) and Geographic information system (GIS). The proposed model will assist practitioners in planning and designing a safer and conflict-free construction site in an attempt to provide comprehensive, flexible, and practical solutions that are not covered in the existing models. The model consists of five modules: a 3D modeling module that links BIM and GIS tools; a scheduling module that automatically calculates the durations of the TFs based on project's activities; a temporary facility library (TFL) pertaining the physical and functional attributes and constraints in a geodatabase; a 4D modeling module that shows the progress of construction and of placing the TFs; and a time-space conflict (TSC) module that uses detection tool to forecast conflicts and clashes so that the layout of the site is adjusted accordingly until no conflict is detected. The successful development of the model would partially fill the needs of the AEC industry to achieve more accurate and reliable solutions to the SLP issues.

Keywords: BIM, GIS, site layout planning, construction

## 1. INTRODUCTION

A meticulous review of the literature on site layout planning models 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 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 its actual shape. In general, despite their vast contributions to the site layout planning field, the models presented in the literature lack some fundamental requirements for a comprehensive and effective site layout planning tool, for which the BIM-GIS integration would be useful, which could be considered as one of their limitations. Having these limitations, or at least one of them, could hinder the capabilities of the proposed model to provide a global optimal solution. These limitations are 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. Spatio-temporal analysis capabilities, site logistics and route planning, 4D visualization and human involvement and interaction are essential features and requirements to a comprehensive solution for the site layout planning issues as it is going to be illustrated in this section. This paper consists of two main sections; first, a literature review explaining the importance of the aforementioned requirements (drawbacks) for the development of an effective site layout planning model then; second, an explanation for the components of the proposed framework to achieve the set goal is discussed. Then, a discussion and the conclusion are presented at the end.

## 2. COMMON DRAWBACKS OF THE CURRENT MODELS FOR SITE LAYOUT PLANNING IN THE LITERATURE.

### 2.1 Technical complications associated with optimization techniques

One of the reasons why models in the literature encounter difficulties in reaching the global optimum solution to the layout, is associated with the nature of the optimization techniques implemented to realize such a solution. The most common optimization techniques used in the literature are the mathematical and the heuristic techniques (Hegazy and Elbeltagi, 1999; Elbeltagi, et al., 2004; Sanad et al, 2008). Each technique has its shortcomings, which hinder it from producing the global optimum solution to the SLP problems.

#### 2.1.1 Mathematical methods

In general, mathematical techniques are more accurate in determining the answer (optimal location) in comparison to heuristic techniques however, this higher accuracy results, generally speaking, in prolonged process to realize an optimal solution and thus; heuristic techniques are more preferable when dealing with real life problems (Bangert, 2012). Furthermore, representing every aspect in the site layout planning problems in a mathematical model is very complex and would result in even more lengthy and demanding computational efforts, which in turn would increase the processing time. Tam et al., (2001) argued that optimization of facilities layout planning (which is a nonlinear and discrete system) using the scientific approach is difficult, if not impossible, to achieve. This has led researchers to lean towards utilizing heuristic techniques as they are easier to implement and generally could solve complex problems faster. This would deem the mathematical techniques as less practical to be applied to solve the SLP issues, especially in case of larger projects, which are unique to every project and mainly dependent on site condition and site surroundings (Sanad et al, 2008). Thus, the early efforts on solving SLP issues presented models that were based on mathematical optimization techniques only, which managed to efficiently solve only a sole or limited number of facilities due to the complexity of problem formulation (Elbeltagi & Hegazy, 2001)

#### 2.1.2 Heuristic methods

As mentioned earlier heuristic techniques seek near-optimum solutions with no guarantee that the outcome would be optimal but rather good enough. In order to accept the solution produced by heuristic model, users have to set a tolerance margin or have an expectation of what is considered to be a sufficient solution (Bangert, 2012). Also, the quality of a solution generated by heuristic techniques is generally dependent on the number of iterations and the defined threshold for the objective function to be reached (Sadeghpour & Andayesh, 2015). In other words, taking genetic algorithms as an example for heuristic techniques as they are the most used ones in the literature due to their simplicity. Easa & Hossain, (2008) said that they are very useful in solving complex non-smooth site layout problems; however, as a genetic algorithm does not rely on gradient or derivative information, it cannot determine whether a given solution is optimal; and some heuristic rules are used to determine when the model should stop. This pushed some researchers, (e.g. Ning et al, 2016), to develop methodologies with the focus on evaluating and selecting the best site layout (solutions) generated from optimization models.

