

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 the construction operations and in reducing the overall cost and duration of the project. The main purpose of SLP is to manage the available spaces on the construction site and to select the most appropriate location for the temporary facilities (TF) needed to complete the project by taking into consideration all the existing constraints between the different TFs and their relationships to the permanent facilities (PFs). Due to its complexity and the wide range of factors and variables included in the site layout planning process, the models discussed in the literature vary in their scope, objectives, and approaches to providing a solution for site layout planning, which decreases the opportunities for studies to build upon each other towards achieving a versatile model to tackle a variety of issues associated with SLP. In general, despite the vast contributions to the site layout planning field of the models found in the literature, there is still room for improvement by fulfilling some neglected requirements and including some functions that are useful in any site layout planning model, which the integration of Building Information Modeling (BIM) with Geographic Information System (GIS) can provide.

This thesis presents a methodology for developing a model for site layout planning based on the integration of BIM with GIS in an attempt to develop a versatile and flexible solution (model) to help professionals during the SLP process. This model will support the decisions of planners

during the SLP process and allow them to apply their knowledge in planning and designing, in an efficient and timely manner, a construction site that is safer, more efficient and keeps potential conflicts to a minimum. The research methodology includes a comprehensive literature review, collecting all the necessary data related to SLP, PF and TF, model development and implementation. The presented model is designed in a modular format and consists of six modules, 1) a 3D modeling module; 2) a route planning and hauling (RPH) module; 3) an execution schedule time entry (ESTE) module that facilitates the daunting and time-consuming process of creating a 4D model; 4) a 4D modeling module that simulates the progress of construction and helps in placing TFs on the right locations on site; 5) a temporary facilities library (TFL) module, which is developed to facilitate selecting TFs, modeling and placing TFs onsite, and planning the construction site; and 6) a rule-based dynamic conflict detection (DCD) module that detects conflicts and clashes in 2D and 3D and then notifies users about the detected conflicts through various feedback including visual, textual, and tabular, all in one data-rich environment. Also, the presented model will provide users with spatio-temporal analysis and data management capabilities.

The successful implementation of this methodology contributes in developing a versatile and flexible SLP model that will provide users with the essential requirements and functions they need for SLP, which can be enhanced and extended to include more modules and functions through further research in this area.

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To

My Parents,

My Wife and Kids, and

My Siblings

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List of Acronyms

| | |
|-------|--|
| 2D | Two Dimensions |
| 3D | Three Dimensions |
| 3DXML | Dassault Systèmes Three-Dimensional Extensible Markup Language |
| ACO | Ant Colony Optimization |
| AEC | Architecture, Engineering and Construction |
| AFT | Actual Finish Time |
| AGC | Associated General Contractors of America |
| API | Application Programming Interface |
| AST | Actual Start Time |
| AVI | Audio Video Interleave |
| BCA | Bee Colony Algorithm |
| BIM | Building Information Modeling |
| BMP | Bitmap |
| bsDD | buildingSMART Data Dictionary |
| CAD | Computer-Aided Drafting |
| C&D | Construction and Demolition |
| CIS/2 | CIMSteel Integration Standards 2 |
| CSI | Construction Specification Institutes |
| DBMS | Data Base Management System |
| DEM | Digital Elevation Model |
| D&R | Demolition and Renovation |

| | |
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| DSLP | Dynamic Site Layout Planning |
| DWG | Drawing |
| DXF | Drawing eXchange Format |
| EA | Evolutionary Algorithms |
| EFT | Estimated Finish Time |
| EPA | The United States Environmental Protection Agency |
| ESRI | Environmental Systems Research Institute |
| EST | Estimated Start Time |
| ETL | Extract, Transform and Load |
| GA | Genetic Algorithm |
| gbXML | Green Building eXtensible Markup Language |
| GIS | Geographic Information System |
| GPS | Geographic Positioning Satellite |
| GSA | General Services Administration |
| GUI | Graphical User Interface |
| GUID | Global Unique Identifier |
| IAI | International Alliance for Interoperability |
| ICT | Information Communication Technologies |
| IGES | Initial Graphics Exchange Specification |
| IFC | Industrial foundation classes |
| IFD | International Framework for Dictionaries |
| IFG | IFC for GIS |
| IPD | Integrated project delivery |

| | |
|--------|--|
| ISO | International Organization for Standardization |
| JPG | Joint Photographic Experts Group |
| LBS | Location-Based Services |
| LEED | Leadership in energy and environmental design |
| LOD | Level of detail |
| MEP | Mechanical, Electrical and Plumbing |
| NIBS | National Institute of Building Science |
| ODBC | Open Database Connectivity |
| OGC | Open Geospatial Consortium |
| OLAP | Online Analytical Processing |
| ORDBMS | Object-Relational Database Management System |
| OSHA | Occupational Safety and Health Administration |
| PDF | Portable Document Format |
| PF | Permanent Facilities |
| PHP | Hypertext Preprocessor |
| PSO | Particle Swarm Optimization |
| RDBMS | Relational Database Management System |
| RVT | Revit Project File |
| SAT | Standard ACIS Text |
| SBZ | Safety buffer zone |
| SKP | SketchUp Document |
| SLP | Site layout planning |
| SOA | Service Oriented Architecture |

| | |
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| SQL | Structured Query Language |
| STEP | Standard for the Exchange of Product Data |
| STL | STereoLithography |
| T.C | Tower crane |
| TCE | Translation, Conversion and Extending of Existing standards |
| TF | Temporary facilities |
| TFL | Temporary facility Library |
| TIF | Tagged Image File |
| TIN | Triangulated Irregular Network |
| TSC | Time space conflict |
| UBM | Unified Building Model |
| UML | Unified Modeling Language |
| USGBC | The United States Green Building Council |
| VRML | Virtual Reality Modeling Language |
| WBS | Work Breakdown Structure |
| XML | Extensible Markup Language |

CHAPTER 1

INTRODUCTION

1.1 General overview

Studies emphasize the importance of the site layout planning (SLP) process as a mean of achieving a productive, efficient, and safe construction site environment (e.g., Hegazy and Elbeltagi, 1999; Kumar and Bansal, 2015; Ning et al., 2018b; Xu et al., 2016). The Occupational Safety and Health Administration (OSHA), mentioned that, in 2014 alone, almost 5,000 individuals died on the job site due to safety-related issues. More than 20% of that number were workers in the construction industry, that is, 2 to 3 workers every day (OSHA, 2016). This is still a concerning issue especially that those incidents occurred in the United States alone and after that the average number of worker deaths decreased by more than 65% between 1970 and 2014 (OSHA, 2016). Moreover, site layout planning has a direct influence on the duration, cost, safety, and efficiency of the construction project and the workers' morale (Ning et al., 2018b). Practitioners have relied mainly on experience in planning the site layout for construction projects (Kumar and Bansal, 2015; El-Rayes and Said, 2009). Traditionally, practitioners tend to plan the site layout via conventional methods that range from sketching manually on paper to simple 2D drafting using Computer Aided Drafting (CAD) software (Kumar and Bansal, 2019).

In the past three decades, this has encouraged researchers to try solving site layout planning issues using computerized programs and Artificial Intelligence (AI) tools to yield optimized solutions to site layout (Andayesh and Sadeghpour, 2013b). In addition, due to the complexity of the site layout

planning process and the wide range of factors and variables included in site layout planning, the models discussed in the literature vary in scope, objectives, and descriptions of site layout problems and in approaches to represent and provide solutions for the problems that faces the site layout planning (Alsaggaf and Jrade, 2017). Most research efforts towards solving site layout planning issues could be categorized under two main groups; namely, mathematical models and metaheuristic models (Sanad et al, 2008). Meta heuristic models (such as evolutionary algorithms and swarm intelligence) have been increasingly implemented in the last two decades (Farmakis and Chassiakos, 2018). This is mainly because mathematical models yield optimum results (Kumar and Bansal, 2015); however, they are suitable for small projects with a more limited number of variables and factors than heuristic models that are easier to be implemented and can include more variables and factors than with mathematical models, which makes them suitable to tackle larger projects; however, heuristic models seek semi-optimal results (Farmakis and Chassiakos, 2018). Furthermore, studies mainly classify the site layout problem in two ways; either as a static site layout, meaning that the site objects will remain onsite for the complete duration of the project; or as a dynamic site layout, which considers the actual durations for which the site objects will remain onsite (Kumar and Cheng, 2015).

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 and Khalafallah, 2005; Sanad et al. 2008; Karan and Ardeshir, 2008; Andayesh and Sadeghpour, 2014a). Furthermore, limited accessibility could decrease efficiency by 58% and the congested work space could lead to reduction in the efficiency up to 65% (Su et al., 2012). Site layout planning can influence the cost associated with travel distance of construction operations (Hammad et al., 2017). Therefore,

most of the studies conducted on site layout planning have focused on solving site layout planning problems by minimizing the travel distance between the temporary facilities and the relocation cost (El-din et al., 2015). Mainly, Euclidean distance and Rectilinear distance were used to measure the distance between site objects in the models represented in the literature (Andayesh and Sadeghpour, 2014a). Also, most studies consider the construction site's surface as plane, which is not practical or realistic as, in reality, terrain and topography influence the distance and path onsite, and thus, ought to be addressed in an SLP model.

Furthermore, accounting for the environment surrounding the building under construction and being able to visualize it in 4D can assist practitioners, during the preconstruction phase, to revise their execution strategy and to foresee any potential errors in the schedule, overlooked tasks, spatial feasibility, and spatial-temporal clashes; and will give users a broader view of the construction process (Bansal, 2015). In addition, traditional planning and scheduling tools (e.g., bar charts or network analyses) have proven to be less helpful when compared to the method of 4D planning and scheduling (Ma et al., 2005). Sugimoto, (2016) praised the role of 4D visualization of the construction schedule as a means to verify the construction plan. Thus, it is important to have 4D visualization capabilities in an SLP model as the nature of the site layout planning process is graphical (El-din et al., 2015).

Temporary facilities should be placed carefully within the construction site with the aim to avoid any hazards, on-ground and underground, that may affect its stability, operation, or functions (Marzouk and Abubakr, 2016). For this purpose, having spatial analysis can greatly help in site layout optimization while insure the safety of the temporary facilities (Karan and Ardeshir, 2008).

Also, having spatial queries and functionalities in an SLP model allows for optimizing the site layout plan while considering risk and visibility analysis for temporary facilities (Abune'meh et al., 2016). In addition, representing a 3D model with the environment surrounding it while including spatiotemporal analysis capabilities in an SLP model would help in space planning (Bansal, 2011b). This is to say that having advanced spatial analysis functionalities and capabilities would add to the site layout planning model as it would augment its efficiency (Marzouk and Abubakr, 2016).

For efficient and quality plans, planner's experience and know-how is still required (Sugimoto, 2016). Zolfagharian and Irizarry (2014) added that site planning still requires human experience and that some required variables are not easily predetermined. El-din et al. (2015) said 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, it does not allow their knowledge contribution to the model. Also, in part, this is due to the discrepancies between the approaches used by AI models and those used by practitioners in generating a solution for the site layout, which render them as incomprehensible to users who then refuse to implement 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.

Recently, both professionals and researchers became very interested in the integration between

building information modeling (BIM) and geographic information system (GIS). BIM is an object-oriented and data-rich model that digitally represents the physical and functional information about a building (NBIMS-US, 2016), which enables users to design, manipulate, extract, analyze, and share the data and information about a building during its life cycle (NIBS, 2007). It is considered a revolutionary technology, as it helps engineers design virtual models of a digitally constructed building, which allows owners to visualize the building before it is built (Jrade and Jalaei, 2013). A geographic information system (GIS) is a framework that allows users to gather, manage, organize, analyze, visualize and share various types of data including geographical and spatial data (ESRI, 2019). GIS allows users to interpret data to understand relationships, patterns, and trends. It can function as decision-support system, as it encompasses all the required qualities for an information system (Liu et al., 2017). BIM and GIS may share some similar qualities, as both enable users to make more informed decisions based on the data that is presented digitally to them; nevertheless, they also have some dissimilarities, one of which is their scope of representation of physical and thematical information. GIS is more concerned about representing information about what can be called the “Macro Area” starting from the world on top of the hierarchy and going all the way down to infrastructure. BIM, on the other hand, is concerned about representing information about what can be called the “Micro Area” starting from the building on top and going all the way down to small building components (e.g., lighting fixtures). Accordingly, integrating both domains will provide users with a broader view and a comprehensive environment and capabilities to tackle wider types of problems compared to solely using either domain. In general, studies on leveraging the BIM-GIS integration in the different AEC industry fields are few; however, in the past few years they have gotten momentum and have been increasing (Ma and Ren, 2017). In the literature, different topics and areas in the AEC industry are introduced by

researchers for the possible applications of the BIM-GIS integration (Bansal, 2015; Liu et al., 2017).

In spite of all this, the author was not able to find any study to date that leveraged the integration of BIM and GIS to develop a model for site layout planning.

Based on that finding, this study aims to develop a site layout planning (SLP) model, based on the integration between BIM and GIS, that assists users and supports their decisions during the process of SLP while allowing them to apply their knowledge and facilitating the different analyses and processes required for planning a site layout that is safe and efficient with minimum potential conflicts. Users will use the discussed integrated SLP model to create a 4D model for the project and simulate the construction process; plan their routes based on actual paths onsite; select and place the different temporary facilities (TFs) required for the construction project, and plan the site layout in light of the 4D visualization of the construction progress. Finally, users will use the model to automatically check their plans for potential time-space conflicts in 2D as well as 3D, assess the risk associated with the detected conflicts, and provide them with feedback in graphical, textual, and tabular form. The presented decision support model for SLP in this study was developed using multiple toolbar extensions and plugins in both BIM and GIS tools (i.e., Autodesk Revit and ArcGIS Desktop respectively). This was achieved by using built-in functionalities from both domains (BIM and GIS), enhancing some of the existing functionalities in both tools, and developing new tools to suit the purpose of planning a site layout in an intuitive, timely and effective manner.

1.2 Problem statement

Even though studies emphasize the crucial role of site layout planning as it affects the cost, safety, efficiency, and duration of the project (e.g., Hegazy and Elbeltagi, 1999; Kumar and Bansal, 2015; Ning et al., 2018b; Xu et al., 2016), practitioners, still to date, rely only on personal experience in planning the site layout without any commercial tool to support the decisions they make in regards to the site layout plan. In spite of the vast contributions by the several studies conducted in the past to find a solution that would help practitioners with the site layout planning (SLP) process and the advantages of their proposals, the need for a complete, practical, intuitive, and flexible solution (model) for site layout planning still exists.

The models presented in the literature for site layout planning are rather scattered in scope and present varied descriptions and methodologies for representing and solving the different issues associated with site layout planning (Alsaggaf and Jrade, 2017). This has led the SLP models presented in the literature to be independent and fragmented in nature, which in turn has decreased the chances for later studies to build on previous ones to achieve a versatile model that can resolve a wider range of issues related to site layout planning.

The SLP studies found in the literature on site layout planning have vast contributions, but in general, there is still room for further improvement by including some additional functionalities and capabilities, which the BIM-GIS integration can provide, that can be quite beneficial when addressed in an SLP model. These include 4D visualization, spatial-temporal analysis capabilities, route planning based on actual path onsite, sufficient human interaction, and to be intuitive with

no requirement for uncommon knowledge for practitioners in the AEC industry (Alsaggaf and Jrade, 2017).

Accessibility and route planning based on actual path are often ignored in the literature even though they directly influence site layout planning and there is a tight relationship between SLP and each of them. An SLP model should allow for modeling and considering actual paths onsite when planning for routes and accessibility of the site layout.

Most of the SLP models in the literature that provide 4D visualizations keep the height of objects fixed for the whole duration of the project which does not realistically reflect the progress of a construction project (Alsaggaf and Jrade, 2017). In addition, most of the models only consider the issues associated with the construction site itself, with little attention paid towards including the environmental factors of the site and its surroundings. In reality, the environmental factors of the site and its surroundings must be taken into account when planning the site layout, as they have a direct influence on the site layout plan (Marzouk and Abubakr, 2016). Also, an efficient 4D SLP model should incorporate two important characteristics. The first is having spatial-temporal analytical functions such as identifying how many site objects are located within the safety buffer zone of a certain tower crane, and the second, is the dynamic representation of the 3D components to reflect the realistic status of their progress (Su et al., 2012). The author has not come across an SLP model in the literature that considers both characteristics.

Although the many models in the literature have the advantage of suggesting a suitable place for or even locating the temporary facilities (TFs) onsite based on user pre-defined constraints, most

of them lack sufficient human input. Users prefer a tool that helps (supports) them with making the right 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. An experienced professional can decide where to locate a temporary facility (TF) for a certain activity within seconds; however, what the professional really needs assistance with is foreseeing whether the selected place will cause any conflict with other site objects (TFs or PFs), as the construction progresses. Conflicts might result in raising safety issues and leading to a delay in the project and eventually a cost increase. Furthermore, each construction project is unique in nature with so many factors and variables to account for including design, engineering, environmental, managerial, and sometimes even social factors (Bansal, 2015). Those factors affect the duration, cost, productivity, efficiency, and quality of the project, as well as the workers' morale and the site layout planning process. The complexity of the different, almost countless, factors makes it almost impossible to include all of them in a single model or computing environment, which means it is not feasible to have a computer system or a model that could solely provide decisions to solve all the different issues associated with site layout planning without proper involvement of human experts. Furthermore, most of the models presented in the literature are limited to only helping users in the planning process during the pre-construction phase. Given the fact that site layout planning is dynamic in nature and an ongoing process through the construction phase, there is a critical need for models that are capable of helping users during the construction phase as well. Thus there is a need for a rule-based model for site layout planning that would help users to check their site layout plan for potential conflicts and assess the risk level of the detected conflicts (Zolfagharian and Irizarry, 2014). To the author's knowledge, no rule-based SLP model that offers those features has been presented in the literature to date.

This research presents a methodology for developing a decision support model that leverages the integration between BIM and GIS to assist users in planning safe, effective and well-organized site layout that would have minimum potential time-space conflicts while considering safety and route planning based on an actual path. The SLP model discussed will enable users to create a 4D model and simulate the construction progress in 4D; to select from a variety of temporary facilities (TFs) required to complete the construction process, place TFs on map, and plan the site layout in light of the 4D visualization of the construction process; and to assist users to (automatically) check their site layout plan for potential issues, in both 2D and 3D, run risk level assessment for the detected conflicts, and provide them with different feedback format including, visual (graphical), textual (i.e., notifications and alert messages), and tabular (i.e., a conflict report). The said model, while checking for the time-space conflicts in 2D and 3D in a rule-based fashion, takes into consideration the different spatial relationships and constraints between site objects (TFs and PFs).

1.3 Research objectives

The main objective of this study is to present a methodology for implementing a versatile and flexible site layout planning (SLP) model that enables users to tackle various SLP issues by providing various functionalities and capabilities in a unified environment, leveraging the integration between BIM and GIS, and assists them in planning a safer and near conflict-free construction site in an intuitive and timely fashion. The model presented is designed in a modular format to insure the flexibility of the model to accommodate previous solutions to the issues of the SLP process presented in the literature and to be extended to include more modules and functionalities in the future, which paves the way towards both tackling more SLP issues and covering more requirements through additional research. The idea behind this model is to support

decisions made by users during the process of solving the problems associated with the SLP, rather than making the decisions on their behalf as some of the models discussed in the literature did.

This main objective of this study is achieved by implementing the following sub-objectives:

Sub-objective 1: Develop a framework for implementing a modular decision support model for site layout planning, based on the integration of BIM and GIS, that provides the essential requirements and functionalities of any effective SLP model that can assist users in reaching a site layout for a more effective and safe construction site.

Sub-objective 2: Identify the gaps in the existing functions in both BIM and GIS tools (i.e., Autodesk Revit and ArcGIS desktop respectively) to achieve the said SLP model and complement them by either enhancing some of their existing functions or developing new ones in order to realize the main objective of this study.

Sub-objective 3: Inspect and test the usability of the presented model and examine its sufficiency and how well it can function as a decision support model for the SLP process.

1.4 Research methodology

In order to fulfill the set objectives of this study, a methodology is developed as presented in figure 1.1. The decision support model for site layout planning is designed in a modular format and is based on the integration of Building Information Modeling (BIM) and a Geographic Information System (GIS). This is done by employing the functionalities that exist within both the BIM and GIS tools (i.e., Autodesk Revit and ArcGIS desktop respectively), and implementing new tools that are custom developed in order to achieve the SLP model discussed in this study.