#### 2.1.3 Especial knowledge

Optimization techniques require a special knowledge about the way they work and how to use them to get to the optimal solution, which is not a common knowledge among the AEC practitioners. Due to the different natures of the solving techniques; their processing time to reach a solution, the quality of the solution and success rate of finding an optimal solution (in case of heuristic techniques) varies as well. Elbeltagiet al, (2005) compared between five different evolutionary algorithms (EAs) based on their processing time, quality of results and the success rate of finding a global optimum solution. While the study used two benchmark problems for continuous optimization and a third problem for discrete optimization, it was found that all of them performed differently on different levels. For instance, the success rate of finding an optimal solution varied substantially from one technique to another to solve the same function depending on the number of variables for the function. Some algorithms performed better as the number of variables for the function increased when others did the opposite. Interestingly, the success rate for a certain algorithm varied when it was applied to solve the two continuous optimization problems from one problem to another. The same algorithm got 0% success rate when it was applied to solve the discrete optimization problem even though it got the results faster than other algorithms. The solution quality also decreased in some algorithms as the number of variables increased. Some algorithms (e.g. Ant Colony Optimization) is suited for discrete problems alone and thus were not used to solve the two continuous optimization problems. In addition, for some algorithms, extensive experimentation was performed to determine the proper number of initial population (solutions) and the number of iterations required for realizing a close to optimum solution, some parameters were defined by trial and error and some factors varies depending on the nature of the problems. This all shows the necessity for the user to acquire some knowledge on the theory (logic) behind the optimization technique used and how it works, which is a non-common knowledge among the practitioners in the AEC industry.

### 2.2 Lack of spatiotemporal functionalities and capabilities

The surrounding environment to a site and its conditions (e.g. topographical characteristics) are unique for each site, and they highly influence the site layout plans and approaches (Tam et al., 2001). The construction site is part of the surrounding environment that affects it thus, it should not be planned isolated from its surroundings, also the location of the building under construction within the site would have a significant influence on its construction strategy (Bansal, 2015). A thorough examination should be conducted on the construction site by taking into consideration the surrounding environment and any obstructions including adjacent buildings that could be in the range of some temporary facilities (e.g. tower cranes), underground structures and conditions (e.g. infrastructures) and any high-risk facilities (e.g. power towers); as this will highly affect the position of the temporary facilities onsite (Marzouk & Abubakr, 2016). A project constructed on one location would have a different construction approach from one that is being constructed at another location with different site characteristics and topography; as it would present different challenges (Bansal, 2015). Temporary facilities should be placed carefully within the construction site with the aim to avoid any hazards, on-ground and underground (e.g. shorings, excavations, embankments or buried tanks/pipes), that may affect its stability, operation or functions (Marzouk & Abubakr, 2016). Spatial analysis could be massively beneficial in optimizing the site layout planning with taking in consideration the safety of the temporary facilities (Karan & Ardeshir, 2008). Also, spatial queries and functionalities in a site layout model facilitates optimizing the site layout based risk and visibility analysis for temporary facilities (Abune'meh et al., 2016). In addition, choosing an optimal location for some temporary facilities such as tower cranes requires special space considerations; as it gets erected and dismantled using other TFs (mobile cranes), which in turn need access road for arriving into and leaving the site along with enough space for maneuvering (Marzouk & Abubakr, 2016). Creating a 3D model with the environment surrounding it and having spatiotemporal analysis capabilities in a planning model would help in space planning (Bansal, 2011). Accordingly, having advanced spatial analysis functionalities and capabilities would enhance the efficiency and add to the site layout planning model (Marzouk & Abubakr, 2016). Thus, an efficient site layout planning model should help the user to perform spatiotemporal analysis such as; what, when and where space is required and available for construction activities, materials and site facilities based on fundamental information including the location of materials coming to and generated onsite, and representation for the spatial characteristics of the construction site (e.g. terrain) along with the surrounding environment. Moreover, the model should be presented in a user-friendly manner including textual, tabular and visualization formats.