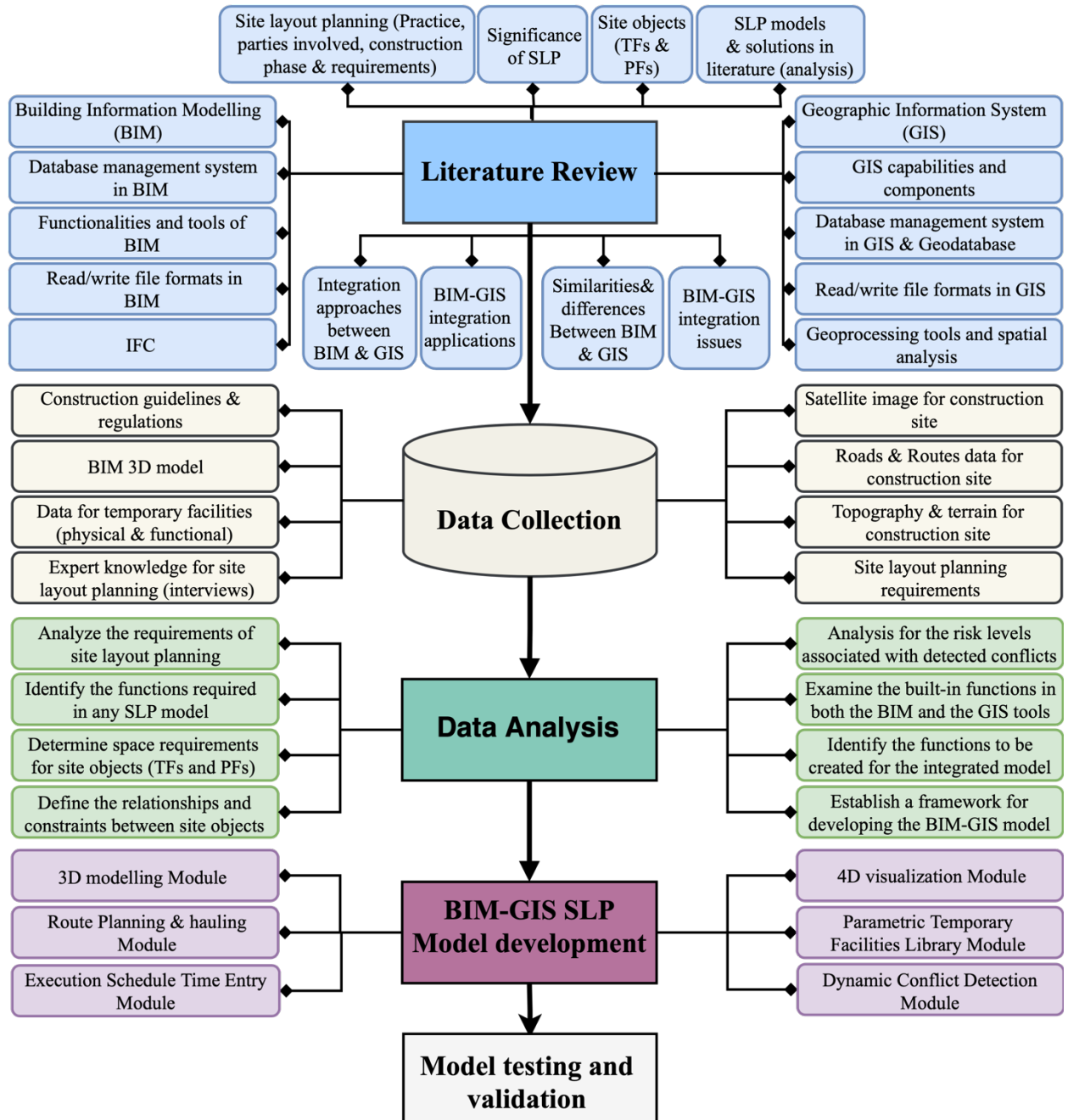


Figure 1.1: Research methodology

1.4.1 Review of literature

A comprehensive literature review on various areas related to site layout planning (SLP) has been conducted including; current practices in SLP, SLP models and solutions, related issues and SLP

requirements; temporary and permanent facilities spatial requirements and constraints; Geographic Information Systems (GIS); Building Information Modeling (BIM); similarities and differences between BIM and GIS approaches for BIM-GIS interoperability and integration and associated issues; and BIM-GIS implementations. The literature is presented in two chapters, Chapter 2 tackles the SLP process, its significance, site objects (temporary and permanent facilities), analysis of the SLP models discussed in the literature, and the useful functionalities and capabilities of an SLP model and Chapter 3 provides an explanation of BIM and GIS, along with the applications and issues of interoperability and the integration of the two environments.

1.4.2 Data collection

Face-to-face interviews were conducted with professionals, including engineers, site supervisors and contractors from different parts of the world, namely, Ottawa, Canada; Dubai, UAE; Cairo, Egypt; and Jeddah and Makkah, Saudi Arabia to collect data on the process of site layout planning and temporary facilities and to provide comments on the functionalities included in the presented model and what other requirements professionals need in an SLP model. Also, more data on the SLP have been collected from a thorough review of the literature. Data for the different categories and types of the temporary facilities along with their dimensions and functions were collected from several manufacturers' manuals. Additional data was collected by reviewing the literature on temporary facilities. Digital maps and satellite images and CAD drawings for the City of Ottawa (owned by the city of Ottawa) including land use, roads, and routes were collected from Carleton University, Ottawa, Canada. 3D BIM models for the buildings in the case studies were created using Autodesk Revit.

1.4.3 Development of the integrated BIM-GIS model for site layout planning

The methodology to achieve the said model will be per the following stages:

1) Looking into the actual needs, gaps and expectations of the AEC industry, adopting a feasibility study concept to identify how sufficient the integration of BIM and GIS is for providing a solution to the SLP process; and how this integration would lay the foundation for a versatile, flexible, and practical solution for the SLP process.

2) Establishing a generic integration framework is to lay out the theoretic foundation for the BIM-GIS SLP model. Then, gap analysis will be conducted to identify the desirable functionalities that the current SLP solutions are lacking and the BIM-GIS integration can enhance.

3) Developing an integrated model for site layout planning that provides a suitable environment for a Decision Support Model (DSM) to aid planners throughout the site layout planning process. To enhance the versatility and flexibility of the developed model, it will be designed in a modular format and will consist of six modules: 1) a 3D modeling module; 2) a route planning and hauling module; 3) an execution-schedule time entry module; 4) a 4D visualization module; 5) a temporary facilities library (TFL) module; and 6) a rule-based dynamic conflict detection (DCD) module.

1.4.4 Test and verify the integrated BIM-GIS model for site layout planning

After developing of the presented model, it will be tested and verified by using a hypothetical case study building project to proof its capability in tackling a variety of tasks that are related to site layout planning and assisting users to efficiently plan a site layout that is safe and efficient in an intuitive and timely manner while applying their knowledge during the planning process.

1.5 Thesis Organization

This thesis is organized according to the following chapters:

Chapter 2 discusses a thorough review of the literature with regard to the site layout planning,

Chapter 3 provides a literature review of BIM, GIS, applications of the BIM-GIS integration in the AEC industry, the interoperability and integration of both domains, and the challenges associated with it.

Chapter 4 presents the methodology regarding the development of the decision support model for site layout planning including the model's components, architecture, and the process workflow.

Chapter 5 explains the BIM-GIS SLP model development and implementation phases and steps.

Chapter 6 discusses the testing and verification of the presented BIM-GIS SLP model.

Chapter 7 covers the research summary and conclusions, as well as the contributions and recommendations.

Chapter 8 provides a list of references used in the literature review and methodology chapters.

1.6 Summary

This chapter provided the introduction of this study. It started with a general overview about the research and after that provided explanations about the research's problem statement, research objectives, research methodology, and the overall organization of this study.

CHAPTER 2

LITERATURE REVIEW

Site layout planning

2.1 Introduction

Site layout planning (SLP) is an important step in any construction project. It takes place during the pre-construction phase (Ning et al., 2018a; Said and El-Rayes, 2013) after finishing the detailed drawings and documentations of a project and before the commencement of construction (Zhou, et al., 2009). Despite the high influence of the outcome of this process (planning the layout for a construction site) on the overall cost, time, efficiency and safety of the project, and the morale of the personnel, SLP is mostly neglected since practitioners are dealing with it in a first-come-first-served manner, which could result in a congested and inefficient work environment due to this spontaneous approach (El-Rayes and Said, 2009). This chapter looks at the literature related to the site layout planning, its significance, and it compares the various efforts and approaches presented by other researchers to solve the various SLP issues and it derives and highlights some of the useful functionalities and capabilities that need to be addressed in any SLP model.

2.2 Definition of site layout planning

The literature is listing various definitions for site layout planning. Zolfagharian and Irizarry (2014) defined site layout planning as the placement of materials, facilities, and equipment within a construction project space. Andayesh and Sadeghpour (2013a) defined dynamic site layout

planning as the task of determining the overall optimum location of objects such as temporary facilities, storage areas, and workshops on the construction site. A number of studies pointed out that the process of site layout planning involves identifying the type, shape, size and number of temporary facilities required for supporting the construction and suitably placing them (Zhou, et al., 2009; Elbeltagi, et al., 2004; RazaviAlavi and AbouRizk, 2016; Tommelein, et al., 1992b; Tommelein et al, 1991). The task of planning the site layout takes place after finalizing the design drawings of a project and prior to its construction (Zhou, et al., 2009). The objective of an effective site layout plan is not only to minimize the distance between temporary facilities needed to support the construction and to reduce the cost of resources, material flow and handling but also to increase safety, productivity, and efficiency (Elbeltagi and Hegazy, 2001; Elbeltagi, et al., 2004). In addition, it should optimize the location and time of the temporary facilities onsite throughout the whole duration of construction (Mawdesley, et al., 2002). Zolfagharian and Irizarry (2014) said that an optimized site layout plan ensures the optimum usage of available space, leads to lower project costs, provides less relocation of materials during construction, better accessibility to and security of a site, and makes a safer work environment.

2.3 Significance of site layout planning

Studies in the literature have emphasized the significance of site layout planning to achieving a more productive, safe, and cost efficient construction environment (Hegazy and Elbeltagi, 1999; Ning et al., 2018b; Razavialavi and Abourizk, 2017; Tommelein, et al., 1992b). Site layout planning could tremendously increase the effectiveness of the different site activities and reduce the overall costs associated with it (Dawood and Marasini, 2001). The findings of a study by Sadeghpour (2004) indicate that the return on investment for each dollar invested in pre-planning

of large projects may be 400% of their overall cost. Failing to properly plan the site layout might increase the construction cost and duration due to the dismantling and setting up associated with relocating the site facilities (Huang and Wong, 2015). The success of any project is related to the efficient use of space onsite to accommodate resources throughout the construction since site layout planning directly influences the project performance (Zhou et al., 2009). Moreover, a thorough planning of the site layout would help reduce the interference of site activities, accidents and impeded workflow due to spontaneous storage of materials on different places onsite (Tam et al, 2002). Previous studies showed that nearly 47% of incidents on site were related to safety planning, which means that site layout planning is crucial to ensuring safety during construction (Ning et al, 2018b). Osman et al. (2003) added that efficient layout planning of a construction site is fundamental to any successful project undertaking. Also, a well-planned site layout can reduce the total traveled distance between site facilities on a project in general, which resulted to less wasted time and better productivity (Andayesh and Sadeghpour, 2014a). Sadeghpour et al. (2004) added that planning the site layout appropriately could reduce the cost and duration of construction by minimizing the travel distance, enhancing the flow of material, lowering the material handling time and effort, boosting up the productivity and augmenting safety. Li and Love (1998) said that the layout of facilities has an important impact on the production time and cost savings, especially for large projects. Yeh (1995) argued that the impact of good layout practices on money and time saving becomes more obvious on larger construction projects. Neglecting planning the site layout and leaving it entirely to experts' judgment might lead to a chaotic site, which could increase safety hazards and reduce productivity (Sadeghpour et al, 2006). In the construction industry the chances of a fatal occurrence among workers is five times higher than that of the manufacturing industry (Xu and Li, 2012). Previous studies conducted by Tommelein, et al. (1992); Hegazy and Elbeltagi

(1999); Hegazy and Elbeltagi (2000); Tawfik and Fernando (2001); Karan and Ardeshir (2008) , and others, praised the role of proper site layout planning in increasing the safety of construction operations along with the overall increase in the efficiency and productivity of the construction process. Tawfik and Fernando (2001) claimed that a research at UCL (University College London) suggested that 20% of reported construction accidents can be attributed to poor site logistics and that low productivity is strongly linked to inefficient space planning and conflicts between subcontractors. Xu and Li (2012) believed that a well-planned and well-run project should be both safe and efficient to save lives and money to reduce injuries and ill-health. Hegazy and Elbeltagi (2000) emphasized how crucial the appropriate layout of a construction site is for enhancing site productivity and safety. Moreover, having all the required TFs for construction and placing them strategically onsite would positively affect the morale, health, and wellbeing of the personnel (Elbeltagi et al., 2004). Thus, it is evident from the literature how important site layout planning is for providing a more efficient, safe, less costly, and more productive construction as it massively influences the duration, cost and performance of the whole project. According to the Occupational Safety and Health Administration (OSHA), in year 2014, almost 5,000 individuals died on the job due to safety-related issues and more than 20% of that number were workers in the construction industry, which is 2 to 3 workers everyday (OSHA, 2016). In 2010, the Bureau of Labour Statistics (BLS) reported that nearly 800 workers died in the construction industry in the United States, which is almost 17% of the number of all workers killed by job-related injuries in the same year (Huang and Wong, 2015).

2.4 Temporary facilities

Temporary facilities (TFs) are all the construction-supporting facilities that are not part of the

project, which are going to be removed from the site after the period in which they are required is finished (Sanad et al, 2008). Thus, the primary objective of TFs is to support the construction process.

These facilities can be classified into three categories (Kumar and Cheng, 2015):

1. **Storage facilities:** Where all materials required for the construction are momentarily stored and stay protected from damages due to external and environmental factors.

There is a wide range of storage facilities, such as;

Warehouses for cement, laydown areas and storage yards for gravel, steel, bricks, tiles, precast panels, etc.

2. **Operation facilities:** they help with handling, lifting, and processing the building components and materials onsite and normally would involve people, and equipment and tools, therefore, they should provide adequate space to safely and efficiently do the activities.

Operation facilities include:

Cranes, hoists, carpentries, and all the different site shops, such as fabrication, welding, rebar cutting, steel bending, etc.

3. **Residence facilities:** The function of such facilities is to accommodate workers during the construction of the project and provide services to them such as health, sanitary services, lodging, etc. Therefore, it should have sufficient space for a productive job environment.

Residence facilities include:

Site offices, pantries, toilets, etc.

The quantity of materials to be stored has an influence on the size of the storage area needed, the size of operation facilities is dependent on the quantity and size of equipment and tools,

while the size and number of residence facilities is determined by the number of personnel.

2.5 Permanent facilities

Permanent facilities are all facilities or objects on site that are going to exist during construction and after it whether they are part of the project or not. Examples are buildings, terrain, plants, signs, obstructions, etc.

2.6 Analysis of the site layout planning models in the literature

A meticulous review of the literature related to the developed published models for site layout planning (SLP) would reveal the variations in their modeling approaches, considerations, assumptions, problem-solving techniques, variables, and the scope and definition of site layout problems in order to generate solutions. 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 shapes. Sadeghpour and Andayesh (2015) conducted a comprehensive and thorough review of more than 70 studies done within the years 1980 and 2014 to generate an overview of the published site layout models. The aim of their study was to identify the differences and similarities between those models to drive a general outline, for a site layout planning model, that represents the common concepts and elements among those published models. Regardless of the wide dissimilarities found between those models, the authors managed to identify common concepts between them, which are called “Constructs” in their study. Sadeghpour and Andayesh (2015) argued that their study could be used in the development of any new site layout planning model. The comparison’s outline (structure) of their study is adopted in this current research.

2.6.1 Site space representation

Space onsite is considered a resource of significance somehow equivalent to those of the 3Ms (money, manpower and material), time and equipment (Elbeltagi et al., 2001; Hegazy and Elbeltagi, 1999). Representing site space is an essential part of any model for site layout planning as it allows for recognizing the available space onsite and for identifying the locations of and for site objects. Abdel-Fattah (2013) stated that the first step in construction-site planning is to determine the area available for placing temporary facilities therefore, different developed models have established different methodologies in modeling the site space. In general, the literature listed three different methods for modeling the site space. Those are: 1) predetermined locations; 2) the grid system; and 3) continuous space.

2.6.1.1 Predetermined locations:

In this method, the problem of site layout planning is simplified to become an assignment problem, which, in some studies, is referred to as the location allocation approach (Hammad et al., 2017). In this method, the SLP model uses a number of predetermined locations to model the available space onsite. These locations have predefined shapes and sizes. Then, the SLP model solves the site layout problem by assigning the site objects to the best predetermined and available locations. Usually, the number of predefined locations is equal to or bigger than the number of site objects (Osman et al., 2003). The simplicity of this method makes it appropriate for projects where the available space onsite is limited to certain zones due to the nature and physical properties of the site. Some studies further simplified this approach by excluding the shape and size factors of site objects, which allows to place all site objects in any predetermined location (e.g., Li and Love, 1998; Tam et al., 2001; Mawdesley et al., 2002; Yeh, 1995). Other studies follow a superior approach by considering different shapes and sizes for the site objects as constraints to allocate

their locations (e.g., Hammad et al., 2017; Huang and Wong, 2015.; Li and Love, 2000; Zouein et al., 2002; Zhang and Wang, 2008). This makes the issue of site layout planning to be more realistic and in turn increases the complexity.

2.6.1.2 Grid system:

In this approach, any irregularly-shaped site is divided into cells. Each grid unit (cell) is given a unique location reference number. This location reference number allows to identify the position of a site object represented on the orthogonal grid. Site objects are individually placed on the grid in two ways:

- 1- The size of one cell (grid unit) is predefined by the user to fit the largest site object in the project. This method is considered as a simpler implementation of the grid system.
- 2- Objects could be modeled using multiple adjacent grid cells. Representing site objects on multiple cells, which enhances the practicality of the grid system as it provides a more realistic representation of the size of site objects during the search process. Also, this allows an object, while keeping its footprint unchanged, to take diverse forms and orientations.

This permits the use of the available space onsite more efficiently.

Previous studies that used this approach include: Elbeltagi and Hegazy 2001; Elbeltagi et al. 2001; Elbeltagi et al. 2004; El-Rayes and Said 2009; Hammad et al. 2017; Hegazy and Elbeltagi 1999; Khalafallah and El-Rayes 2006a; Khalafallah and El-Rayes 2006b; Khalafallah and El-Rayes 2011; Ning et al. 2010; Ning et al. 2018a; Ning et al., 2019; Osman et al. 2003; Razavialavi and Abourizk 2017; and Sanad et al. 2008. The grid system method helps detecting conflicts in space between site objects throughout the process of locating them onsite. Also, it facilitates examining the location process as well as allowing to search through the whole area available on the

construction site without any limit to certain zones as is the case in the predetermined location approach.

2.6.1.3 Continuous space:

The grid system does not reflect the true nature of the construction site where objects could be placed in any suitable location and unbound by any grid lines. Ali et al. (2016) believed that a more accurate method for placement lies with the continuous representation of space since it allows objects to be located anywhere on the site in order to get the optimal location with exact shapes. The continuous approach is more flexible and realistic when presenting site objects if compared with the other two approaches. No restrictions limit the site objects to be positioned in any place onsite. Studies that used this approach include: Zouein et al. 2002; Sadeghpour et al. 2004a; Sadeghpour et al. 2004b; Sadeghpour et al. 2006; Easa and Hossain 2008; and Andayesh and Sadeghpour 2011.

2.6.2 Shape representation of site objects

Knowing the geometry of site objects, such as the dimensions and forms, is essential to identify the space needed for them and consequently for the SLP. Razavialavi et al. (2014) stated that underestimating the facility size can lead to facility space's shortage, productivity loss, and safety problems while overestimating it can result in lack of space for the other facilities. Published studies listed three common ways for modeling the boundaries of the site objects in 2D, those include:

2.6.2.1 Dimensionless objects

Previous studies that used this method consider site objects as shapeless and as a result they model them as set of points on the site (e.g., Yeh 1995; Li and Love 1998; Tam et al. 2001; and

Mawdesley et al. 2002). This method is suitable with the location allocation approach since no dimension or form is required. Accordingly, objects' boundaries are not factored into the optimization process because their positions on the site are already determined (e.g., Wang et al., 2015). Sadeghpour and Andayesh (2015) stated that because their positions are predetermined, there will be no need to verify any overlaps or space conflicts between those objects.