### 2.3 Absence of Site logistics, access roads & route planning

Procurement of materials for new project, estimating the quantities of demolition and renovation (D&R) waste generated onsite and the availability of space onsite all have a direct influence on site logistics; which in turn affects the decisions made regarding some of the TFs involved in the construction process (e.g. storage areas, trucks and equipment). Ali et al., (2016) defined site logistics as reducing the cost of storage and the distance between the stored materials and equipment from the work area, while increasing site productivity through scheduling and planning. This shows that site logistics and site layout are interrelated and interdependent on one another, which encouraged researchers to developing models that integrate and optimize site layout planning and site logistics especially for congested sites (e.g. Said, 2010; Su et al., 2012; Ali et al., 2016). Said (2010) believed that overlooking these critical interdependencies between material procurement and site space availability can lead to significant adverse impacts on project performance including material shortages, improper storage, poor and unsafe site layout, and productivity losses. Furthermore, the quantity of materials to be stored has an influence on the size of the storage area needed and the size of operation facilities is dependent on the quantity and size of equipment and tools (Kumar & Cheng, 2015). Also, reducing the material handling costs and the distance between TFs and their supporting activities to minimize travel time is dependent on the development of dynamic material requirement, which is achieved through incorporating material estimates with execution schedule (Bansal, 2015). Said (2010) emphasized that coordination between the decisions of material procurement and material storage onsite is vital to avoid major site problems and increase the efficiency of these two tasks. Therefore, extensive descriptive information and data input has to be specified by practitioners during the process of site and logistics planning, which include site spatial information, interior building spaces and execution schedule (H. M. M. Said, 2010). Accordingly, knowing the amounts of materials coming to the site, the amounts of waste generated onsite and their potential location will aid layout designers to come up with more informed decisions on the numbers and sizes of TFs required (e.g. number of trucks, storages, and laydown areas etc.). While most studies conducted on SLP mostly focused on integrating the material procurement process (e.g. Said, 2010 ; H. Said & El-Rayes 2011; Su et al., 2012), taking into consideration the D&R waste generated onsite, which have a potential to be recycled and reused in such projects or other projects in the future, is so beneficial in improving the sustainability of the SLP practice and cost savings. For more on how knowing the amounts of waste generated onsite and their locations is beneficial in estimating the number of trucks required the reader is referred to (Al-saggaf & Jrade, 2015). Finally, a versatile SLP model should provide the user with the information on the amounts and locations of materials and waste generated onsite, which will enable layout designers to make more informed decisions on the numbers, optimal position and sizes of TFs required (e.g. storages, laydown areas and number of trucks etc.). Efficiently planned access roads can decrease the time and cost of handling resources, and can improve the safety on construction sites (Mawdesley, et al., 2002; El-Rayes & Khalafallah, 2005; Sanad et al. 2008; Karan & Ardeshir, 2008; Sadeghpour & Andayesh, 2015). For instance, Tower cranes need special consideration when performing site layout planning such as storage places as well as access roads, installation and dismantling spaces and other criteria that ought to be considered when planning for a crane position (Marzouk & Abubakr, 2016). Yet, to date, the planning of access roads has been neglected in the literature despite the fact that the travel distance between site facilities is the most common factor used in optimizing the site layout in the models; which means that including access roads in modeling the site layout is vital (Sadeghpour & Andayesh, 2015). Generally, there are two simplified approaches used in the literature to represent the distance between the site facilities these are: 1) rectilinear distance and 2) Euclidean distance; even though in real life, “actual paths” defined onsite are used to measure the distance between any two facilities (Sadeghpour & Andayesh, 2015). Some of the studies that used rectilinear distance in their models are: Zouein & Tommelein 1999; Mawdesley et al. 2002; Zouein et al. 2002; El-Rayes & Said, 2009 while the studies that used Euclidean distance include: Li & Love 1998; Elbeltagi & Hegazy, 2001; Osman et al 2003; Andayesh & Sadeghpour 2013a. It is worth mentioning that both (rectilinear and Euclidean) approaches suffers a drawback which is they do not allow evading obstacles onsite (Andayesh & Sadeghpour, 2014). In addition to access roads planning, path (route) planning is essential for site logistics and for a safe and efficient SLP; however, examining the accuracy of the approaches used for route planning did not get sufficient attention (Andayesh & Sadeghpour, 2014). In addition to the two previously mentioned approaches (rectilinear and Euclidean), some other approaches such as grid based and visibility graph are also implemented to determine the shortest path onsite; a comparative study between the different approaches is done by Andayesh & Sadeghpour, (2014). The problem with all the aforementioned approaches, despite their contributions to solving the path planning issues, that almost none of them considered the site spatial (topographic) conditions. In reality, the ground or site surface is not plane; but rather changing with slopes and sometimes difficult terrain that would affect the distance length, travel distance time and the selection of the shortest path between site facilities thus, a real representation the site spatial (topographic) conditions is vital in an SLP model. The authors have developed a methodology for an integrated BIM-GIS model that facilitates the estimation and categorization of D&R waste generated onsite for multiple distributed locations and estimates the number of trucks required for hauling and relocating the D&R waste based on the travel distance, which is calculated for actual roads and paths defined onsite, between the location of the waste and the targeted destination (Al-saggaf & Jrade, 2015). The model is also capable of determining the closest destinations (e.g. storages or landfills) to the location of the waste and identify the shortest path between the two points.