2.6.2.2 Approximate geometry

This is the most common approach listed in the literature. The actual shape of the site object is encapsulated in a basic two-dimensional or three-dimensional geometric shape such as a rectangle or cylinder. Some past models augment this approach by permitting rotation for the encapsulating shape, which enhances the flexibility of the model and the efficient use of space onsite. Studies that used this approach include: Andayesh and Sadeghpour 2011; Andayesh and Sadeghpour (2013a); El-Rayes and Khalafallah 2005; Easa et al. 2006; Easa and Hossain 2008; El-Rayes and Said 2009; Hammad et al. 2007; Hammad et al. 2017; Khalafallah and El-Rayes 2011; Ning et al. 2010; and Razavialavi and Abourizk 2017.

2.6.2.3 Actual object shape

Modeling the actual shape of objects in 2D or 3D allows for more accurate and realistic identification of their location and the available space on the site. The necessity for exact shape representation arises in cases where space onsite is limited, such in high-density urban centers (Ali et al., 2016). Nevertheless, the use of this approach comes with a cost because it demands intensive computation efforts, which makes it time-consuming. Also, this demanding process becomes even more time-consuming when the actual shape approach is combined with the continuous space approach. This requires more efficient computation techniques to detect and resolve space issues

(e.g., Sadeghpour et al. 2004a; Sadeghpour et al. 2006). Studies that used this approach include: Elbeltagi et al. 2001; Hegazy and Elbeltagi 1999; Osman et al. 2003; and Sanad et al. 2008.

2.6.3 Time representation

Typically, there are two main approaches when it comes to define the site layout problems with respect to time, which are, the static site layout planning approach and the dynamic site layout planning approach (Ning et al, 2010). One part of the listed models in the literature adopted the static approach to solve the SLP-related issues however, the other part of the models embraced the dynamic approach as they found it to be more realistic and more representative to the SLP issues. Some studies have managed to overcome the limitation of the static approach by dividing the project's duration into intervals; this approach is referred to as a phased approach where the fully dynamic approach would consider the space required for a site object only for the duration for which that object is required on the site (Andayesh and Sadeghpour, 2013b; Andayesh and Sadeghpour, 2014b). Therefore, the time representation approaches for SLP can be classified as static, phased, and dynamic.

2.6.3.1 Static site layout planning approach

In this approach, the site layout does not change, which means that all the TFs will remain fixed in their selected locations from the start of construction to its end as it does not account for the factor of time (Andayesh and Sadeghpour, 2013b; Kumar and Cheng, 2015). Part of previous studies used the static site layout planning approach to simplify the problems associated with SLP, however the literature found that this approach was deemed to not reflect the true nature of the site layout planning, which is dynamic, and it considered it to be more suitable for small and short-period construction projects (Andayesh and Sadeghpour, 2013b). A comparison study between the

results when using the static approach and dynamic (staged) approach was done by Huang and Wong (2015). Their study showed that using the static site layout approach does not reflect the true nature of the construction and accordingly the optimization results of this approach is less accurate if compared with the dynamic (staged) approach.

2.6.3.2 Staged site layout planning

Tommelein and Zouein (1993) presented a model called “MovePlan” where the term dynamic layout, which refers to a sequence of layouts covering the whole duration of the construction process, was first introduced. Elbeltagi et al. (2004) defined the dynamic site layout planning (DSLPP) as the reorganization of the location and/or areas of the needed TFs on site at various time intervals, throughout the project’s duration to suit the dynamic need of TFs by the associated activities. The logic behind this approach is to split the construction lifetime into separate durations (partial stages), each of which has a separate partial layout. Each of those separate layouts is generated in chronological order and they usually get optimized individually by taking into consideration only the site objects that are required for that specific period. Site objects that exist between two consecutive time intervals are considered permanent facilities (fixed) during the second interval who occupy the same location that was allocated to them during the first interval while the layout is optimized accordingly. The remaining of the site objects are optimized and assigned optimal location from the available area onsite. Previous studies that adopted the staged approach include: Al Hawarneh et al. 2019; Zouein and Tommelein 1999; Elbeltagi et al. 2001; Elbeltagi et al. 2004; El-Rayes and Said 2009; Said and El-Rayes 2013; and Sanad et al. 2008.

2.6.3.3 Dynamic site layout planning approach

The layout in this approach is constantly changing depending on the planned schedule as the construction progresses. Andayesh and Sadeghpour (2013a) defined dynamic site layout planning as the task of determining the overall optimum location of objects such as temporary facilities, storage areas, and workshops on the construction site. This requires efficient use of space onsite to accommodate site objects (TFs and PFs) over the entire duration of a construction project (Zouein and Tommelein, 1999). In general, dynamic site layout planning is said to yield more accurate and realistic results if compared to static layout planning, because it takes into consideration the actual duration for which the temporary facilities are needed onsite; it permits to reuse the space that becomes available; and it accommodates for the continuous changes as required by the construction (Andayesh and Sadeghpour, 2013b). Sadeghpour and Andayesh (2015) argued that in order for the site layout planning approach to be rendered as fully dynamic, two time-related properties must be included. The first one is concurrent optimization of the layouts and site objects throughout the construction duration. Second, the process should reflect the alterations that occur to site objects. This approach allows the space used by one object to be reassigned to another one as long they do not have a time conflict (overlap in time).

In a fully dynamic approach, fewer site objects compete over available space on site that would increase the chance for each object to get an optimal location. Numerical examples explained by Andayesh and Sadeghpour 2013b; Andayesh and Sadeghpour, 2014b and Sadeghpour and Andayesh 2015 demonstrated the advantage and efficiency of how the fully dynamic approach who realistically represents the changes in space requirements over time if compared to the other two approaches.

2.6.4 Planning goals and objectives

Site layout planning models are implemented with the purpose of achieving one or more projected goals. Those goals are listed in the literature as: increasing productivity; safety; and security (Tommelein et al., 1992b). Goals must be interpreted by attainable objectives that can be achieved. Objectives related to site layout planning are defined as spatial relationships between site facilities. For instance, the goal for improving the efficiency of construction activities could be realized through the objective of reducing the travel distance between the site facilities (Elbeltagi, et al., 2004; Hammad et al., 2017; RazaviAlavi and AbouRizk, 2016). The goal of optimizing safety could be attained by decreasing the intersections between roads and paths onsite (El-Rayes and Khalafallah, 2005; Karan and Ardeshir, 2008). The objective of enhancing visibility is used to realize the goal of improving security onsite (Sadeghpour et al., 2006; Abune'meh et al., 2016). Objectives are expressed clearly in most of the studies listed in the literature about SLP, unlike goals, which are only denoted implicitly (Sadeghpour and Andayesh, 2015). Generally, a goal could be achieved through one or more objectives while an objective could be utilized to achieve a single or multiple goals. The objective of reducing the intersections between roads and paths, for example, would result in improving safety by decreasing the potentials of collision onsite and it would increase productivity since fewer site objects may be delayed due to the waiting time for a road to be cleared and be ready to use. Likewise, the goal for enhancing security onsite can be realized by increasing the visibility onsite and/or reducing the distance between site guards and the valuable site objects.

The literature listed three concepts in relation to site layout planning that represent the objectives:

1) a utility function; 2) spatial relationships; and 3) constraints and penalties.

2.6.4.1 Utility function

Generally, planning an optimal site layout requires implementing more than one goal, a mathematical formula known as a “utility function” is often used to represent a combination of multiple objectives in a single formula (Marler and Arora, 2004). Not all objectives included in the utility function, which is known in the literature as an objective function, have the same importance. Thus, weight values are assigned differently to each individual objective in the formula to reflect its significance and to model users’ preferences (Marler and Arora, 2004). This is helpful in cases where objectives included in the SLP model are paradoxical and would have a counterinfluence on the final optimal location of the facilities. For instance, while decreasing the distance between site objects would improve productivity, in some cases, maximizing that distance is required for safety purposes. This applies in cases such as explosives storage that should be close to the work area to improve productivity but at the same time maximizing distance is recommended for safety purposes. Equation 2.1 shows an example of a utility function, expressed as the summation of weighted distances, that aims to minimize the travel distance between facilities (Razavialavi and Abourizk, 2017).

$$\text{Utility function} = \text{minimize.distance} \sum w \times d \quad [2.1]$$

where W denotes the weight assigned to the objective of closeness (significance or cost of the interaction) between different pairs of facilities. It worth mentioning that weights can be identified based on various factors such as cost, travel frequency, and/or decision makers preference. The optimization model seeks the optimal solution based on the identified utility function then the level of the generated solutions for fulfilling the different objectives is assessed based on the score that

each solution achieves by satisfying the objective function constraints. Some of studies that used the utility function in Equation 2.1 include: Andayesh and Sadeghpour 2013a; Elbeltagi and Hegazy 2001; Li and Love 1998; Zouein and Tommelein 1999; Osman et al. 2003; and ; Hammad et al. 2017; RazaviAlavi and AbouRizk 2016; and Zhang and Wang 2008.

2.6.4.2 Spatial relationships

Site facilities have diverse spatial relationships that govern the interaction between them. Typical relationships that are used in published studies for site layout planning include closeness, farness, visibility and containment. The different relationships between facilities are defined by the objectives that reflect the type of the spatial relationship between those facilities. For example, the spatial relationship of farness between two site objects is presented by the objective of maximizing the travel distance. Even though there are several different spatial relationships among site objects, the objective of minimizing the travel distance, that represents the closeness, is most often addressed in the literature of site layout planning (Razavialavi and Abourizk, 2017). The other spatial relationships, such as farness, are applied for maximizing the distance between facilities that should be kept far from one another (Farmakis and Chassiakos, 2018). For instance, a storage space for combustive materials needs to be located far from sources of heat. Visibility is used for facilities that need to be seen from one another (Abune'meh et al., 2016). For example, a site office should be located in a place where construction activities can be seen. Containment is assigned for facilities that should be positioned inside or outside the boundary of one another; for instance, materials, equipment, tools, building components, etc., should be located within the operational radius of a tower crane. It is known that a utility function is utilized in a multi-objective model to present more than one objective, several of which may, sometimes, have contradictory effects on locating facilities. The degree of satisfaction of an objective function can be presented either in

binary (0 and 1), which can be used to present containment (in or out), or continuous, which can be used to represent closeness such as, in the closer the distance between two facilities is, the higher the value of the objective function is (Sadeghpour and Andayesh, 2015). Equation 2.2 illustrates an example of a formulation (utility function) taking into consideration the multiple objectives between two facilities (Sadeghpour and Andayesh, 2015).

$$\text{Utility function} = \sum W_{ijx} S_{ijx} \quad [2.2]$$

where S_{ijx} denotes the satisfactory value for the objective x between facilities i and j ; and W_{ijx} denotes the weight, which reflects the relative significance of that same objective.

2.6.4.3 Constraints and penalties

Constraints are set of limiting considerations, defined in the SLP model, to form a boundary within which acceptable solutions can be generated (Ali et al., 2016). Constraints and objectives can be looked at equally as design metrics or criteria (Marler and Arora, 2004). Thus, a solution is considered feasible when it satisfies all the constraints provided by a model. However, not all the generated solutions satisfy the defined objectives or constraints to the same degree. Thus, a concept known as penalties is applied to solutions that violated the constraints set by the model, this is a way to show the level of tolerance for that violation. Depending on the level of violation, penalties influence the overall score of the generated solutions, deeming them to be less desirable but does not reject those solutions. This adds to the flexibility of the model to provide a solution that satisfies the defined constraints to an acceptable level and, which will be added into the utility function as shown in Equation 2.3 (Sadeghpour and Andayesh, 2015).

$$\text{Utility function} = \sum W_{ijx} S_{ijx} + P_{kn} \quad [2.3]$$

where P_{kn} denotes the value of penalty k applied to each n (number of instance) occurrences.

Penalties are used in cases where a solution partially violates a constraint but to a tolerable extent.

For example, if an optimum location is allocated to an important facility that is scheduled to arrive at a later time to the site while that same location was assigned to a less important facility that arrives at the start of construction and both facilities are expected to have a time overlap then the less important facility should be relocated. In that case, a penalty, could be applied in the form of a “relocation cost”, which includes the cost of setting up, dismantling, and removing the facilities.

This relocation cost is applied whenever a facility is moved from one place to another during the construction. In that example, the space of the site was used efficiently, which resulted in less total travel distance and consequently a higher value for the objective function. However, in case numerous relocations occurred, the associated cost will accumulate leading to an increase in the overall cost of the solution, which makes it less desirable than the other solution that has higher travel distance cost. Thus, the cost penalty affects the final outcome for the optimum layout (e.g., Zouein and Tommelein, 1999; El-Rayes and Said, 2009; Ning et al., 2010). Safety could also be improved by applying a penalty to the objective function whenever a hazard occurs. El-Rayes and Khalafallah (2005) implemented penalties to enhance safety onsite by applying a penalty for every intersection of roads that occurs, which would reduce the potential of collision hazards onsite. Applying a penalty in the utility function should be done wisely because it could result in degrading the other weighted objectives included in the utility function. Sadeghpour and Andayesh (2015) argued that the challenge in adding the penalty to the utility function is that it is difficult to normalize the variables such that one does not outweigh others. Thus, using penalties should be

applied in a way that helps in excluding solutions that do not satisfy the minimum requirements as defined in the model for a feasible solution.

2.6.5 Optimization and search approaches of site layout planning

The optimization step usually takes place when all site objects (temporary facilities and permanent facilities) intended to be used in a project are known. Afterwards, a search approach and an optimization technique are selected. The objective of the search approach is to determine the method and order of selecting an optimum position onsite for site objects. There are numerous search methods that have been presented in the literature. During earlier efforts of site layout planning, there were two search approaches commonly used, which are the construction approach and the improvement approach. In 2015, the concurrent approach, was identified and introduced by Sadeghpour and Andayesh. The optimization technique is mainly used to implement the selected search approach and to realize the optimum layout. Many studies have applied different optimization techniques such as metaheuristic, mathematical, and knowledge-based systems (Farmakis and Chassiakos, 2018). All site layout planning concepts (i.e., time representation, space representation, site objects representation, and goals and objectives) play a role in defining the optimization technique, however the search approach and its level of sophistication and accuracy is the most critical when selecting the optimization technique.

2.6.5.1 Construction approach

In this approach, site objects arrive to the site one after the other and the optimum space is allocated for every individual site object at its arrival time. This means that at first, the space optimization process for each object is dependent on the positions of other objects that exist onsite at that time. Second, the order by which the site objects are selected has high influence on the final solution

since selecting the optimal location relies on the arrangement of previous locations of objects. Studies that used this approach include: Tommelein et al. 1992b; Tommelein and Zouein 1993; Zouein and Tommelein 1999; Sadeghpour et al. 2004a; and Sadeghpour et al. 2006. Defining the order is done either by the user or by the model, which it is set as the default order. This procedure is based on factors such as the cost of relocation, the interaction frequency with other objects (Zouein and Tommelein, 1999) or multiple combined factors (Sadeghpour et al. 2004a).

2.6.5.2 Improvement approach

This approach starts with a primary layout including all facilities (TFs and PFs), that is usually arbitrarily produced. Then, this initial layout is progressively optimized and new layouts are produced in the process. Every new optimized layout is assessed based on an objective function to determine the one that is the fittest. Normally, this process is repeated until it reaches the limit value of the objective function is or until no more enhancement is achieved in the produced answers (solutions). Examples of metaheuristic techniques that are commonly used in executing the improvement approach include: Ant colony optimization (ACO) (e.g, Ning et al., 2019); Approximate dynamic programming (e.g., El-Rayes and Said, 2009); Bee colony algorithm (BCA) (e.g., Yahya and Saka, 2014); Firefly algorithm (FA) (e.g., Wang et al., 2014); Genetic algorithm (GA) (e.g., Farmakis and Chassiakos, 2018; Sanad et al. 2008); Particle bee algorithm (PBA) (e.g., Lien and Cheng, 2014); Particle swarm optimization (PSO) (e.g., Zhang and Wang, 2008); and mixed-integer programming (e.g., Hammad et al., 2016; Hammad et al., 2017; Wong et al., 2010; Huang and Wong, 2017). Generally, those methods enhance the quality of the solutions (often referred to as genes) through different steps or generations. However, there are some techniques that allow for optimization within the same generation (Elbeltagi, 2013). Typically, this approach only seeks for semi-optimal solutions while a global optimum layout will not necessarily be

reached. This is due to the way the heuristic algorithms work and because at every step in the process there are lots of possibilities. Explanations and comparisons of different metaheuristic algorithms are found in studies conducted by Elbeltagi et al. 2005; Elbeltagi 2013; Nguyen 2013; and Wong et al. 2010. In general, the quality of a solution generated by heuristic techniques is dependent on factors such as the number of iterations, determining the proper number of initial populations (possible solutions), and the defined threshold for the objective function to be reached. Also, it was found that determining the proper number of the first population requires experimentation and that the processing time and the success rate for the heuristic techniques massively increases when the size of the project or the number of variables increases.

2.6.5.3 Concurrent approach

The idea behind this approach is to achieve the global optimum solution by simultaneously allocating positions to all site objects. The concurrent approach seeks to produce a single globally optimized layout. This differs from the improvement approach where multiple layouts are generated during the process of gradually optimizing the layout. Furthermore, the concurrent approach differs from the construction approach in the way of allocating to site objects. In the construction approach a position is allocated to each site object individually in a sequential manner, whereas in this approach the space is allocated to all facilities concurrently. Easa and Hossain, (2008) used a mathematical model to implement the concurrent approach on a static layout. This case is considered to be less complex than the case of combining the concurrent approach with the dynamic layout problems (Andayesh and Sadeghpour, 2013b) because the durations of site objects on the site (including time of arrival and departure) and the interrelationships between facilities (that change over time) must be considered.

2.7 Functions and capabilities needed in any model for site layout planning

In light of the previous section, it is obvious that the SLP models presented in the literature offered numerous advantages and great contributions which include automating the processes of selecting temporary facilities and site plan optimization while considering one or more objectives such as enhancing safety and/or minimizing travel cost. Nevertheless, due to the fragmented nature and variation in the approaches adopted in the published studies used to define and solve SLP issues, the probability for finding past studies to build upon newer ones to realize a SLP model that addresses a broader range of SLP issues may be questionable or even diminished. This means that there is a need for improvement by considering some additional requirements, functionalities and capabilities are useful to be addressed in a site layout planning model, including familiar and intuitive environments with no special knowledge required, spatiotemporal functionalities and capabilities, site logistics, accessibility, and route planning, 4D visualization, and human involvement and interaction. Those are essential features and requirements for a versatile solution that tackles various site layout planning issues.

2.7.1 Spatiotemporal functionalities and capabilities

Despite the critical need for such a function, spatial-temporal analysis is not incorporated in most of the previously developed models for site layout planning. The surrounding environment of 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). A construction site is part of its surrounding environment, which affects it, thus, a site should not be planned in isolation of its surroundings. The location of a building while is under construction on the site, has a significant influence on the construction strategy (Bansal, 2015). A thorough examination of the construction

site should be conducted, 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) because those will highly affect the position of temporary facilities onsite (Marzouk and Abubakr, 2016). A project constructed in one location would have a different construction approach from one that is being constructed at another location with different site characteristics and topography; because it would present different challenges (Bansal, 2015). Temporary facilities should be carefully placed in the construction site with the aim of avoiding any hazards, on-ground and underground objects (e.g., shorings, excavations, embankments, or buried tanks/pipes) that may affect its stability, operation, or functions (Marzouk and Abubakr, 2016). Spatial analysis can be highly beneficial in optimizing the site layout planning by taking into consideration the safety of temporary facilities (Karan and Ardeshir, 2008). Moreover, spatial queries and functionalities in a site layout model facilitate 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, since it gets erected and dismantled using other TFs (mobile cranes), which in turn need an access road for arriving at and leaving the site along with enough space for maneuvering (Marzouk and Abubakr, 2016). Creating a 3D model that includes the environment surrounding the site and having spatiotemporal analysis capabilities in a planning model would help in space planning (Bansal, 2011b). Accordingly, having advanced spatial analysis functionalities and capabilities would enhance the efficiency of the site layout planning model (Marzouk and Abubakr, 2016). Therefore, an efficient site layout planning model should help users to perform spatio-temporal 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 all the materials coming to and generated on the site and a representation of the spatial characteristics of the construction site (e.g., terrain) along with its surrounding environment. Moreover, the model should present all those in a user-friendly manner including textual, tabular, and visualization formats.