### 2.4 Ineffective 4D visualization

Being able to visualize the construction progress in 4D (3D + time dimension) is a key for providing planners with more comprehensive view on what the conditions are and the sequence of work might be in reality throughout the duration of the construction process (Bansal, 2015). In comparison to 4D visualization, traditional methods have a higher chance to be error prone as the planner must have a very good imagination to identify how the arrangement of PF, TF, available area onsite and the accessibility to the site would be throughout the duration of the construction. Ma et al., (2005) mentioned that visual 4D planning and scheduling technique that combines static 3D CAD models with construction schedules has proven to be beneficial over traditional tools such as bar charts or network analyses. Akinci et al, (2002) argued that 4D simulation by itself has proven to be a much better environment for construction planning than Gantt charts or CPM schedules. Sugimoto, (2016) praised the role of 4D visualization of the construction schedule as a mean to validate the construction plan. Marzouk & Abubakr, (2016) explained that BIM 4D planning is very helpful in understanding the sequence of the lift operation and checking if there are possible collisions that could happen between cranes during the operation stage. They also, suggested that current limitations in their framework could be enhanced by enabling the dynamic nature of construction sites and incorporating simulation tool that addresses the variability and ambiguity (Marzouk & Abubakr, 2016). 4D based models could assist practitioners, during the preconstruction phase, in revising their execution strategy and foresee any potential errors in the schedule, overlooked tasks, spatial feasibility, Spatial-temporal clashes, evaluating different approaches for construction and investigating the constructability through simulation (Bansal, 2015). Models that support 3D and time integration provides more clarity and increase the understanding of the practitioner to the construction process and accordingly make them more likely to allocate resources more effectively (Bansal & Pal, 2008). There is an important requirement in a 4D SLP model, which is to represent and manage the space needed for conducting an activity in addition to represent the building components and activities; a lack of such feature (activity space requirement) in the planning and scheduling process leads to spatial-temporal clashes due to the interference of one activity space with another (Akinci et al, 2002). Bansal, (2011) claimed that, in space planning, to finalize a plan in terms of when, where, and how long a space is required on the jobsite, a space-loaded 4D animation is helpful because the overlaps among various spaces are verified visually through the animation; and that visualization of the construction site helped significantly in the identification of activities progressing virtually without even inspecting the construction site. Furthermore, an efficient 4D SLP model should incorporate two important characteristics; first, is spatial-temporal analytical functions such as identifying how many site objects are located within the safety buffer zone of a certain tower crane; second, is the dynamic representation of the 3D component to reflect their realistic progress status (Su et al., 2012). With that said, most models that support 4D modelling in the SLP literature are in fact 2.5D + time (with fixed height and shape), which means that they do not reflect the actual progress of construction and site condition realistically; for instance, visualizing the progress of floors completion in a multi-story building in relation to the consumption of materials onsite (Sadeghpour & Andayesh, 2015). Su et al., (2012) explained that visualizing 3D objects at discrete points throughout the duration of the associated task, i.e. displaying the entire product for the whole task duration, is not representative of the construction process. Being able to visualize the site layout in three dimensions throughout the different stages would lead to a smooth and easier planning for a dynamic construction site (Zolfagharian & Irizarry, 2014). El-din et al., (2015) said, since the site boundaries, existing permanent structures, the structure to be constructed, and temporary facility locations all occupy space in three dimensions the layout of temporary facilities is inherently graphical in nature. Accordingly, the 4D model should integrate 3D models for the PFs (e.g. buildings) and TFs (e.g. storage areas, batch plant etc.) with the construction schedule. Ma et al., (2005) argued that this structure not only enables resource, schedule and manpower management of the project, but also provides convenience to 4D layout across the construction site. Thus, the need for an SLP model that supports and provides 4D visualization capabilities is crucial.