2.7.2 Site logistics, access roads, and route planning

2.7.2.1 Site logistics

Procurement of materials for a new construction project, estimating the quantities of demolition and renovation (D&R) waste generated onsite, and the availability of space onsite have a direct influence on site logistics, which affect the decision made in relation to some of the TFs needed during in the construction process (e.g., storage areas, trucks, and equipment). Ali et al. (2016) defined site logistics as reducing the cost of hauling storage and the distance of materials and equipment from the work area, while increasing site productivity through planning and scheduling. This shows that site logistics and site layout are interrelated and interdependent on one another, which encouraged researchers to develop models that integrate and optimize site layout planning and site logistics especially in congested sites (Said, 2010; Su et al., 2012; Ali et al., 2016). Said (2010) believed that overlooking these critical interdependencies between material procurement and the availability of site space can lead to negative 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 while the size of operation facilities is dependent on the quantity and size of equipment and tools (Kumar and Cheng, 2015). 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 requirements, which are achieved by incorporating material estimates with an 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 to increase the efficiency of these two tasks. Therefore, extensive descriptive information and data input have to be specified by practitioners during the process of site and logistics planning, which include site spatial information, interior building spaces, and an execution schedule (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 reach more informed decisions related to the numbers and sizes of TFs required (e.g., number of trucks, storage spaces, laydown areas, etc.). While most published studies conducted on SLP focused on integrating the material procurement process (Said, 2010; Said and El-Rayes 2011; Su et al., 2012) by taking into consideration the demolition and renovation (D&R) waste generated onsite, which has the potential to be recycled and reused in such projects or in other projects in the future is very beneficial to improve the sustainability of the SLP practice and to have cost savings, although they were not considered in previous site layout planning studies. Wu et al. (2015) considered that rapid urbanization has not only contributed to an increasing use of non-renewable resources but has also led to generate a significant amount of construction and demolition (C&D) waste with its associated environmental concerns, although it is widely recognized that the demolition waste has very high recycling potential. Poon et al. (2001b) stated that the weight of the demolition (D) waste is estimated to be 10 to 20 times more than the waste produced from new construction (C). Llatas (2011) emphasized that as requirements for C&D waste quantification become more and more accurate, concise and detailed, it is believed that computer-aided

estimation has good development prospects. Wu et al (2014) believed that one advantage of giving a detailed classification for construction waste is that the chances of recovering the waste may be increased. As a result, there is an increasing need for such tools that use BIM technology in construction management. Cheng and Ma (2013) developed a model to improve C&D waste sorting, quantification and estimation processes by leveraging BIM tools. Jalali (2007) considered that the estimation results could provide fundamental data for practitioners to evaluate the true size of the waste and to make an adequate decision for their minimization and sustainable management. Wu et al (2014) believed that the waste generation rates that were derived from different projects can assist in providing information for benchmarking the effectiveness of different management practices. D&R waste can be categorized based on building materials (e.g., glass, concrete, wood, steel, etc.), building components (e.g., doors, windows, walls, slabs, etc.), or materials condition (e.g., recyclable, reusable, or total loss). Also, an additional categorization method is to classify the building materials into “inert” and “non-inert” materials as stated by Zhang et al. (2012). Common inert materials include “reinforced concrete, asphalt, cement plaster, mortar, aggregate, sand, bricks, rocks, rubble, and soil”, while common non-inert materials include “wood, metal, plastic, and other organic materials” (Cheng and Ma 2013). Some of the waste estimation approaches as discussed in the literature, are mentioned in a study by Cheng and Ma (2013) as “Global Index” and “component index” methods, which were first introduced by Jalali (2007). The “waste index” was presented by Poon et al. (2001a) while the GIS approach was mentioned by Wu et al. (2015), which considers the land use (private residential, public residential, or commercial buildings), structure type (brick, steel structure, etc.) and floor gross area to estimate the generated waste. Cheng and Ma (2013) described the waste index as the amount (in unit of volume or weight) of construction waste generated per m² of Gross Floor Area (GFA); The global index, as a more

detailed method, that allocates certain changes or increased percentages to every kind of building material; and the component index approach that estimates the amount of C&D waste based on the type and amount of the construction components in a building facility. Therefore, a versatile SLP model should provide the user with detailed information about the amounts and locations of materials and waste generated onsite that will enable the layout designer to make more informed decisions on the numbers, optimal positions and sizes of the required TFs (e.g., storage areas, laydown areas, number of trucks, etc.).

2.7.2.2 Access roads and route planning

Well planned access roads can decrease the time and cost of handling resources and can improve safety on construction sites (Mawdesley et al., 2002; El-Rayes and Khalafallah, 2005; Sanad et al. 2008; Karan and Ardeshir, 2008; Andayesh and Sadeghpour, 2014a). For instance, tower cranes need special consideration when performing site layout planning such as places for storage as well as access roads, installation and dismantling spaces, and other criteria that ought to be considered when planning for a crane position (Marzouk and Abubakr, 2016). Furthermore, limited accessibility could decrease efficiency by 58% and the congested work space could lead to an efficiency reduction of up to 65% (Su et al., 2012). Site layout planning can influence the cost associated with the travel distance of construction operations (Hammad et al., 2017). Most of the studies conducted on site layout planning have focused on solving site layout planning problems by only minimizing the travel distance between the temporary facilities and the relocation cost (El-din et al., 2015). Yet, to date, the planning of access roads has been neglected in the literature despite that the travel distance between site facilities is the most common factor used to optimize the site layout in the models presented in the literature, which means that including access roads

while modeling the site layout is vital (Sadeghpour and Andayesh, 2015). Generally, there are two simplified approaches introduced in the literature to represent the distance between the site facilities. Those are Rectilinear distance and Euclidean distance. In real life projects, “actual paths” as defined onsite are used to measure the distance between any two facilities (Cheng and Kumar, 2014). Previous studies that used rectilinear distance in their developed models are: Zouein and Tommelein 1999; Mawdesley et al. 2002; Zouein et al. 2002; and El-Rayes and Said 2009 and the ones that used Euclidean distance include: Li and Love 1998; Elbeltagi and Hegazy, 2001; Osman et al 2003; and Andayesh and Sadeghpour 2013a. It is worth mentioning that both rectilinear and Euclidean (i.e., direct approaches) approaches are simple and can quickly find the path between two points however, they do not account for any of the obstacles on that path (Andayesh and Sadeghpour, 2014a).

In addition, 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 has not gotten sufficient attention (Andayesh and Sadeghpour, 2014a). In addition to the two previously mentioned approaches (rectilinear and Euclidean), other approaches such as grid based and visibility graph were also introduced to determine the shortest path onsite. A comparative study that compared those approaches was done by Andayesh and Sadeghpour (2014a) found that a grid-based approach considers the obstacles found in the path but the accuracy of the path depends on the grid size; whereas, the visibility graph was the most accurate approach. Nevertheless, when the site is congested more computation is needed, compared with the other approaches. The problem with all those approaches, despite their contributions to solving the path planning issues, is that almost none of them has considered the site spatial (topographic) conditions. In reality, the ground or the site surface is not plane but rather has variation in its slopes, while complex terrain would

affect the distance's length, travel distance, time, and the selection of the shortest path between site facilities. Therefore, a real representation of the site spatial (topographic) conditions is vital in any SLP model. A methodology was introduced by Al-saggaf and Jrade (2015) for an integrated BIM-GIS model that simplifies 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 waste based on the travel distance, which is calculated for actual roads and paths defined onsite, between the waste site location and the targeted destination. The model is also capable of determining the closest destinations (e.g., storage spaces or landfills) to the location of the waste and it can identify the shortest path between the two points.

2.7.3 4D Visualization

Being able to visualize the progress of construction in 4D (3D + time factor) is a key to provide planners with a real and comprehensive view of what the conditions are and what the sequence of work might be throughout the duration of construction (Bansal, 2015). If compared to 4D visualization, traditional methods have a higher chance to errors since the planner is required to have a very good imagination to picture how the arrangement of PF, TF, available area onsite and the accessibility to the site would be throughout the duration of construction. Ma et al. (2005) claimed that a 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 means to validate the construction plan. Marzouk and Abubakr (2016) explained that BIM-4D planning is very helpful

in understanding the sequence of the lift operation and in checking if there are possible collisions that could happen between the cranes during the operation time. They also suggested that current limitations in their framework could be mitigated by enabling the dynamic nature of construction sites and incorporating a simulation tool that addresses the variability and ambiguity. 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 provide more clarity and increase the understanding of practitioners to the construction process and accordingly make them more likely to allocate resources more effectively (Bansal and Pal, 2008). An important requirement in a 4D SLP model is in presenting and managing the space needed for conducting an activity in addition to presenting the building components and activities because a lack of such a feature (an activity space requirement) in the planning and scheduling process may lead 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 the spatial-temporal analytical functions such as identifying how many site objects are located within the safety buffer zone of a certain tower crane and the second is the dynamic representation of the 3D components to reflect their realistic progress status (Su et al., 2012). However, most of the models presented in

the literature for SLP that support 4D modeling are in fact 2.5D + time (with fixed height and shape), which means that they do not reflect the actual progress of construction and the site conditions realistically. For instance, visualizing the progress of floor completions in a multi-story building in relation to the consumption of materials onsite (Sadeghpour and 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 a presentation to the construction process. Being able to visualize the site layout in three dimensions throughout the different stages would lead for smoother and easier planning for a dynamic construction site (Zolfagharian and Irizarry, 2014). El-din et al. (2015) said that because the site boundaries, existing permanent structures, new buildings, 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 site facilities (e.g., storage areas, batch plants, etc.) with the construction schedule. Ma et al. (2005) argued that this structure not only enables resource, schedule, and manpower management for the project but also provides convenience to 4D layout across the construction site. However, developing a 4D model is a daunting and a time consuming process that could take several personnel hours (Bansal, 2011b). Developing a 4D model almost feels like creating a 3D model from scratch. Thus, the need for an SLP model that supports and facilitates 4D modeling and that has visualization capabilities is crucial.

2.7.4 Familiar and intuitive environment with no especial knowledge required

A SLP model should be intuitive and provide a user-friendly environment that does not require users to obtain knowledge that is not directly related to their field to be able to operate it and get

efficient results. For instance, the most common optimization techniques mentioned in the literature are mathematical and heuristic techniques (Elbeltagi and Hegazy, 2001; Elbeltagi, et al., 2004; Hegazy and Elbeltagi, 1999; Sanad et al, 2008). Each technique has its advantages and contribution to solve SLP issues. In general, mathematical techniques are more accurate in determining the optimal solution than heuristic techniques, however this high accuracy makes them take longer to realize (Kumar and Bansal, 2015). Heuristic techniques seek near-optimum solutions but they can be applied to solve larger and more complex problems (Bangert, 2012; Farmakis and Chassiakos, 2018). Commonly, the quality of a solution generated by heuristic techniques is dependent on factors such as the number of iterations, determining the proper number of initial populations, and the defined threshold for the objective function to be reached. In general, due to the different natures of the problem-solving (optimization) techniques, their processing time to reach a solution, the quality of the solution, and the success rate of finding an optimal solution (especially in the case of heuristic techniques) varies, an extensive experimentation is required to determine the proper number of initial populations (solutions) and the number of iterations required to realize a close to optimum solution while some parameters are defined by trial and error and some factors vary depending on the nature of the problems (Elbeltagiet al, 2005). In order to accept the solution produced by a heuristic model, users must set a tolerance margin or have an expectation of what is considered to be a sufficient solution (Bangert, 2012). In other words, taking genetic algorithms (GAs) as an example for artificial intelligence (AI) heuristic techniques since they are the ones mostly mentioned in the literature due to their simplicity, Easa and Hossain (2008) said that they are very useful in solving complex nonsmooth site layout problems however, as a genetic algorithm does not rely on gradient or derivative information, it cannot determine if a given solution is optimal while some heuristic rules are used to determine when the model should

stop. This has guided other researchers, such as Ning et al (2016), to develop new methodologies with the focus on evaluating and selecting the best site layouts that are generated by optimization models. All this requires users to acquire knowledge about the theory (logic) behind the optimization technique used and its application to reach the optimal solution before using the model, which is not a practice by the AEC practitioners. Also, this can increase the likelihoods of practitioners being intimidated and discouraged when using such a model.

2.7.5 User involvement

The adequate interference and preference of practitioners for the final site layout is almost neglected in the literature. This hinders practitioners from accepting the automatically generated solutions for the site layout as different practitioners have different preferences and views for the site layout that comply with their personal style and experience (Tommelein et al., 1992a). El-din et al. (2015) supported this argument by stating 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 most important, it does not allow their knowledge contribution to the model. This is due to the discrepancies between the approaches used by AI models and the practitioners in generating a solution for the site layout, which render them as incomprehensible to users who would refuse to implement them or to 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. Zolfagharian and Irizarry (2014) claimed that 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. 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) stated that in practical applications, the predetermination of the construction cost and interactive cost is not easy, and professional experience is necessary. Cheng and 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 and Irizarry (2014) added that site planning still requires human experience and some required variables that are not easily predetermined. Thus, enabling planners to queue facilities in accordance to their expertise, intuition, and due considerations of applicable site constraints is crucial (Sadeghpour 2006), as determining the required TFs and their spatial requirements is mainly knowledge dependent (Elbeltagi and 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 they believed that prioritizing multiple objectives in site layout planning is a highly subjective and non-trivial task for which no agreed-upon method exists. Hence, in light of this, an effective SLP model should allow users to apply their knowledge in the design and selection of the required TFs and should aid 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 final outcome.

2.8 Summary

This chapter provided an overview of the literature related to site layout planning. The importance of SLP to the construction process and the overall cost, time, safety, and the goodwill of the labor was discussed. An analysis of the SLP solutions listed in the literature was presented in terms of their approaches, geometric representation of the site facilities (temporary and permanent), space representation, planning goals and objectives and the temporal approach to the site layout and representation. Each of those has different subcategories and methods used towards addressing the SLP process and helping to solve the problems associated with it. Even though there are no real rules to determine the best practices or approaches that should be implemented in any SLP model, the section analyzing the literature on SLP models highlighted some of the approaches that should be considered to achieve a more efficient SLP model and to get more accurate results. For site objects shape representation, it was found the actual shape approach (including 3D representation) is preferable. In terms of temporal representation, the dynamic representation approach should be considered. Whereas for selecting the optimization approach, it was found that the concurrent approach is recommended. The SLP models presented in the literature have provided vast contributions towards solving the problems of SLP nevertheless there are some useful functionalities and capabilities that should be considered when developing SLP models to be adopted by the AEC industry. These are a familiar and intuitive environment with no especial knowledge required, spatiotemporal functionalities and capabilities, site logistics, access roads and routes, 4D visualization, and user involvement. As a conclusion, addressing those useful functionalities and capabilities is important in order to achieve an efficient and versatile solution to the SLP issues, which can facilitate the planning, analysis and other tasks involved in the SLP process and help users apply their knowledge throughout in order to reach a desirable outcome.

CHAPTER 3

Literature review

BIM, GIS and BIM-GIS integration and applications

3.1 Introduction

BIM and GIS are powerful platforms widely used in the construction industry due to their various individual features and capabilities however each platform lacks important features the other platform offers. For instance, GIS provides topological (georeferenced) data, that allows for 3D analysis, spatial analysis, and queries such as calculating the distance between two different points, calculating and planning routes, logistics planning, and defining the optimal location (Irizarry and Karan, 2012; Bansal 2014). BIM, on the other hand, is incapable of such analysis, but it provides a detailed database of object-oriented parametric information for the building and represents it in a 3D model, a feature that GIS is lacking (El-Mekawy, 2010). In addition, data transition, query and analysis between BIM and GIS are further problematic due to interoperability issues between both platforms at a semantic level, among other issues (El-Mekawy, 2010). This chapter discusses the literature related to BIM, GIS, their similarities and differences; BIM-GIS integration applications, the interoperability and integration between BIM and GIS and associated issues.

3.2 Building Information Modeling (BIM)

BIM is a methodology by which the facility design and information are electronically managed throughout the facility's life cycle (Bryde et al., 2013). This methodology is a result of interacting

policies, processes and technology (Succar, 2009). It is considered a revolutionary technology, as it helps engineers design virtual models of a digitally constructed building that allows owners to visualize the building before it is built (Jrade and Jalaei, 2013). Also, it is a revolutionary process that led to a drastic transformation in the approach by which practitioners conceive, design, construct and operate facilities (Azhar et al., 2012). Early studies on BIM started in the early 1970's but began to grow in the mid 1980's (Howard and Björk, 2008). BIM can digitally provide an owner with almost all the data required about a facility (NBIMS-US, 2016). In the AEC industry, the abbreviation BIM indicates parametric 3D CAD technologies and processes (Taylor and Bernstein, 2009), but BIM offers more than just a simple visualization of a 3D data-rich model of a facility. It supplements the 3-dimensional representation with the addition of a fourth dimension (4D), which is time (i.e., scheduling information) (Bryde et al., 2013), and a fifth dimension (5D), which is cost (Kraus et al., 2007). The AEC industry's nature is rather fragmented and needs a considerable amount of collaboration, communication, and coordination among the different practitioners involved in one project (Alshawi and Faraj, 2002; Deng et al., 2016b; Walasek and Barszcz, 2017). Thus, BIM was established to potentially answer some of the requirements set by the AEC industry that have stemmed from the industry's increasing complexity and changing nature (Bryde et al., 2013).

In addition, the terminology BIM can be used with different definitions (Hannon, 2007). As illustrated in Figure 3.1, the National Institute for Building Science (NIBS) stated that the term BIM can be exploited to denote multiple meanings; 1) a product (building information model); 2) an activity (building information modeling); and 3) a system (building information management) (NIBS, 2007).

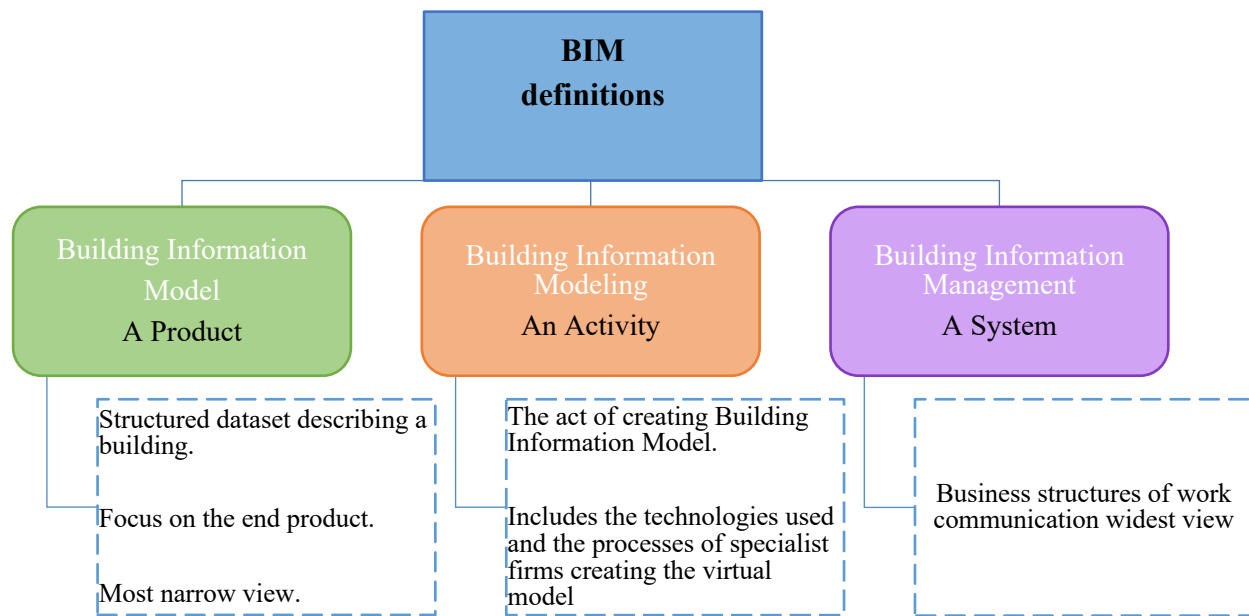


Figure 3.1 Different definitions of BIM (NIBS, 2007)

The Associated General Contractors of America AGC (2006) stated that the Building Information Model (a product) is a data-rich, object-oriented, intelligent, and parametric digital representation of the facility from which views and data appropriate to various users' need can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility. The Building Information Modeling process constitutes a single element of Building Information Management (a system), also known as big-BIM, which covers wider aspects of the construction process including design, construction, site activities, communication down the supply chain, and facilitating the construction activities electronically (Davies and Harty, 2013). According to The US National Building Information Model Standard Project (NBIMS-US) Committee, Building Information Modeling (BIM) is a “digital representation of physical and functional characteristics of a facility” (NBIMS-US, 2016). It provides a shared knowledge source for information about a facility, which aids users in the decision making process, throughout its life cycle from earliest conception to demolition (NIBS, 2007). The resulting Building Information

Model is a data-rich, object-based, intelligent, and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design. In general, BIM benefits the different parties involved in a project in making the project's work flow faster and more efficient, making the facility design more accurate, lowering the environmental and overall lifecycle cost of projects, enhancing productivity, automating assembly, improving customer service, and documenting information about a project throughout its life cycle (Azhar et al., 2008; Azhar, 2011).