### 2.5 Insufficient user involvement

The adequate interference and preference of the practitioner for the final site layout is almost neglected in the literature. This is to say, just because a final layout (a global optimum solution) is generated by a model and achieved the highest score for the predefined utility function it does not mean that it will be adopted or implemented as it is by the practitioner. This only means that this final layout is the best in comparison to the other generated solutions and in some cases, as in heuristic models, even that is debateable as it depends on the success rate of the model to generate a global optimal solution. This hinders the possibility for practitioners to accept the automatically generated solutions for the site layout as different practitioners have different preferences and views for the site layout that complies with their personal style and experience (Tommelein et al., 1992a). El-din et al., (2015) supported the statement that site planners prefer to alter decisions made by a computer system, based on their knowledge and experience; and that preventing user interference, does not allow the utilization of users' experience and knowledge in designing a site layout, and more importantly, does not allow their contribution to the knowledge of the model. Also, in part, this is due to the discrepancies between the approaches used by artificial intelligence (AI) models and the practitioners in generating a solution for the site layout, which renders them as incomprehensible to utilizers and thus refuse to implenet them and fully accept the solution generated by such models (Sadeghpour et al., 2004b). In addition, site layout problems, variables, factors and challenges are numerous and they change over time and from one region to another, which makes it difficult to successfully interpret them all in a fully automated model. This explains why most of the models for SLP decision making presented in the literature are ineffective and impractical as they generally include one or a few variables for the optimization process (Zolfagharian & Irizarry, 2014). For efficient and quality plans, planner's experience and know-how is still required (Sugimoto, 2016). Tam et al., (2001) said site facility layout is a nondeterministic polynomial problem that is difficult to solve by other polynomial algorithms, and because of human involvement, there are no conditions that lead consistently to the same result, therefore, site layout planning is usually an art rather than a science. Yeh, (1995) claimed that in practical applications, the predetermination of the construction cost and interactive cost is not easy, and professional experience is necessary. M. Y. Cheng & O'Connor, (1994) suggested that the knowledge and experience that the project manager brings to the TF site layout is nearly impossible to quantify. Zolfagharian & Irizarry, (2014) added that site planning still requires human experience and that some required variables that are not easily predetermined. Thus, enabling the planners to queue facilities in accordance to their expertise, intuition, and due considerations of applicable site constraints is crucial (Sadegphour 2006); as determining the required TFs and their spatial requirements is mainly knowledge dependent (Elbeltagi & Hegazy, 2001). Tommelein et al. (1992a) argued that it is obvious that the preferences of the person responsible for the layout's design will greatly impact the decision-making process, and that one person's final layout will be different from someone else's; and believed that prioritizing multiple objectives in site layout planning is highly subjective and non-trivial task which no agreed upon method exist. Hence, in the light of this, an effective SLP model should allow users to apply their knowledge in the design and selection of the required TFs and aids them throughout the process until the optimal site layout is reached instead of making the decisions for them; as this will insure the user's acceptance and satisfaction with the outcome.

## 3. COMPONENTS OF THE PROPOSED FRAMEWORK

Based on the aforementioned problems and drawbacks, the proposed model's requirements and components are defined and categorized accordingly. The most important thing for an integrated development methodology is a system that employs the effective integration of BIM and GIS towards facilitating, aiding and engaging the user throughout the process of site layout planning. To achieve this, five components (modules) are proposed; 1) a 3D modeling module; 2) a scheduling module that automatically calculates the durations of the TFs based on project's activities; 3) a 4D module preparation by combining the 3D model with the execution schedule using a scheduling tool; 4) Preparation of a geodatabase for temporary facility library (TFL) module and 5) space-time conflict detection tool. The proposed framework is developed based on Autodesk Revit for BIM and ESRI ArcGIS for GIS environment. However, the concept of the frame work could work for most BIM and GIS environments. Figure 1 shows the process flow of the model proposed in the framework.