Currently, BIM is being leveraged in various applications. Some of the BIM applications are design visualization, fabrication/shop drawings, code reviews, 4D construction sequencing and scheduling, 5D cost estimating (e.g., quantity take off), clash, interference and collision detection (e.g., piping, duct, steel beams, etc.), forensic analysis (e.g., potential failures, leaks, evacuation plans, etc.), facility operation and maintenance (Azhar et al., 2008; Azhar, 2011), which is also referred to as (7D) in a study by Czmocho and Pekala (2014), supply chain management, site layout planning and site utilization, fieldwork and layout (e.g., materials and systems layout), constructability review (Campbell, 2007), and sustainability (e.g., energy consumption and environment preservation) also can be called 6D (Czmocho and Pekala, 2014). First, BIM got the attention of academic researchers and then the AEC industry professionals. Some BIM applications in research areas are design and engineering, construction, facilities management, sustainable practices in the AEC industry, integrating BIM with analysis tools, sustainability throughout the phases of construction and post-construction, energy innovations, Integrated Project Delivery (IPD), interoperability, modifications to practice and BIM best practices (Becerik-gerber and Kensek, 2010). Azhar et al. (2012) described Integrated Project Delivery (IPD) as a novel project delivery approach to integrating people, systems, business structures, and

practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle. Despite of the benefits of BIM, some studies, such as (Fischer and Kam, 2002; Fox and Hietanen, 2007; Taylor and Levitt, 2007; Azhar et al., 2008; Azhar, 2011; Azhar et al., 2012; Czmoach and Pekala, 2014; Walasek and Barszcz, 2017), among others, have reported challenges and risks of adopting BIM in the AEC industry, which has resulted in a slower useable rate than what was expected (Walasek and Barszcz, 2017). Table 3.1 shows a comparison between the most common commercial BIM platforms based on a study by Eastman et al. (2008) and Eastman et al. (2011).

Table 3.1: Common commercial BIM platforms in the market (Eastman et al. 2008 and Eastman et al. 2011)

| <i>BIM tool</i> | Autodesk Revit | Bentley | Vico | ArchiCAD |
|------------------------------------|--|--|--|---|
| <i>IFC certified</i> | Yes | Yes | Yes | Yes |
| <i>Operating system</i> | Windows and Mac OS X (via BootCamp plugin) | Windows | Windows | Windows and Mac OS X |
| <i>ODBC support</i> | Yes | Yes | Unknown | Yes |
| <i>Supported interfaces</i> | DGN, DWG, DWF, DXF, SAT, SKP, gbXML, AVI, BMP, JPG, TGA, TIF and API | DGN, DWG, DFX, PDF, STEP, IGES, STL, Primavera, STAAD, RAM | DWG, DXF, PDF, VRML, JPG, Primavera, MS Project, Revit, ArchiCAD | DWG, DXF, STEP, IGES, STL, VRML, STL, SAT, 3DXML, IGES, CIS/2, SDNF |
| <i>Strengths</i> | Market leader, user friendly, direct link interfaces, excellent | Almost full AEC modeling tools, support complex | Best contractor-oriented tool, first real 5-D support, | Oldest tool, intuitive interface, easy to use, large |

| | | | | |
|-----------------|--|--|--|---|
| | object library, multi-user interface and bidirectional drawing support | curved surfaces, support developing Parametric objects, provide scalable support | Direct support for Revit, Tekla, Primary and ArchiCAD®. Complete project management. | object libraries, rich supporting application, only strong BIM tools for MACs |
| Weakness | Limitations on parametric rules dealing with angles and does not support complex curved surfaces | Large and non-integrated user interface, heterogeneous functional modules include different object behaviors | Complex package of highly Specialized modules, expensive, sharp learning curve. | Limitations on parametric modeling, not supporting update rules between objects and scalability issue |

In short, a BIM tool enables users to design a facility and visualize its design in a detailed 3D model. It also enables collaboration and communication between the different parties involved in the project such as: architects, engineers (i.e., civil, mechanical, electrical, etc.), construction and project managers, contractors, and financial entities (Bryde et al., 2013) and aids in solving the factors that lead to a decrease in productivity and inefficiency (Walasek and Barszcz, 2017).

3.2.1 Industry Foundation Classes (IFC)

Typically, a construction project is complex and fragmented in nature with multidisciplinary involved parties that have led to insufficient communication and performance among them. Almost US\$16 billion is spent annually due to the lack of interoperability (Isikdag et al., 2008). In 1994, the International Alliance for Interoperability (IAI), which changed its name to BuildingSMART

in 2008 to better reflect the nature and goals of the organization, established an object-oriented open standard called IFC (Cheng et al., 2015; Deng et al., 2016b), which became an ISO publicly available standard (ISO 16739) in 2005 (Isikdag and Zlatanova, 2009). IFC is the most renowned standard of interoperability used in the AEC industry for exchanging information (Karan and Irizarry, 2015) and is implemented by the majority of BIM platforms in the industry (Gröger et al., 2012). IFC is meant for facilitating interoperability by sharing and reusing data about a facility throughout its lifecycle between different parties involved in a project (El-Mekawy et al., 2012b). IFC is specified as an EXPRESS data modeling language (Cheng et al., 2013) that is built on the ISO 10303 Standard for the Exchange of Product model data or STEP (Borrmann et al., 2014). Irizarry et al. (2013) said the IFC is the only public, non-proprietary and well-developed data model for buildings and architecture that exists today. In IFC a “Class” is a specification that is meant to provide a description for a range of entities that share common characteristics such as slabs, columns, walls, etc. (Isikdag et al., 2008). There has been some efforts to extend IFC to the geospatial domain as IFC for GIS (IFG), an initiative was carried out by the Norwegian State Planning Authority Statens Bygningstekniske Etat, with the purpose of including geographic data within the IFC framework (Karan and Irizarry, 2015). Nevertheless, only 60 to 70 classes out of the 900 found in the IFC schema can be transformed to GIS (El-Mekawy et al., 2012b). Even though IFC has provided a robust solution for BIM integration and interoperability issues, it still suffers from some inherent limitations (Azhar et al., 2012). The introduction of the IFC4 version provides more support for interoperability with GIS by adding new geographic elements including “ifcGeographicElement” and “ifcGeographicElementType” (buildingSMART, 2013).

3.3 Autodesk Revit (BIM tool)

Autodesk Revit is the dominant and most popular Building Information Modeling (BIM) platform in North America. In the past, Autodesk Revit software included different software packages for multi AEC disciplines such as Revit Architecture, Structure, and MEP. However, since 2013, Autodesk combined all the aforementioned tools in one single package. Autodesk Revit is a BIM tool with a database system that helps to design a facility and provides comprehensive drawings, multiple viewing options for a facility including plans, sections, elevations, and 3D perspective views. The object-oriented database in Revit consists of libraries that contain families, with extensive details, for different building components about a facility such as walls, columns, beams, ceilings, roofs, floors, doors, windows, stairs, etc. The specifications of the various facility components are compatible with the Construction Specification Institutes (CSI) MASTERFORMAT and UNIFORMAT.

In addition, Revit offers multiple import/export options for different industry-related formats including IFC. IFC export dialogue provides users with different exporting options for the created 3D model of a facility.

Revit has been selected for this research, as a BIM tool, for the following reasons:

1. **Availability:** Autodesk Revit is offered by Autodesk to the online Student and Educator community for free.
2. **User Interface:** Interfaces used in Autodesk Revit are similar to those in AutoCAD, which is very convenient for CAD users.
3. **Software Accessibility:** Autodesk provides free access for students and faculty to an enormous number of tutorials and curriculum, which are hosted online.

4. **Interoperability:** There is a variety of file formats that are supported by Autodesk Revit including IFC and CAD import and export. In addition, Autodesk Revit supports ODBC, which allows for flexible transition of data.
5. **Extensibility:** Autodesk Revit allows the development of third-party plug-ins and extensions along with an API guide that is intuitive and thorough.

3.4 Geographic Information System (GIS)

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. It lets users to visualize, analyze, and interpret data, to understand relationships, patterns, and trends. Also, in recent years, GIS has benefited many organizations of different sizes in almost every industry (ESRI, 2016d). GIS can function as a decision-support system because it encompasses all the required qualities for an information system (Liu et al., 2017). Figure 3.2 illustrates the architecture of GIS from an information system point of view as presented by Longley et al. (2011). Generally, GIS support 2D modeling, however 3D GIS (2.5D) has been implemented and utilized in an increased trend in recent years. Many studies have described the benefits of utilizing GIS and its potential applications in the AEC industry (Sebt et al., 2008; Bansal, 2011a; Bansal, 2015). For instance, Bansal (2015) said GIS can provide innovative solutions to AEC practitioners as typical projects will encounter different challenges depending on both the location and position. In addition, while using information such as site conditions and terrain and material amounts, GIS finds locations with a potential fit for storing materials. Bansal (2011b) stated that other factors, such as environmental condition, site topography, thermal comfort, and access-route planning that cannot be modeled with BIM tools, influence space requirement. Moreover, BIM and 4D CAD lack

geospatial analyses such as evaluation of jobsite with respect to flooding (because spaces planned earlier would need to be modified accordingly), site drainage planning if a flood occurs, and route planning for vehicles carrying consignments from different access routes to the jobsite. GIS provides 4D capabilities where the progress of the end product is illustrated, however, not the interactions between different resources (Bansal, 2015). Bansal (2014) added that GIS helps in route and logistics planning. A comprehensive view for the construction process is crucial for data management; BIM tools suffers from poor spatial analysis and in locating objects on larger sites (Mignard and Nicolle, 2014). Boyes et al. (2015) claimed that environmental data such as ambient temperature and air and noise pollution are commonly available as GIS datasets.

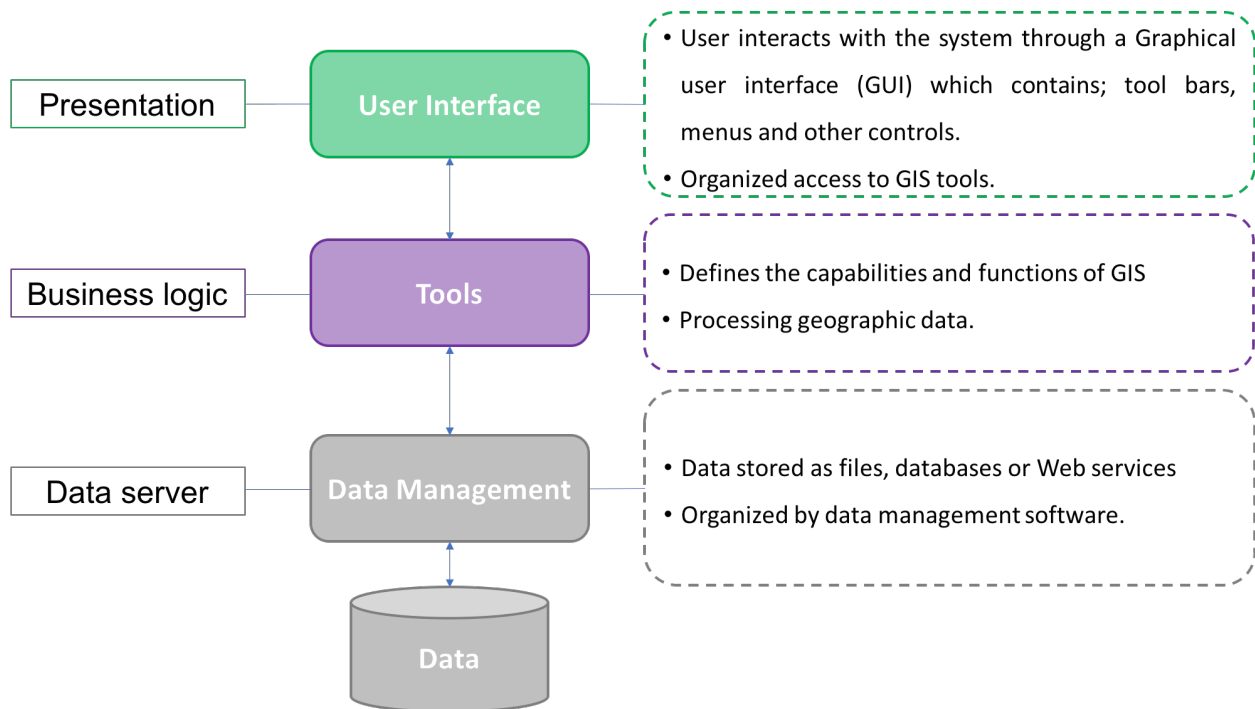


Figure 3.2: Architecture of GIS (Longley et al., 2011)

3.4.1 Representing features in GIS

A geographic information system represents a variety of geographic information with three simple types of spatial entities: points, lines, and areas. There are two main methods to model the data related to the aforementioned kinds of entities in the digital world: vector data and raster data (Bansal and Pal, 2008).

In Vector Data, the geographic data is represented as points, lines, and polygons, in the following format:

- A point is represented as a single pair of X, Y coordinates.
- A line is stored as a series of points (vertices) connected by straight segments.
- A polygon (area) is represented as a closed series of vertices (X, Y coordinate pairs) defining the boundaries of an area.

Vector data is most suitable for representing discrete objects (Kumar and Navaneethkrishnan, 2012).

In Raster Data, the spatial variation of an object is represented by a grid (Bansal and Pal, 2008). The object is divided into cells or pixels, which are normally square-shaped cells, and each cell is referenced by the number of row and column (Longley et al., 2011). Also, each cell is inherently allocated a certain single value, which is stored in that cell along with other information such as the X, Y coordinates of the upper left corner of the cell and map projection data. In Raster Data the geographic data of the entities is presented as follow:

- A point is represented by a single grid cell.
- A line: is represented as a number of consecutively adjoining cells.
- An area: is represented as a cluster of adjacent cells.

Raster data is most suitable for representing continuous space such as an environmental phenomena (Kumar and Navaneethakrishnan, 2012). Both methods have advantages and disadvantages as shown in Table 3.2 which is based on the findings of studies done by (Sebt et al., 2008; Longley et al., 2011).

Table 3.2: Advantages and disadvantages of raster and vector data modelling methods

| Data modelling method | Advantages | Disadvantages |
|------------------------------|--|--|
| <i>Raster</i> | <ul style="list-style-type: none"> • Cost efficient • Simplicity • Ease of data collection. • Fast performance of spatial analysis | <ul style="list-style-type: none"> • Less representation accuracy • Less data variation representation • Large data size (depending on the cell size). |
| <i>Vector</i> | <ul style="list-style-type: none"> • High precision of data representation. • Quality of cartographic output. • Data storage efficiency (depending on the number of vertices). • Wide variety of cartographic analysis, overlay processing and map projection. | <ul style="list-style-type: none"> • Intensive data processing. • Topology update is required after data modification. • Poor representation for continuous fields. |

In vector data, the features that share a similar representation type (e.g., point, line, etc.) are stored within the same geographic database known as a feature class (Longley et al., 2011).

The selected construction plan's implementation dictates the method of data modeling (vector or raster) however, differences between both methods are becoming more narrowed in light of the advancement of new technologies (Sebt et al., 2008).

The previous feature representation discussed 2D modeling however, GIS provides the capability of representing 3D models such as 3D surfaces (e.g., Triangulated Irregular Network or TIN and Digital Elevation Models or DEM) and 3D features (e.g., multipatches), which can be used for modeling terrain and topography and to represent pipelines, buildings, etc. 63 respectively. TIN is actually considered 2.5D as it does not contain various height attributes at the same X, Y position, as 3D representation usually does. It represents surfaces as contiguous non-overlapping triangular features and is created from a collection of points containing X, Y, and Z attributes (Longley et al., 2011). Moreover, grid surfaces (e.g., DEM) are in fact a sort of raster dataset containing Z values in each cell at certain positions. In GIS, both TIN and Grid surfaces are mainly used to model terrain and topography.

3.4.2 Spatial analysis

In GIS, spatial relationships exist between different feature classes (layers). These relationships can be validated via nine Boolean operators, based on ISO and OGC standards, in order to identify the spatial relationship between two or more different layers where each layer has at least one object. A study by Longley et al. (2011) listed these nine validation processes as shown in Table 3.3.

Table 3.3: Validation processes of spatial relationships

| Validation method | Description |
|--------------------------|--|
| <i>Equals</i> | Are geometries the same? |
| <i>Disjoint</i> | Is there a common point between geometries? |
| <i>Intersects</i> | Do geometries intersect? |
| <i>Touches</i> | Do geometries intersect at their boundaries? |
| <i>Crosses</i> | Is there an overlap between geometries? (type of geometry could differ, for instance lines and areas). |
| <i>Within</i> | Is one geometry partially inside another? |
| <i>Contains</i> | Is one geometry completely inside another? |
| <i>Overlaps</i> | Is there an overlap between geometries? (must be same type of geometry). |
| <i>Relate</i> | Are there intersections between the interior, boundary, or exterior of the geometries? |

The main core and most crucial part of GIS is its spatial analysis as it involves all the required processes (i.e., transformation, manipulation, and procedures) in order to provide value to the geographic data by turning it into valuable information for the decision-making process and make clear information that is otherwise implicit, such as patterns and anomalies (Longley et al., 2011). According to ESRI (2017a), spatial analysis is the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other analytical techniques in order to address a question or gain useful knowledge; spatial analysis extracts or creates new information from spatial data. Spatial analysis is performed and achieved through a set of tasks and procedures

performed on geographic data. ESRI (2017c) stated that by using spatial analysis, one can combine information from many independent sources and derive a new set of information (results) by applying a large, rich, and sophisticated set of spatial operators. All those spatial operations are all part of the suite of geoprocessing tools. ESRI (2016a) Provided a list of the most common spatial operations used for spatial analysis process, which include overlay and neighboring, surfaces, spatial and non-spatial statistics, table management, and selection and extraction.

- Overlay analyses (e.g., Intersect and Union) are meant to identify the layer that is on top of another, for instance, to identify the roads running on certain lands.
- Proximity analyses (e.g., Buffer and Near) are used to identify the objects that fall within a certain distance and to measure the closest distance between two objects. The result of the Buffer operation is a polygon based on the queried distance, while the Near operation adds values distance the measurement into the input features.
- Surface analysis entails different types of operations. This involves obtaining new surfaces from existing surfaces, reclassifying surfaces and merging surfaces such as TIN (ESRI, 2017a).
- Spatial and non-spatial statistics are used to examine the distribution of values for a particular attribute (e.g., ethnicity distribution) or to spot outliers (extreme high or low values). Examples of data from non-spatial statistical tools include minimum, maximum, sum, frequency, mean, and standard deviation of particular attribute (e.g., population size).
- Table management is crucial to spatial analysis since all the information related to objects is kept in easy-to-access tables so that most processes and operations have direct access to the data in those tables (i.e., establishing relationships among tables, creating features, creating fields etc.).

- Selection and extraction normally include narrowing down the data from a vaster and more complex collection of data based on certain criteria. This includes operations such as selection based on location, selection by attributes and clipping. In case of selection by location, the input layer is evaluated based on its locational relationship to the target layer and when the selection criteria are met, the target features are selected. While in selection by attributes, instances are selected in a layer/table based on the attribute queries.

In this study, only the most common spatial analysis operations and tools, which serve the purpose of this study, are discussed.

3.5 ArcGIS Desktop (GIS tool)

The Environmental Systems Research Institute (ESRI) ArcGIS platform offers a wide variety of products and services. One of ESRI's products is the "ArcGIS Desktop" package, which includes ArcMap (provides 2D modeling and analytics), ArcScene (provides 2D modeling and analytics), ArcCatalogue (provides data management functionalities). In addition, ArcGIS Desktop provides a tool for translating numerous data formats (developed by Safe Software's FME). This "Data Interoperability extension" can read and write more than 70 file formats such as GML, XML, Autodesk DWG/DXFe, MicroStation Design DGN, MapInfo NID/MIF and TAB, Oracle Spatial, Intergraph GeoMedia Warehouse. It also has the ability to import multiple popular 3D model formats including SketchUp (.skp), 3D Studio (.3ds), OpenFlight (.flt), and VRML (.wrl) (Bansal, 2011a); BIM (.ifc) and Revit (.rvz) file formats are also supported by the Data Interoperability extension of ArcGIS (ESRI, 2013). In this study, ArcGIS Desktop 10.2.2 will be used to develop the proposed model. It supports a variety of programming languages such as .NET, Python, and ArcObjects, for developing APIs and custom plug-ins. There are multiple scripting languages

however, ESRI uses Python as its preferred scripting language because of its power and wide acceptance (ESRI, 2017d). According to EDN (2016), ESRI Developers Network, ArcObjects is a set of platform-independent software components, written in C++, that provides services to support geographic information system (GIS) applications on the desktop in the form of thick and thin clients and on the server. In addition, ArcGIS offers Geoprocessing tools that provide a large suite of tools for performing GIS tasks that range from simple buffers and polygon overlays to complex regression analysis and image classification (ESRI, 2017c).

ArcGIS has been selected for this study, as a GIS tool, for the following reasons:

1. **Availability:** ArcGIS is offered by ESRI around the globe for the community of educational institutes' active members (Students and Educators) for free.
2. **User Interface:** ESRI ArcGIS desktop has a user friendly and a very familiar UI for users in the AEC industry, which is very convenient and does not intimidate practitioners.
3. **Software Accessibility:** ESRI provides free access to students and faculty teaching members and hosts an enormous amount of ArcGIS tutorials and curriculum online.
4. **Interoperability:** ArcGIS supports various file formats conversion including IFC read and write along with ODBC support that allows for flexible extraction of data.
5. **Extensibility:** ArcGIS allows the development of third-party plug-ins and extensions, which will serve this study, along with an API guide that is intuitive and thorough.

3.5.1 Types of Geoprocessing tools

ESRI uses the term Geoprocessing to refer to a package of tools used to perform spatial analysis. These include the spatial operations (e.g., overlay, neighboring, surface, selection and extraction,

etc.) as shown in Table 3.4, which is adopted from ESRI (2016b). It lists the kind of tools available for geoprocessing.

Table 3.4: Categories of Geoprocessing tools (ESRI, 2016b)

| Tool's type | Description |
|--------------------------|--|
| Built-in tool. | These tools are built using ArcObjects and a compiled programming language like .NET. |
| Model tool. | These tools are created using ModelBuilder. |
| Script tool | These tools are created using the Script tool wizard and run a script file on disk, such as a Python file (.py), AML file (.aml), or executable (.exe or .bat). |
| Specialized tool. | These tools are rare—they are built by system developers and have their own unique user interface for using the tool. The ArcGIS Data Interoperability extension contains specialized tools. |

A combination of tool's types (namely, built-in tools, Model tools, and specialized tools) will be used in the methodology to develop the proposed BIM-GIS model.

3.5.2 Database management systems (DBMS) and Geodatabase

The Database management system (DBMS) is an integral part of GIS. Primarily, there are three types of DBMS that are normally used with GIS: 1) the Relational Database Management System (RDBMS), which is considered useful and flexible and therefore widely implemented due to its simple structure; 2) the Object Database Management System (ODBMS), which was developed to overcome limitations in RDBMS such as the inability to store geographic information, poor query performance regarding various types of geographic information, and issues with providing

extensions to support geographic data types and processing functionalities; and 3) the Object-Relational Database Management System (ORDBMS), which is considered a hybrid data structure developed by RDBMS vendors to add the essential capabilities and functionalities of ODBMS when dealing with objects such as functional information (e.g., interpolation algorithms, drawing instructions, and query interfaces) and descriptive attributes (e.g., size and color) for an object (Longley et al., 2011). The elements that distinguish spatial information from other kinds of information are geographic locations, functional semantics, spatial relationships (e.g., topography), and time-based connections. Moreover, GIS allows for systematically retrieving, storing, analyzing, and presenting (spatial and non-spatial) information from multiple data sources (Sebt et al., 2008). An example ORDBMS is the geodatabase (GDB) implemented in ESRI ArcGIS. GDB is the common data storage and management framework for ArcGIS and has been the primary data model for ArcGIS since version 8.0. It functions as a container for spatial and attribute data. The term consists of two parts: 1) geo (denoting spatial), and 2), database (specifically, a relational database management system or RDBMS). Also, it allows for flexible access and management via uniformly depositing all GIS information in a central place (ESRI, 2009a). ESRI (2016c) considered GDB as a collection of geographic datasets of various types held in a common file system folder, a Microsoft Access database, or a multiuser relational DBMS (such as Oracle, Microsoft SQL Server, PostgreSQL, Informix, or IBM DB2). Also, geodatabases come in many sizes that can scale from small, single-user databases built on files, up to larger workgroup, department, and enterprise geodatabases accessed by many users. In addition, attributes regarding each instance in a feature class are stored in a feature table (specific for that feature class or layer) where every single row represents a unique object with a unique ID and all information regarding that particular object is stored in the columns of the same row (Longley et

al., 2011). Vector data are saved, in the form of feature classes within the geodatabase. It is possible to combine multiple feature classes and put them in a feature dataset. On the other hand, in raster data, every single raster image is kept as a layer in a raster dataset. A group of raster layers could be combined in a raster catalog or a raster mosaic (providing they are adjacent to each other) (ESRI, 2009a).

3.5.3 ModelBuilder

ESRI (2017d) described ModelBuilder as an application used to create, edit, and manage models, where those models' workflows string together into sequences of geoprocessing tools, feeding the output of one tool into another tool as input. ModelBuilder could be looked at as a graphical programming language for constructing and automating workflows. The following are some benefits of ModelBuilder;

- User-friendly application for building and running workflows containing a sequence of tools.
- Building customized tools that can be used in Python scripting and other models.
- Facilitating the integration of ArcGIS with other applications in addition to scripting.

Thus, ModelBuilder is basically an application that can help users automate sequences of multiple geoprocessing tasks by developing their own tool (model). Accordingly, tedious repetitive tasks will be done easier and faster. It is user-friendly and an easy-to-learn application.

3.5.4 Time Slider

Time Slider, in ArcGIS, is a tool that allows users to visualize the chronological sequence and progress for the time-enabled layers. The user can set the time interval for each layer and specify

whether to visualize the objects in one layer in a cumulative manner or in time-based order. Also, for each layer, the user can specify if the objects have a single time field (i.e., just a start time) or two time fields (i.e., start and finish time). Also, Time Slider has features such as exporting the visualized data as video.

3.5.5 *Network analyst*

ESRI (2009b) claimed that ArcGIS Network Analyst provides network-based spatial analysis tools for solving complex routing problems and that a network is a system of interconnected elements, such as edges (lines) and connecting junctions (points) that represent possible routes from one location to another. It adds that Network Analyst can provide answers to various routing and transportation questions such as “what is the shortest route between two points?”. Also, a network dataset (transportation network) is capable of modeling a single mode of transportation, like roads, or a multimodal network made up of several transportation modes like roads, railroads, and waterways.

3.6 Applications of BIM-GIS integration in the AEC industry

In recent years, integrating BIM and GIS has gotten the attention of both professionals and researchers. Even though, studies related to the integration of BIM and GIS in the different AEC fields have been few, it has been increasing in the past few years (Ma and Ren, 2017). In the literature, different topics pointed out to the application of BIM-GIS integration where it was shown that this integration can contribute towards solving the related issues including site layout planning. Those include: site layout planning and site selection, safety, asset management, location based services and navigation, urban environment analysis, 3D cadastre (Liu et al., 2017), and heritage (Li et al., 2017).

3.6.1 Site Layout Planning and site selection

In planning the construction of a facility, the location and site on which it is being constructed should not be neglected. This is where BIM-GIS integration becomes important, where BIM can provide a detailed virtual 3D model that could facilitate the decision making and analysis process for the practitioners (Li et al., 2009). On the other hand, GIS provides users with spatial analytical and assessment capabilities (Sebt et al., 2008). Karan and 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 authoring tools do not support the geospatial analysis needed in the process of locating temporary facilities, GIS can be leveraged throughout the preconstruction phase of a project. For instance, GIS can be used to detect the conflict in material layout and to evaluate the accessibility onsite (Su et al., 2012). A study by Bansal (2018) demonstrated the benefits of using GIS in construction planning. The study showed the capabilities of GIS in helping users to identify potential conflicts in the construction plan; to schedule the activities in the construction plan; to simulate the construction process in 4D; to identify drainage areas on a construction site; and to estimate the quantities of cut and fill for excavation and backfilling. Likewise, a study by Kumar and Bansal (2019) explored the use of GIS to identify suitable and safe locations on construction sites to place TFs in a consecutive manner while considering topology and zones, however the study does not recognize the spatial relationships and constraints, such as minimum distance or within a distance, between the different TFs involved in the construction process. 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 construction site.

Isikdag et al. (2008) suggested a BIM-GIS model for the support of site selection and fire response management processes. Bansal (2011b) developed and implemented an integrated model that includes GIS and 4D modeling, which enables space planning, time-space conflict identification, and conflict resolution prior to the construction. He leveraged GIS functionalities to model topology and to conduct geospatial analysis on site. He also used BIM features to link the 3D model with an execution schedule to enable users to identify time-space conflicts. Alsaggaf and Jrade (2017) presented a framework for an SLP model based on BIM-GIS integration and discussed the potential of the model in solving issues related to the site layout planning.

3.6.2 Safety

BIM and GIS integration allows for more comprehensive view of safety in construction (Zhou et al., 2012). A comprehensive view for the construction site and relation to the surrounding environment allows for more efficient environmental risk analysis — GIS is beneficial in this process (Elbeltagi et al., 2004). Bansal (2011a) highlighted two shortcomings of BIM in construction simulation and identifying hazards: 1) lack of topological modeling, and 2) geospatial analysis. Moreover, he proved that by combining the safety database with a navigable 3D model and topology modeling, the user would be able to visualize and identify hazards during the construction sequence and retrieve information required for making the right decisions on the issues at hand. BIM can provide information about the facility from the design stage that can contribute in identifying the potential hazards (Zhang and Hu, 2011). A BIM-GIS model was presented in a study by Isikdag et al. (2008), which showed that it could 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) presented 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 integrating BIM and geospatial models helps to model the surface and sub-surface facilities (e.g., buildings and geology).

3.6.3 *Asset Management*

Normally, asset management involves certain types of processes related to operation, maintenance, and renovation. A comprehensive asset management system is beneficial for the process of making well-informed asset deployment decisions (Lemer, 1998). 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 land acquisition cost, construction cost, and operations and maintenance. Irizarry, et al. (2013) developed a BIM-GIS integrated model to improve the visual monitoring of construction supply chain management, as 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. Liu and Issa (2012) emphasized the importance of 3D visualization for pipeline maintenance and how it overcomes the shortfalls of 2D illustration, which enhance facilities management. Borrmann (2010) developed a spatial query language for 3D building models on BIM, using tools and concepts from GIS. The query language is meant to enable inquiries about walls located in a certain storey, whether a certain room is equipped with heating system tools, determining the columns that intersect with a certain slab, defining the fire extinguishers positioned within a given distance from a certain building component such as a window or a column, etc.

3.6.4 Location based services (LBS) and navigation

Ryschka et al. (2016) described Location Based Services as services that depend on and are enhanced by the positional information of the mobile device. It could be either user-requested or triggered, depending on the type of service or application (Roza and Bilchev, 2003). Navigating to a target facility dynamically and in a timely fashion on a GIS platform has been made possible with modern-day technologies, including architectural and engineering information such as floor plans and utilities (e.g., water and electricity supply) would lead to more effective decisions (Lapierre and Cote, 2008). BIM could provide this information, thus, the conventional two-dimensional (2D) LBS could evolve into three-dimensions (3D) by integrating it with BIM as it provides geometric and semantic information for the building interior (Y. Li, 2012). A smart indoor solution by Shayeganfar et al. (2008) integrates BIM with the environment and user's 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 administrators. Some studies on indoor navigation systems are more focused on tool development for combining BIM and GIS

for indoor space (Hwang et al., 2012; Zverovich et al., 2016). In addition, increasing the accuracy and timely indoor positioning could improve the navigation environment of indoor space, which could be achieved by implementing Radio Frequency Identification (RFID) or indoor wireless network technologies (Truijens et al., 2014), and detailed representation of a facility, as in IndoorGML, which was discussed by Hwang et al. (2012) and Li et al. (2014). Moreover, there are various implementations that could leverage unifying BIM and LBS such as indoor pedestrian traffic (Lee et al., 2008), road monitoring and reporting (Chang et al., 2012), and construction activity tracking (Shahi et al., 2013).

3.6.5 3D Cadastre

Applying the integration of BIM and GIS into the 3D cadastre field became of significance. Cadastre is represented as a two-dimensional boundary coupled with associated descriptive information and related legal and property data (Frédérique et al., 2011). According to Frédérique 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. Implementing BIM can be useful as it provides extensive information about facilities nevertheless, data could be simplified for the purpose of 3D cadastre. BIM lacks some data such as ownership and transaction history that are required for cadastre (Shojaei et al., 2014), which led researchers such as Frédérique et al. (2011) and Aien et al. (2013) to work on BIM and GIS interoperability to reach a unified 3D model. However, besides the technical issues associated with the development of 3D cadastre, there are legal and organizational issues involved (Aien et al., 2013; Aien et al., 2015).

3.6.6 Other BIM-GIS applications

Presently, efforts are toward the process of capturing, documenting, and managing of architectural heritage data that are getting easier in the light of new techniques, (Fai et al., 2011; Saygi and Remondino, 2013; Li et al., 2017). Usually, this procedure involves radiometric, geometric, spatial and multi-temporal information. The design condition of a facility varies from as-built and as-used conditions. One of the benefits of BIM is the ability to reflect such variations in the 3D model (Huber et al., 2011). In general, segmentation, structuring the hierarchical relationships and semantic enrichment are three fundamentals to improve the 3D data management of historic buildings (Saygi and Remondino, 2013). The aforementioned fundamentals are implemented for producing an as-built BIM (Hichri et al., 2013). Dore and Murphy (2012) mapped the information captured by laser scanning or photogrammetric survey into parametric features representing the architectural components, whereas the GIS environment was used to model the environmental data (e.g., street view, transportation, and cadastral data) to be integrated with the three-dimensional model. Data-rich 3D features were implemented in a GIS platform in both studies conducted by SanJosé-Alonso et al. (2009) and Centofanti et al. (2011). Yang et al. (2012) introduced a GIS-based system for safety monitoring aiming towards managing the cultural heritage in a historic street in Taiwan; the 3D data of which was represented by laser scanning technology. El Meouche, et al. (2013) investigated multiple approaches to integrate BIM and GIS but did not propose a model or a solution to a particular construction related problem.

3.7 Differences and incompatibilities between BIM and GIS

Both BIM and GIS are powerful platforms widely used in the AEC industry due to their various individual features and capabilities (Al-saggaf and Jrade, 2015). BIM and GIS may share some similar qualities, as both enable users to make more informed decisions based on the data that is presented digitally to them, nevertheless they also have some differences. For instance, they are developed for completely different purposes, where BIM is meant to serve AEC industry requirements, whereas GIS is meant to provide mapping (geometrical and functional) information regarding geographic features such as land zones, parcels, rivers, topography, etc. GIS provides topological (georeferenced) data, which allows for 3D analysis, spatial analysis, and queries, such as calculating the distance and routes between two different points and defining the optimal location (Irizarry and Karan, 2012). BIM, on the other hand, is incapable of such analysis, however, it provides a detailed database of object-oriented parametric information for the building and represents it in a 3D model, a feature that GIS is lacking (El-Mekawy, 2010). Table 3.5 provides an illustration for the differences and incompatibilities between BIM and GIS based on the findings of studies done by Isikdag et al. (2008); El-Mekawy (2010); and Cheng et al. (2013).

Table 3.5: Differences between BIM & GIS

| Element | BIM | GIS |
|--------------------------------------|--|---|
| Modeling Objective/Purpose | AEC modeling (Building components) | Geographic mapping (surrounding environment). |
| Geometry Representation | BRep, CSG, Swipt Solid (Cheng et al., 2013) (Isikdag et al., 2008). | BRep |
| Coordinate System | Local Coordinate System (Cheng et al., 2013) | Universal Coordinate System |
| Representation/modeling scope | Object-oriented, detailed information on building components. Generally, used for new non-existing buildings. | Generally, simple geographic representation for existing features (i.e., rivers, buildings, etc.) |
| Modeling capabilities | Advance modeling capabilities with complex parametric shapes (including 2D & 3D). | Simple CAD-like drafting capabilities (mostly 2.5D with fixed height) |

Figure 3.3 illustrates one of the big differences between BIM and GIS and that is the scope of representation of both domains. GIS is mainly concerned with representing what we can call the “macro world” starting from representing the world on top and goes all the way down to representing a piece of land. BIM, on the other hand, is mainly concerned with representing what we can call the “micro world” starting from representing the facility on top and goes all the way

down to a single building component. Accordingly, it is apparent how integrating both domains will provide a more comprehensive environment for users and a broader scope of representation for physical and functional information than using each domain individually.

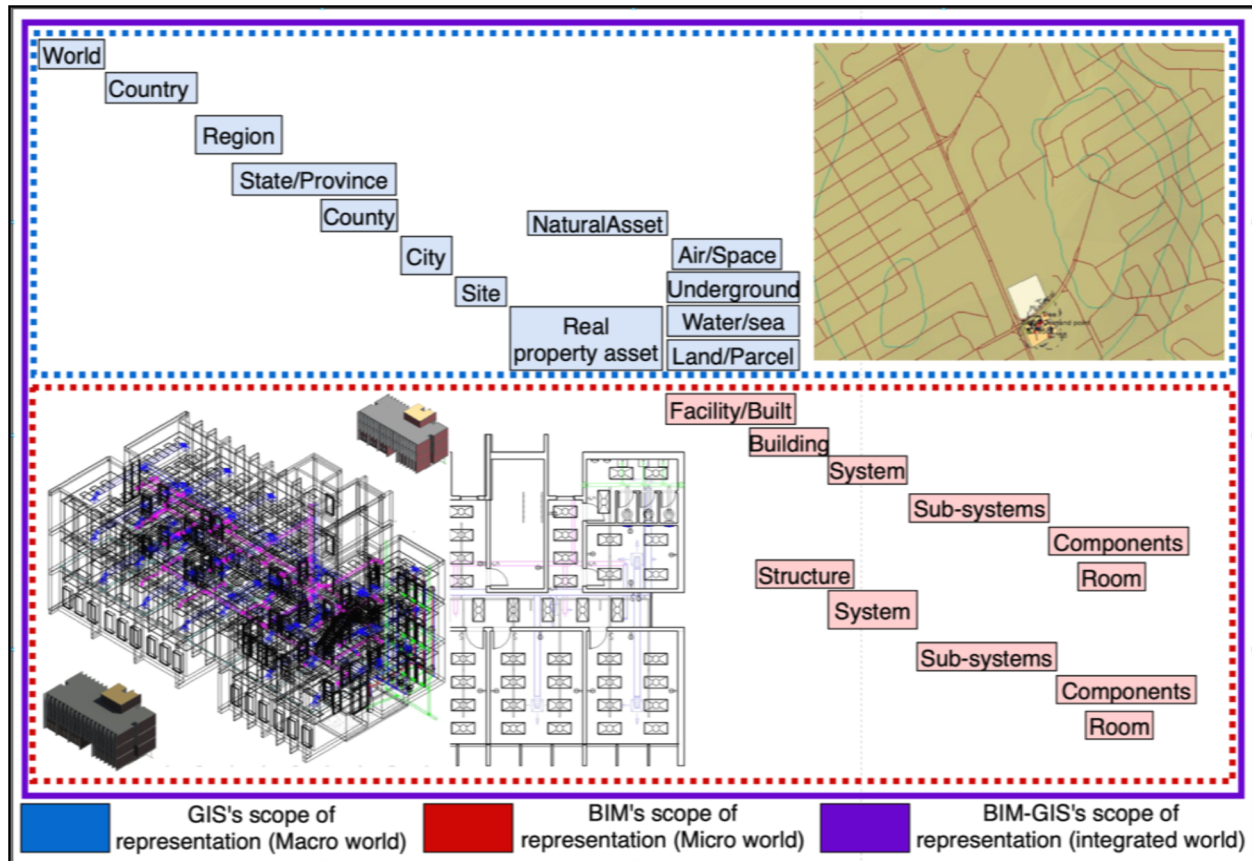


Figure 3.3: Scope of information representation for BIM, GIS and BIM-GIS integration

The demand to integrate both domains has grown in recent years. This could be achieved through more openness and collaborative efforts between BIM and GIS professionals. Based on previous experience, openness and collaboration result from; 1) demand-driven developments (e.g., development of a smart city) (Månsson, 2015); 2) more communication (Liu and Issa 2012); 3) government initiatives (Saygi and Remondino, 2013).