### 3.1 3D modelling module

In this module, all information related to the new facility under construction and/or facilities under D&R is identified along with the construction site. A 3D model for the project is developed containing all the required information for the facility. Then the 3D model is exported as an IFC 2x3 file to be imported in the GIS environment. A plugin is created in BIM tool to seamlessly open the GIS environment from within the BIM environment. After the IFC file is imported into GIS, all data regarding the transportation network, routing, roads and paths are either imported from a ready-made source (e.g. municipality) or defined by the user. The information for the transportation network include, the names, lengths, width, elevation, speed limits for the roads and routes for the project area. While other information related to the representation of the construction site include; land use, construction site boundaries and triangular irregular network (TIN) and digital elevation model (DEM) for realistic representation for the site surface (e.g. terrain). Since IFC files only allow limited attributes to be transferred along with the 3D model, users could export all the information and attributes they need to an external database (e.g. MS Access), open it within the GIS tool and associate the attributes they want with the corresponding feature classes (layers) based on unique common column, such as global unique identifier (GUID) or TAG No., using the built-in options in GIS such as "join attributes". Attributes required in the 3D model include, Length, width, height (thickness), area, volume, level (floors), name, GUID, TAG etc. Also, the information regarding the different activities (IFC components) such as; ifcWall, ifcSlab, ifcBeam etc. is exported to an Excel sheet to estimate the activities duration, which will be used as an input for the scheduling tool.

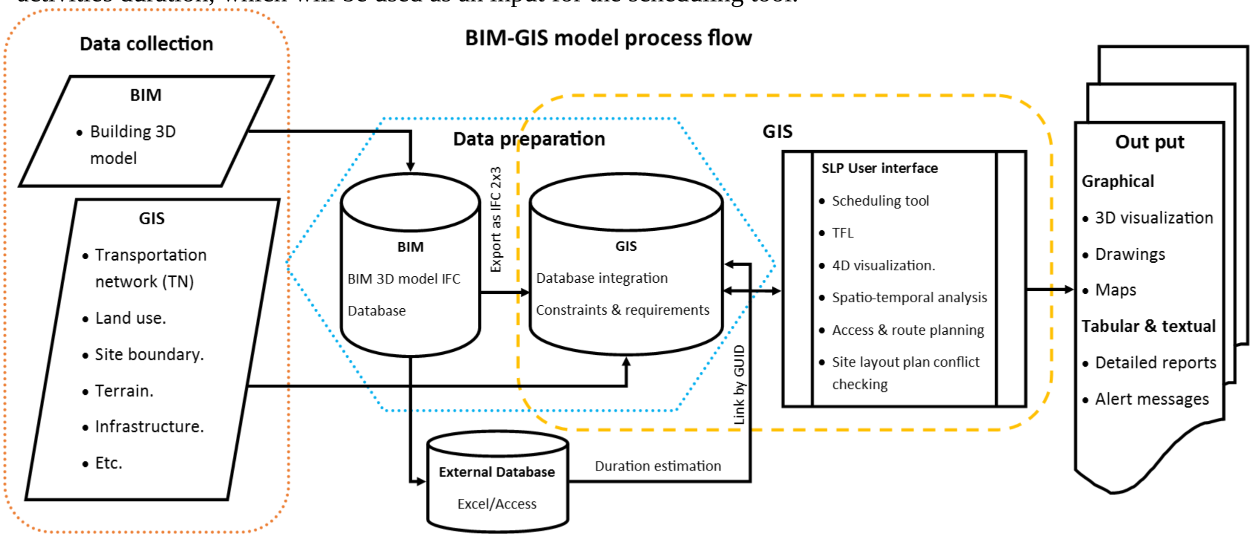


Figure 1: Process flow for the proposed framework of the BIM-GIS integrated model for site layout planning

### 3.2 Scheduling module

A detailed construction execution schedule should be already available at this point (prior to the site layout planning process). After, the data pertaining to the different main activities (e.g. slabs, beams, columns, floors, walls, windows, doors, etc.), the sub-activities and required resources is exported to an Excel spread sheet/external database (e.g. Access database). Then, the required TFs for the different sub-activities and resources are identified by the user. Consequently, a link is established between all the sub-activities, resources and the associated TF/s needed to support the activities. The estimated duration for each TF is determined based on the summation of the total durations of each sub-activity associated with it; and thus, the duration for every TF is automatically calculated. Finally, the user could enter the estimated start and finish time for each main activity (layer) in the 3D model imported in GIS and revise the schedule and construction work flow using the 4D module. GIS enables the user to identify the required activities for start and finish date entry based on locational and attribute enquires such as; select all columns in the first and second floor with a specified width and length or based on a specified component number or GUID. This is an advantage of the GIS analytical capabilities, which most of the commercial scheduling tools (e.g. MS project, primavera etc.) lack.

### 3.3 4D module

After the durations for the different activities are estimated, the user can use the GIS built-in options to enter the durations for the corresponding activities (layers). Then, using the time representation functionalities within GIS, the user can create a 4D simulation to the construction progress. The time representation functionalities enable the user to set different display output 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; even after the finish time of the activity is passed, it is still going to be displayed for the user; other layers could be assigned to be represented only for the time for which they exist onsite (e.g. temporary facilities) thus, they will be visible only for that period which enables the user to have sense of the availability of space onsite. Part of the advantages of the BIM-GIS integrated 4D module is that only the layers displayed in a specific period in the simulation are the ones which attributes are shown in their attribute table. For instance, if a 3D model for a ten-storey building is simulated and only four floors are completed during the first 5 months then, only the attributes of those floors are going to appear in the attribute table of the floor layer, which makes it easier for the user to identify and manipulate only the layers of concern along with their data. Another advantage of the integrated model is that the user can conduct spatial-temporal analysis such as "how many (e.g. floors, windows, slabs, walls etc.) are going to be done after the first 3 months?"; how many site objects are covered by the tower crane's operation radius at a specific date and time?"; how far or close a certain TF (e.g. batch plant or parking) from the site office; and what is the area of the floors finished after the first 9 weeks (e.g. when the site becomes congested and less area onsite is available for storing materials).” Such information and capabilities are very useful for the site planners.

### 3.4 Temporary facility library (TFL) module

A geodatabase containing the actual physical (geometrical) representation and associated attributes for all types of the temporary facilities (TFs) is prepared. The attributes maintained in the TFs geodatabase include, depending on the shape of the TF, length, width, height (thickness), area, safety distance (buffer zone), operational space required for the TF (buffer zone), the feature ID (FID) and TF ID. This will facilitate the selection and placement of the TFs required for the construction for the user. GIS provides the capability of developing custom tools using programming languages such as; VB, Python, Arc objects library (based on C# programming language) which is used to develop the user interface for selecting and placing the required TFs. The user, also can have the option of determining different parameters for the TFs (e.g. width, height and height (thickness), safety distance etc.) according to their liking if required and choose to update the field for selected TFs. First, the user is asked to select the main group (family) of the TF (e.g. Cranes) and then he/she is directed to select a sub-category of types of cranes (e.g. tower cranes, cranes, mobile cranes etc.) and finally he/she is asked to select the required size of the selected TF. In addition, GIS provides CAD-like drafting capabilities, which means that the users can edit the geometries of the TFs to their liking without compromising the functionality of the proposed BIM-GIS model in predicting the time-space conflict.

### 3.5 Time-space conflict detection module (TSC)

In this module, the created plugin in GIS is going to check all the different layers against each other for potential time-space conflict. First, the algorithm is going to identify all the layers that have time overlap. If there is a time overlap the algorithm will check the buffer distance attribute (e.g. safety distance, circulation requirement or processing space requirement) if exist in the attribute table of each feature class then, it will create the buffer zone around those layers. After the check for space overlap is conducted, if a conflict exists, an alert message is generated and all the information for the conflicted layers will be sent and saved into a spread sheet for checking and documentation purposes. The information in the spread sheet include: the XY coordinates of the centroid of the conflicted layers along with the duration of conflict and its start time and finish time, names of the TFs in conflict and FID number. The advantage of GIS is that all conflicted features are going to be highlighted on screen and when the user open its attribute table only the attributes for those conflicted features will be selected in the table. This saves time and effort for the user to identify and conduct the required adjustments for the layers (e.g. TFs) in conflict. In addition, the visualization and data manipulation capabilities of GIS make it easier for the user to see the areas of conflict and adjust the facilities of concern easily in accordance to what is displayed on the screen. Finally, the user will repeat this step until no more conflicts are identified then, they could print the final output (layout). Figure 2 illustrates the space-time conflict detection process.