3.8 Approaches of integration and interoperability between BIM and GIS

BIM and GIS are two different domains that are made for different purposes. This has led researchers, (El-Mekawy., 2010; Berlo and laa., 2011; Borrmann., 2010; Karan and Irizarry., 2015; Karan et al., 2015) among others, to work on the integration and interoperability issues between BIM and GIS and on bridging the gaps between both domains to achieve an easier and more efficient communication and data transfer between the two. “Interoperability is the ability to exchange data between applications to facilitate automation and avoidance of data re-entry” (Azhar et al., 2012). There are numerous ways to categorize the previous approaches in the literature used on integrating BIM and GIS, such as the semantic or geometric level, unidirectional or bidirectional approaches, and commercial or open source platforms (Liu et al., 2017). In order to review the previous approaches applied on the integration of BIM and GIS, this study will use a classification that was first introduced by Amirebrahimi et al. (2015a) and then adopted and extended by Liu et al. (2017), which categorizes the previous work into three main groups: data 1) level; 2) process level; and 3) application level of integrations. This study will follow the taxonomy of Liu et al. (2017)

3.8.1 Data Level integration between BIM and GIS

Typically, this level of integration consists of new standards being developed, modification of standards that were previously developed, or translation or conversion of data formats.

3.8.1.1 New Standards and Models

Developing new standards eliminates the barriers between both BIM and GIS environments, which enable for a revolutionary and seamless integration between both domains, but these developments can only solve the integration issues from a certain angle, such as building infrastructure and indoor

space. This is because developing new standards and models is very expensive in terms of both time and money, which makes it very hard for one standard to include all the aspects in a region. Moreover, the loss of information during the development of new standards is inevitable, even more when the new standard and models aim towards a comprehensive representation to everything in a region. However, initiatives that tend to be more focused in nature are less likely to suffer from loss of information and are more flexible and labor-cost-efficient. Examples of new standards and models include: InfraGML (OGC, 2014); IndoorGML (Li et al., 2014); The Unified Building Model (UBM) (El-Mekawy et al., 2012a; El-Mekawy et al., 2012b); and QUASY (Quartierdaten-Managementsystem) (Benner et al., 2005).

3.8.1.2 Extension of Existing Standards, translation, and conversion (ETC)

Linking both the BIM and GIS domains is very crucial to the AEC industry and to other fields as well. Accordingly, many projects have been presented to either convert, translate, or extend one domain to the other; nevertheless, a fully automated conversion process does not exist. This integration has been looked at as a means to realize a comprehensive range of 3D modeling modules at a variety of levels of detail (El-Mekawy., 2010). With this objective in mind, many research projects have been made where the focus was mainly on the conversion of geometry (Nagel et al., 2009; Isikdag and Zlatanova., 2009; Hijazi et al., 2009; Berlo and laa., 2011), which is, in general, implemented between IFC and CityGML to a lesser level of detail (LODs) (Berlo and de Laat, 2011). A point of interest to another group of studies was the semantics and mapping between the IFC and CityGML data structures (Cheng et al., 2013; Borrmann et al., 2014; Cheng et al., 2015). Some discussed the potential of transforming some feature classes between BIM (e.g., IFC) and GIS (e.g., CityGML) along with an explanation for the similarities and differences between both domains (El-Mekawy et al., 2012b). However, loss of information (e.g., semantics

and/or geometry) in the process is almost inevitable, which is one of the drawbacks associated with the translation/conversion between IFC and GIS (Zlatanova et al., 2013); especially when we know that this could be true when converting information from one system to another due to the differences in the geometric, semantic, and topological properties between the different systems (Zlatanova and Beetz, 2012). Also, a change in the original meaning of the attributes of the successfully converted/translated semantics would occur (Kang and Hong, 2015). Moreover, it is challenging to translate geometric data from IFC to GIS (Cheng et al., 2013). In addition, converting data (e.g., geometry and semantics) can be even more troublesome, especially from GIS to BIM (Mignard and Nicolle, 2014). This can be enhanced by providing a stricter standard (as opposed to the generic nature of CityGML) and describing the boundary surface type in CityGML and the “IfcSpace” in IFC more sufficiently (Donkers, 2013; Donkers et al., 2016).

Another methodology of BIM-GIS data translation/conversion is known as the Extract, Transform, and Load (ETL) process. Kang and Hong (2013) said that ETL is a technology that extracts, transforms, and loads information from a variety of data sources and has been used for OLAP (Online Analytical Processing) function implementation via data mining in the engineering arena to present perspective-oriented information. It extracts the information from the originating systems, transforms it into an appropriate format, and loads it into a data depository. Typically, the geometry data of the BIM components is first processed by ETL prior to being modeled in the integrated model to enhance the loading time (Kang and Hong, 2013). A thorough illustration of ETL for integrating BIM and GIS is presented in a study by Rafiee et al. (2014) and it was also discussed with a refined and further specified software architecture by Kang and Hong (2015). In the study, the geometry data is converted first from an IFC data structure to a GIS data structure,

and then a common identifier (e.g., Global ID), which will be used to automate the association process of semantic information between the features in the original data and its corresponding converted ones, is assigned to each corresponding converted features (Rafiee et al., 2014). There are few examples of popular tools for BIM-GIS data transformation that implement spatial ETL to integrate various sources of data. The Oracle Spatial with spatial ETL by Oracle Spatial, by Oracle implements ETL (Lutz, 2009) is one of example. Also, the Feature Manipulation Engine (FME), one of the globally renowned integration and interoperability software packages, implements ETL and provides a bidirectional data translation tool (Safe Software, 2017). In addition, the extension to the ArcMap named “ArcGIS Data Interoperability” by ESRI is a successful and well-known tool for data conversion between BIM and GIS (ESRI, 2013). Therefore, the ESRI “Data Interoperability function” will be used in the proposed BIM-GIS model for site layout planning presented in this study for transforming the IFC data from BIM (Autodesk Revit) to GIS (ESRI ArcMap). ETL can provide a reliable geometry and semantic conversion between BIM and GIS in theory however, user experience and background knowledge about the two domains is a prerequisite (regarding the semantic translation part in particular). Moreover, IFC requires further steps such as the LocalCoordinateSystemSetter function in FME to determine the correct position of the IFC model. In general, some of the reasons are: 1) It supports a local coordinate system and not the real-world coordinate system; 2) It does not store the locational information for the model. Even though ETL is considered flexible, as it provides a complete and customized conversion process, the mapping method of the model is still deemed expensive (time and cost wise), while the effort of mapping associated with it is more efficient than what is required at a deeper standard level. In general, platforms that apply ETL are good for sizable information translation processes that include large quantities of data. Still, inaccuracies are inevitable for the

two main reasons: 1) incompatible nature of both domains (BIM and GIS); and 2) human errors, especially at the early stage of mapping and translation. For instance, it is hard for ETL to completely transform contiguous space boundaries in IFC where some manual tweaking is needed to convert it (Boyes et al., 2015).

3.8.2 The integration at the process level between BIM and GIS

At this level of integration, the source data structure and format in both BIM and GIS are preserved while, at the same time, both domains remain live and distinctly participate in the operations that require functions of both (Amirebrahimi et al., 2015).

3.8.2.1 SemanticWeb Technologies

BIM and GIS are conceptually different when it comes to the way they process and represent data. For instance, BIM features are more descriptive and data rich than GIS features. Reference ontology, in a sense, is a new category of ontologies that is meant to increase the homogeneity of ontologies about a domain, and to facilitate the sharing and reusing of data. It is built by extending or specializing high-level ontologies that take a comprehensive view of several domains (Zemmouchi-Ghomari and Ghomari, 2009). Some studies such as (Kang and Hong, 2015) among others, suggested reference ontology, as part of semantic web technology, as a solution to achieve a smooth and efficient integration that could bridge the gap between the two domains, as it could store and express dissimilarities. The main purpose of the semantic web is to provide the effective distribution of information to the largest spectrum of users possible, and to make it accessible to both people and specific software (Horrocks, 2008). All previous characteristics show that the semantic web is capable of integrating data from heterogeneous data sources. Some studies that

used this method include: Deng et al. (2016b); Beetz (2014); BuildingSMART (2017); Karan et al. (2015); Mignard and Nicolle (2014); and (Vanlande et al., 2008).

3.8.2.2 Services-Based Methods

In this method of the integration at the process level, a Service Oriented Architecture (SOA) is normally implemented, which enables harvesting both BIM and GIS to concurrently contribute towards solving an issue, while retaining the original data format and structure of both environments (Amirebrahimi et al., 2015). Some studies that used this method include: the initiative known as “OWS-4” (OGC, 2007); and (Lapierre and Cote, 2008) where CityGML, WFS, and a 3D viewer were incorporated to manage city information. Generally, the service-based methodology can efficiently convert data (geometric and thematic) with fewer data loss can result. Nevertheless, due to its technical downsides, the flexibility and extensibility of this methodology is generally low (Kang and Hong, 2015). In addition, it has low productivity due to user involvement in the data integration process. Also, it requires specialized solving techniques when issues arise.

3.8.3 Application Level of integration between BIM and GIS

No service or ontology is established at this level and both the source data and object data are preserved, as this kind of integration is mainly meant to support a one-purpose usage. A demonstration of this type of integration is found in a study by Al-saggaf and Jrade (2015) where information regarding potential waste generated on site was estimated separately in BIM and GIS and then used to estimate the number of trucks required for the loading and hauling processes. Another illustration is presented through a study by Deng et al. (2016a), where data concerning noise was calculated from BIM and GIS independently and functions as a medium for integrating

and exchanging the required data among both domains. Irizarry, et al. (2013) provided another case for this approach, where the required data was exported from BIM using a built-in export option (IFC export) and transferred to GIS where spatial analysis operations were performed. Finally, the data was saved into an external database. In addition, schema, such as Green Building XML (gbXML), is used as a mean of integrating BIM and GIS, as presented in the study of Niu et al. (2015), where the needed data was obtained, modified to be simple and exported as a gbXML file. After performing energy simulation, the data was transformed into KML and COLLADA formats to be demonstrated in Google Earth. Overall, that approach is quite sufficient in terms of both time and effort; nevertheless, it is problem-specific, which normally hinders the possibility of implementation by other methods (Amirebrahimi et al., 2015).

3.9 Comparison between the different integration approaches

In this section, a summary of the comparison between the previous approaches of integration and interoperability between BIM and GIS will be presented. The goal is to provide the logic behind the integration approaches that will be used in the methodology for developing the integrated model BIM-GIS for site layout planning.

Liu et al. (2017) created a comparison criterion called “EEEEF” which is an abbreviation for the following four words:

- 1) **Effectiveness:** less information loss.
- 2) **Extensibility:** high level of openness.
- 3) **Effort:** in time, cost, and labor.
- 4) **Flexibility:** the potential of using one solution for this and other studies.

All the previous approaches of integration and interoperability between BIM and GIS can be evaluated based on the EEEF criteria, as follows.

New standards and models: Huge effort is involved in this approach in time, cost and resources. New standards and models cover a broad variety of applications for infrastructure (e.g., InfraGML), indoor space (e.g., IndoorGML), and urban (e.g., QUASY project) with various purpose of application and level of details. However, new standards and models can vary in their score of the EEEF criterion depending on the scope of the problem they intend to solve. They can get a satisfying score when the objective is to be more focused in scope and to provide a solution for a specific issue. Otherwise, they will score poorly when looking to involve all aspects of BIM and GIS. Due to their higher potential in solving integration issues between BIM and GIS, this approach should nevertheless be encouraged.

Translation, conversion, and extension of existing standards (manual or semi-automatic): Due to the process of semantic filtering (ignoring and mapping), which is typically involved in this approach, a certain degree of loss of information is hard to avoid. Manual ETC has higher extensibility as it normally results in introducing novel objects and ontologies that can be extended by future efforts. Semi-automatic ETC (e.g., ETL) has lower extensibility since it focuses on the process description, which varies in accordance to different applications. Semi-automatic ETC entails changing the information format (e.g., IFC to geodatabase) during the integration process.

Process level integration between BIM and GIS: Little loss of information is involved in this approach as it aims towards distribution of information rather than translating current standards or establishing novel ones. It has low flexibility resulting from its problem-focused nature. Also, a service-based integration approach has a low possibility of extensibility as it is an “extensively specialized problem-solving method.” In addition, it does have low flexibility for the same reason. Low productivity is normally associated with most process level approaches as they need a large amount of human involvement at the early development stage of the process.

Application level integration between BIM and GIS: This approach is time and cost efficient where less resources are involved since source information, target information, service, and ontology are not developed or altered. There is a potential of loss of information through this approach, as an information filtering process might be required. Also, the extensibility of this approach is considered low. The effectiveness of the application integration approach varies from one application to another.

As a result, two main integration approaches will be used in the proposed methodology to achieve the BIM-GIS for SLP model: 1) conversion and translation (semi-automatic), and 2) An application-focused approach, which is going to be developed for the purpose of this study. More elaboration on the two approaches will be provided under the methodology section.

The literature review in both chapter 2 and 3 will be summarized in this paragraph. Site layout planning is an important step to every construction project yet to date no commercial solution is offered to assist practitioners with crucial task. The studies found in the literature thus far have great contributions, but they are fragmented in nature, which makes it less likely for future studies to build upon previous ones. There is still a room for enhancement as studies listed in the literature highlights the potential of applying the integration between building information modeling (BIM) and geographic information system (GIS) towards site layout planning. Up to the knowledge of the author, there is no model for site layout planning, that is based on the integration of BIM and GIS, listed in the literature on site layout planning. In addition, based on the comprehensive literature review and the collected data, the author realized that professionals do not lack knowledge or have issues with making decisions as to where to place objects (e.g., facilities or building materials) onsite. However, the impact that these decisions might have in the long run,

whether onsite or in the surrounding environment, is where the real problem usually is. This is to say that, being unable to foresee or predict where and when conflicts might occur can result in negative consequences on the project such as delays and increases in cost; thus, it is necessary for the practitioners to get assistance in this particular area.

Each of BIM and GIS provides capabilities that is lacking in the other and they can complement each other when integrated in a way that offers a wider scope to tackle various issues related to the AEC industry, which would be difficult to be addressed by each concept (BIM or GIS) individually. However, the integration between both domains has many barriers due to the many difference exist between them. This encouraged many from the academia and the industry to find ways to integrate both concepts. One of those ways is the ETL (Extract, Transform, and Load) approach. The ArcGIS Data Interoperability Extension, which is based on the ETL approach, will be used in this study as a mean of integration between BIM and GIS.

3.10 Summary

This chapter reviewed the literature related to Building Information Modeling (BIM) and Geographic Information Systems (GIS). BIM is an object-oriented and data-rich concept that can provide a robust 3D model with rich attributes for the building. GIS can be leveraged to run various analyses required for the SLP process. Moreover, similarities, differences, and the approaches of integration and interoperability between both domains has been discussed. In addition, this chapter provided a literature review on the various applications of BIM-GIS integration in the construction management field and benefits of BIM-GIS integration were discussed. The literature has found that BIM-GIS integration is beneficial for various applications in the AEC industry and there has been big growth in the number of studies related to this topic. Also, a brief comparison between the previous approaches of integration and interoperability between BIM and GIS was presented. The goal of the comparison was to provide the rationale behind the selecting the integration approaches to be used in the proposed methodology for developing the integrated BIM-GIS model for site layout planning. The integration approaches used in the methodology to achieve the BIM-GIS for SLP model are mainly two: 1) conversion and translation (semi-automatic), and 2) an application-focused approach, which is going to be developed for the purpose of this study. The main reason for choosing these approaches are the ease of use and bulky data translation capability of the semi-automatic approach and the high efficiency and solid capability of the application-focused approach to provide a robust solution for the application it is meant to solve. The BIM tool that will be used in this study is Autodesk Revit 2020 and the GIS tool will be ESRI in ArcGIS

10.6.

CHAPTER 4

DEVELOPMENT METHODOLOGY OF THE MODEL

4.1 Introduction

This chapter explains the methodology to be used in the development of the proposed BIM-GIS integrated model for site layout planning at the preconstruction phase that takes into consideration: 1) users' interactions and input (applying their knowledge and experience); 2) space requirements (i.e., operation distance and safety distance) for site objects (temporary and permanent facilities); 3) spatial constraints and relationships between TFs and other TFs, TFs and PFs; 4) risk assessment for detected conflicts; and 5) consideration of the surrounding environment (i.e., surrounding buildings, actual roads and paths onsite, and topographical and soil information). The flexibility of the proposed integrated model will allow it to be applied during the construction stage of projects in cases where changes occur to the design or where when construction interruptions occur. The presented methodology will be implemented through the design and development of an integrated SLP model that is designed in a modular format to simplify the process of planning a safer, more efficient and almost conflict-free site layout. This is achieved by facilitating the creation of 4D models by implementing the concept of a virtual review of the construction sequence as well site layout and route planning to assist users during the process of selecting TFs and laying out the site, checking their plan for potential conflicts in 2D and 3D throughout the whole duration of the project and assessing the risk for potential conflicts. In addition to providing users with feedback on their plan in multiple formats and aiding them while preparing project's documentation. Figure 4.1 illustrates the workflow of the development methodology for the

proposed BIM-GIS SLP model. A step-by-step workflow implemented in this research is as follows:

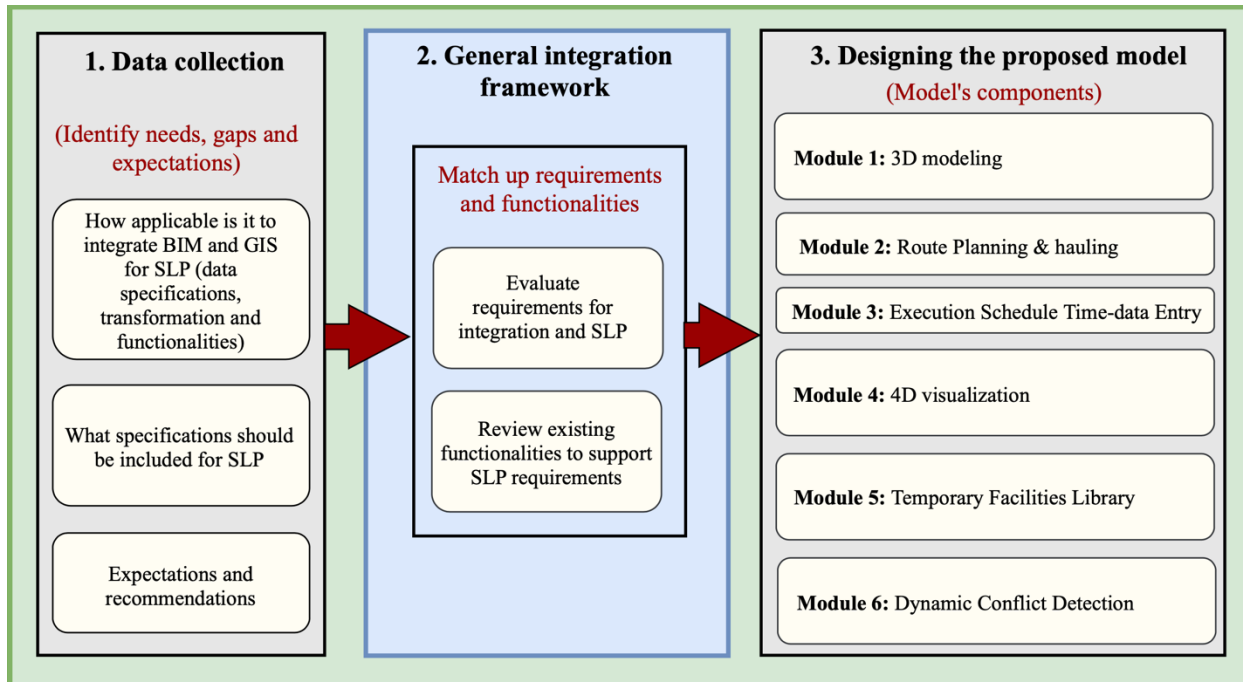


Figure 4.1: Workflow for BIM-GIS integration for SLP model

Step 1: This research first looks into the actual needs, gaps and expectations of the AEC industry, adopting a feasibility study concept, to identify: how the integration of BIM and GIS is sufficient to provide a solution to the SLP problems and how this integration will lay the foundation for a versatile, flexible, and practical solution for the SLP.

Step 2: An integration framework will be established to lay out the foundation for the BIM-GIS SLP model. Then an analysis will be conducted to identify the desirable functionalities in any SLP model that would be enhanced or realized by the BIM-GIS integration.

Step 3: Develop an integrated model for site layout planning that provides a suitable environment for a Decision Support Model (DSM) to aid planners throughout the SLP process. To enhance the flexibility of the developed model, it will be designed in a modular format and will consist of six modules.

Step 4: Test and verify the developed SLP model by using a hypothetical case building project. This case project is used to test the said model and its different modules to verify their capabilities and functionalities.