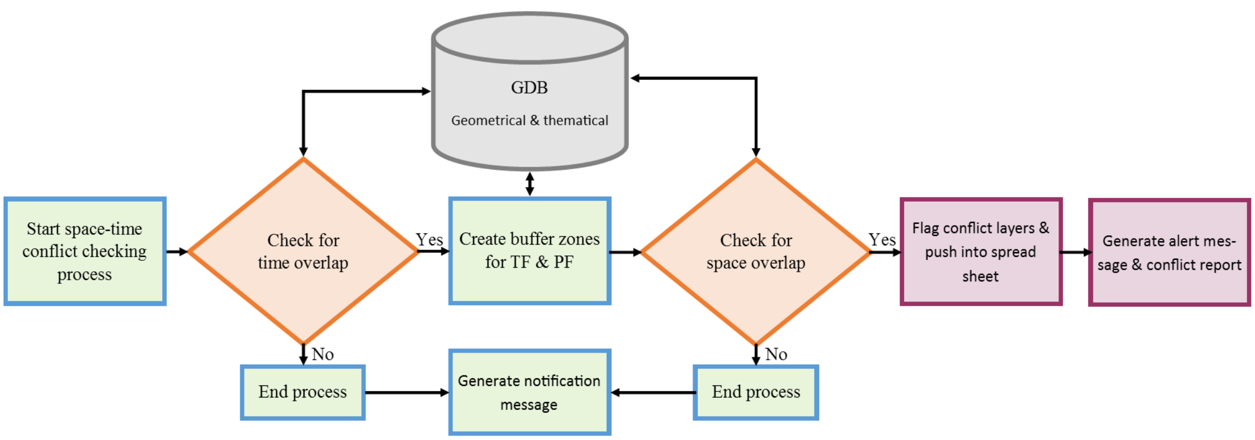


Figure 2: Space-time conflict detection process

## 4. DISCUSSION

The framework for the BIM-GIS integrated model for site layout planning (SLP) holds a promising potential for solving the different issues associated with SLP process. The authors are currently in the development phase of the suggested integrated model and the initial results are encouraging. Other potential useful applications are not discussed in this paper due to the limited number of pages such as the accessibility and route planning. The authors have developed a methodology for an integrated BIM-GIS model that estimates the number of trucks required for hauling and relocating the D&R waste based on the travel distance, which is calculated for actual roads and paths defined onsite, between the location of the waste and the targeted destination (Al-saggaf & Jrade, 2015). The model is also capable of determining the closest destinations (e.g. storages or landfills) to the location of the waste and identify the shortest path between the two points. Also, it is worth mentioning that the model has some limitations, such as loss of information when transferring the BIM model to the GIS environment, due to BIM and GIS integration and interoperability issues; however, they were not discussed here due to the limited number of pages.

## 5. CONCLUSION

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 models discussed in the literature about site layout planning. A framework to develop a model for site layout planning that integrates Building information modeling (BIM) and Geographic information system (GIS) is presented. The proposed model will assist practitioners in planning and designing a safer and conflict-free construction site to provide comprehensive, flexible, and practical solutions for the areas not covered in the existing models and add to the conveyed areas. The model consists of five modules: a 3D modeling module that links BIM and GIS tools; a scheduling module that automatically calculates the durations of the TFs based on project's activities; a temporary facility library (TFL) pertaining the physical and functional attributes and constraints in a geodatabase; a 4D modeling module that shows the progress of construction and of placing the TFs; and a time-space conflict (TSC) module that uses detection tool to forecast conflicts and clashes so that the layout of the site is adjusted accordingly until no conflict is detected. The successful development of the model would partially fill the needs of the AEC industry to achieve more accurate and reliable solutions to the SLP issues.

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