Some of the objectives of the development methodology include verifying the requirements of the BIM and GIS integration to realize an efficient and helpful SLP decision support model. Also, the sufficiency of the IFC schema and the data transformation approach used in the methodology (The ETL approach through the Data Interoperability extension in ArcGIS) to convert IFC to Geodatabase will be tested. This study will check if the retained information of the 3D building after the data transformation process from one format (i.e., IFC) to another (i.e., Geodatabase) is sufficient to develop the presented SLP model, or there is a need to other measures to overcome such shortcomings. This study aims towards creating a parametric temporary facilities library, which includes physical and functional information about temporary facilities, and evaluating the capability of developing a rule-based checking module that would check for conflicts in both 2D and 3D, as well as providing 4D visualization of the site layout and the construction sequence. This is achieved in an interactive, intuitive, and timely manner while providing a user-friendly and informative environment to support users' decisions. The successful implementation of such a methodology will help practitioners make efficient decisions related to planning a safe site layout that complies with their personal expertise and needs.

4.2 Evaluating the requirements of SLP and the developed model

Most of the data needed for the integrated model is gathered from the literature review, while some of the data related to the process of site layout planning is collected through interviews conducted with professionals, including engineers, site supervisors and contractors from several parts of the

world, namely, Ottawa, Canada; Dubai, UAE; Cairo, Egypt; and Jeddah and Makkah, Saudi Arabia. Data can be updated based on manufacturers' manuals and regulations and guidelines (e.g., from municipalities, OSHA, etc.). There are three main types of constraints between the site objects in site layout planning are identified by Abdel-Fattah (2013) those are: 1) regional constraints, which define the placement area for a site object (TF and PF); 2) interference constraints, which define the spatial relationships between site objects (e.g., overlapping or not overlapping); and 3) dimensional constraints, which include angular dimensions that define geometrical, shape, position, orientation, and distance relationships between site objects (e.g., within or not within a certain distance or height of a site object, maximum and/or minimum distance and/or height from a site object, etc.).

This study identifies some of the essential functionalities and requirements that site planners need, while making efficient decisions. Those include: a) having 4D capabilities (visualization and enable the creation of 4D model in an intuitive manner), because being able to virtually review the sequence of construction operations and the construction site along with its surroundings can assist planners in making more competent decisions, and allocating time to the different components of a 3D model is a demanding procedure (Bansal, 2015; Bansal, 2011b; El-din et al. 2015; Su et al., 2012; Zolfagharian and Irizarry, 2014); b) having the capability of spatial-temporal analysis is essential as users need to know what, when and where resources (e.g., site objects) are onsite and the type of relationships they have throughout the construction period (Abune'meh et al., 2016; (Bansal, 2011b; Karan and Ardeshir, 2008; Marzouk and Abubakr, 2016; Su et al., 2012); c) having a comprehensive parametric library that holds physical and functional information about temporary facilities to aid them in selecting the required TFs and accurately planning the site layout in an intuitive and quick manner (see appendix II); d) identifying any potential conflict in 2D and

3D for the whole duration of the construction project is crucial for an effective SLP model because users may overlook some of those during the planning process especially when dealing with larger and more complex projects (see appendix II); e) encourage professionals to apply their knowledge throughout the planning process until they reach an optimal site layout plan experience (El-din et al. 2015; Sugimoto, 2016; and Tommelein et al., 1992a); f) documenting and generating, reports (e.g., conflict and safety) and getting variety of outputs, such as graphical, textual, and tabular formats for checking and referencing purposes (see appendix II); g) route planning of construction resources based on their actual path (Andayesh and Sadeghpour, 2014a; Cheng and Kumar, 2014; and Sadeghpour and Andayesh 2015).

The model will be designed to have the following characteristics:

- Information intensive: it provides a data rich environment containing information about the topography and soil information of the construction site and its surroundings; the building and its surroundings; the transportation network; and temporary facilities to support users' decision-making processes throughout the process of site layout planning (SLP).
- Versatile: it assists the decision-making process for planners throughout the planning process by supplying a variety of analyses and functionalities that are required for an efficient SLP. This includes route planning based on actual paths, selecting and placing of temporary facilities on suitable locations onsite, 4D visualization for the construction site and its surroundings and virtually reviewing the construction sequence and site layout, dynamic conflict detection in 2D and 3D, risk assessment, documenting the project, and providing users with a variety of outputs including graphical, textual and tabular, in an intuitive and timely fashion and all in one data-rich environment.

- Flexible: The modularity of the presented model allows it to include more modules and functions, whether from past studies in the literature or through future research, to achieve a more versatile SLP model. In addition, it enables users to add and modify data in a user-friendly manner. This include modifying the physical and functional information of the temporary facilities and the safety distance values for the IFC components.
- Efficient: it allows users to apply their knowledge and experience while using the model to facilitate the different tasks related to SLP throughout the process of planning the site layout without being worried about not having technical backgrounds, experience or any type of knowledge that is not common in the AEC industry.
- Automatic: it assists users in adding temporal information to the 3D building model and TFs based on visual selection and locational and functional information; selecting and placing different temporary facilities; 4D reviewing for the construction site and its surroundings, buildings and site objects; dynamically checking the site layout plan for potential conflicts in 2D and 3D for the entire duration of the project along with providing feedback and risk assessment in an automatic, intuitive, and timely fashion.

4.3 Screening existing functionalities of BIM and GIS tools

The previously discussed sets of functionalities of both software applications for BIM and GIS may not be sufficient to satisfy the requirements for the site layout planning. Those requirements that can be achieved through the available functionalities, will be pointed out and performed accordingly. For complex requirements, some customized and or combined functionalities across different tools can help perform the task or resolve the problem. Nevertheless, it is possible that no existing functionality can meet the requirements for certain aspects. In this case, a gap is

identified so it will be evaluated later for potential solutions. Finally, the integrated model should be flexible and expandable to include more functions in the future (e.g., environmental analysis and indoor navigation).

Based on the evaluation of the built-in functionalities of both BIM and GIS tools, two methods are followed:

- 1) The functions related to 3D modelling, 4D modelling, exporting, importing, and data transformation will either be used as they are or will be customized in order to achieve the development needs of the integrated BIM-GIS SLP model;
- 2) Additionally, functions that are necessary for the integrated BIM-GIS SLP model (i.e., opening GIS tool from within the BIM tool, time-entry based on locational and functional attributes, temporary facilities library, and the rule-based dynamic conflict detection) will be created either as an application/extension with a user interface (within BIM or GIS tool), or as plugins that will be linked to the associated tool (BIM or GIS).

4.4 Components and architecture of the proposed model

The most important step in the development of an integrated methodology is to adopt a method that leads to an effective integration between BIM and GIS to facilitate aiding and engaging users throughout the process of site layout planning. This is achieved by designing the model in a modular format by incorporating six modules: 1) a 3D modeling module; 2) a route planning and hauling module; 3) an execution-schedule time entry module; 4) a 4D visualization module; 5) a temporary facilities library (TFL); and 6) a rule-based dynamic conflict detection (DCD) module. The different modules are inter-related to each other in a way that makes the proposed model versatile

to cover some essential requirements for SLP and flexible as it can be expanded to include more modules and new functions in the future.

Figure 4.2 shows the architecture of the proposed integrated BIM-GIS SLP model. The input section illustrates the required data for each module. The analysis section explains the different types of analysis conducted by each module to reach the final outcome. The criteria section provides a description of the criteria used by each module to run the required analysis and achieve the final outcome. To meet the automation objectives of the proposed integrated model, it is vital to take into consideration the programming capabilities of BIM and GIS tools in developing extensions and plug-ins. The three main outputs of the proposed model will be: 1) a map, presenting the final selected site layout plan that considers constraints and relationships between site objects (TFs and PFs) for the complete duration of the project and that allows for an efficient and timely construction process; 2) a 4D model to visualize and simulate the construction progress and locations of site objects, and 3) a report that holds detailed information about detected conflicts between site objects. Figure 4.3 illustrates the data process flow for the integrated BIM-GIS model for site layout planning.

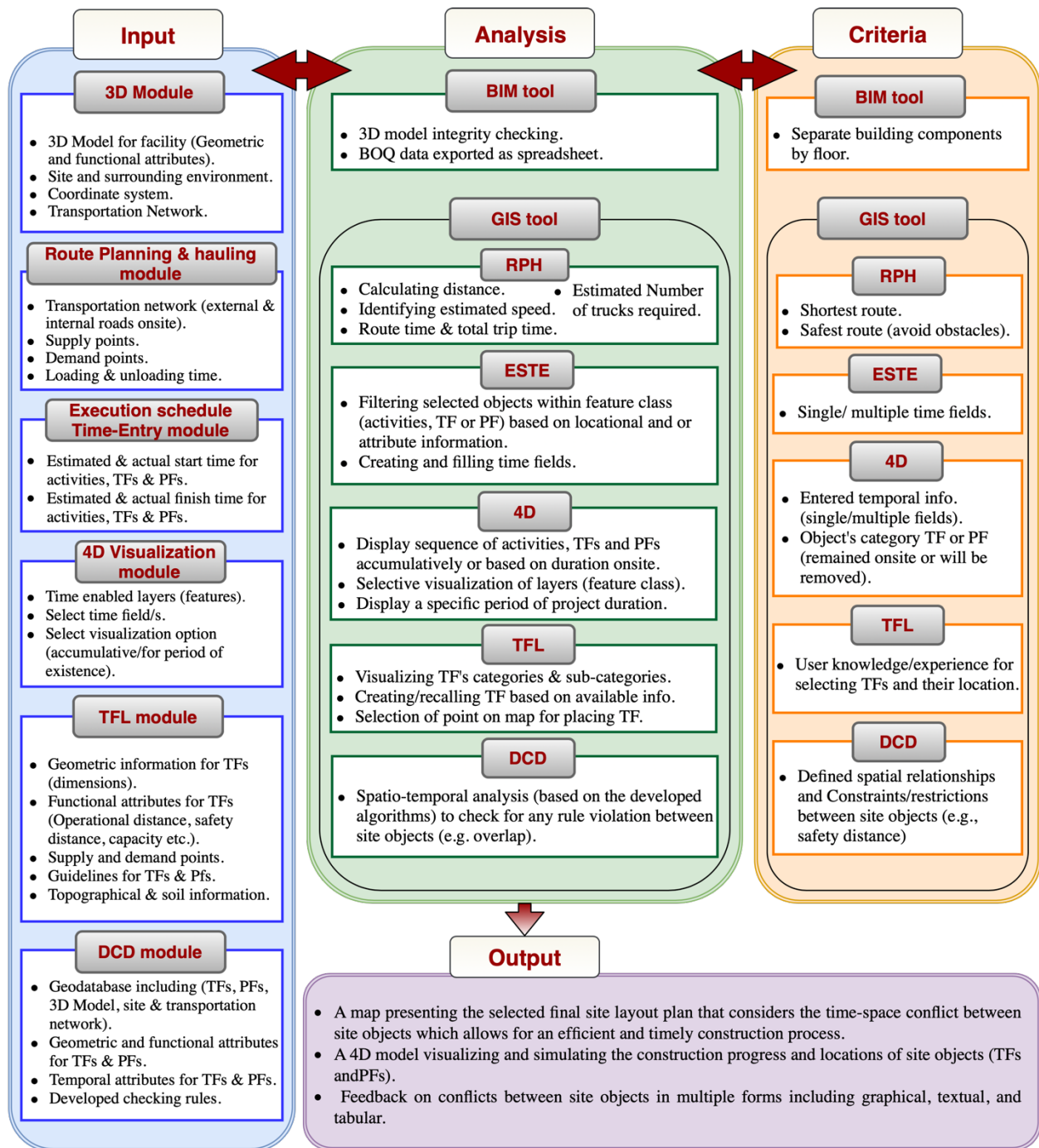


Figure 4.2: Architecture of the proposed BIM-GIS SLP model

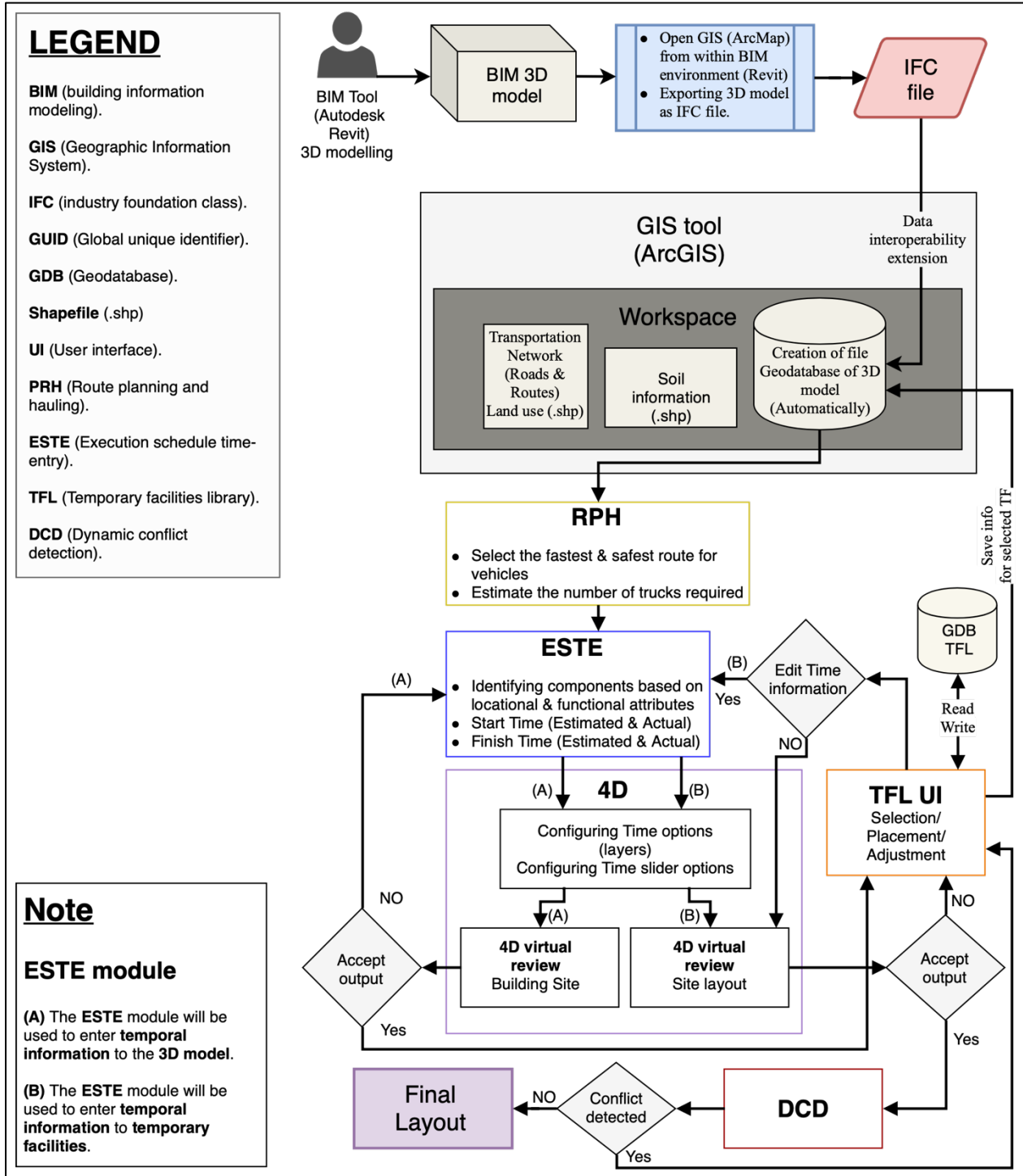


Figure 4.3: Data process flow for the proposed BIM-GIS SLP model

4.5 Modules of the proposed model

The proposed BIM-GIS model is designed in a modular format to augment its flexibility and efficiency. The model will leverage the functionalities of the existing tools in both environments, Autodesk Revit (BIM tool) and ArcGIS desktop (GIS tool) respectively, by using their existing functionalities and by developing a customized Application Programming Interface (API) for new ones.

The proposed model consists of six major modules as follows:

4.5.1 Module 1: 3D modelling

4.5.1.1 Objectives of module 1:

- Designing a detailed 3D BIM model for the facility under construction and surrounding facilities.

A detailed BIM 3D model will be created using BIM tool (Autodesk Revit) and will be exported to GIS tool (ESRI ArcMap desktop). As shown in Figure 4.4, all the information related to the new facility for construction and/or existing facilities is identified along with the construction site. Users will review the BIM 3D model for the proposed project to make sure it contains all the required information for the facility before exporting and importing it as an IFC file format into ArcMap then transforming it into a FileGeodatabase format file.

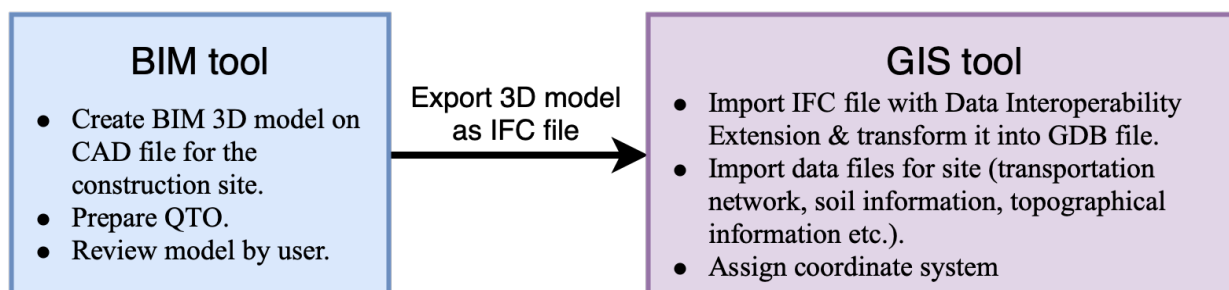


Figure 4.4: Process flow of module 1 (3D modeling)

To ensure that the project’s 3D model is placed at the exact location in ArcMap, it should be created on an aerial photograph or a satellite image for the project area (the construction site and its surroundings) in BIM tool. In case the 3D model was not created on an aerial photograph or a satellite image in BIM tool, then a layer for the project area should be available in ArcMap where it will be exported as a CAD file and imported into Revit to model the 3D model on top of it. After that, the coordinates of that CAD file will be published to the 3D model using the existing “coordinates” function (menu) in Revit as shown in Figure 4.5.

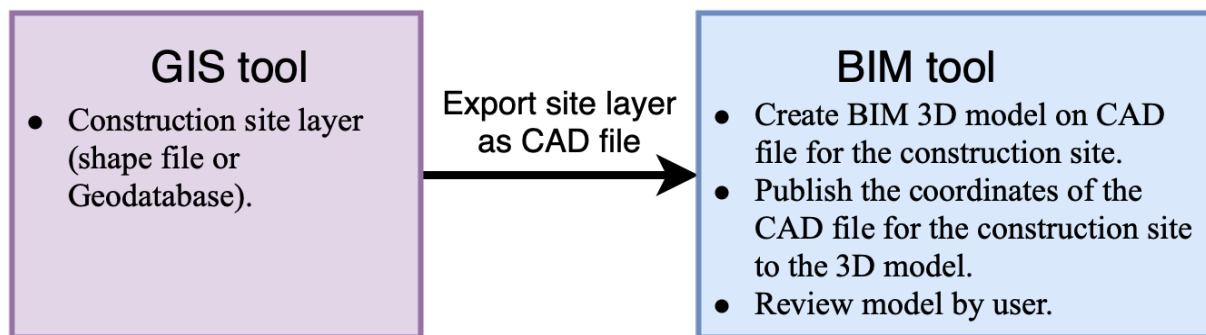


Figure 4.5: Process flow for exporting the layer for project area from GIS tool to BIM tool

Afterward, the 3D model is exported as an IFC 2x3 file then imported into the ArcMap. It is very important to make sure the 3D model’s components are divided by level (floor) before exporting the 3D model as an IFC file from the IFC export menu in Revit. A plugin will be developed and linked to Revit to seamlessly help users open the ArcGIS from within Revit. The same methodology is used by ESRI to open ArcScene (3D ArcGIS platform) from within ArcMap (2D ArcGIS platform). After that, the IFC file is imported into ArcMap and transformed into FileGeodatabase file format using the data interoperability extension. Then, users can set up a real-world coordination system for the project that is consistent with its real location on the globe by using the coordination tool in ArcMap. The process flow of module 1 is shown in Figure 4.4.

The IFC schema allows limited attributes of the 3D BIM model to be transferred along with the exported IFC 3D model. Therefore, if required, all the information and attributes needed can be

exported to an external database (e.g., MS Access) or spreadsheet (e.g., MS Excel), and be opened within ArcMap where the selected attributes can be linked with the corresponding feature classes (layers) based on unique common column (e.g., GUID or TAG No.) by using the built-in tools in GIS such as “join attributes” as shown in Figure 4.6. Attributes required in the 3D model include length, width, height (thickness), area, volume, level (floor) number, name, GUID, TAG, etc.

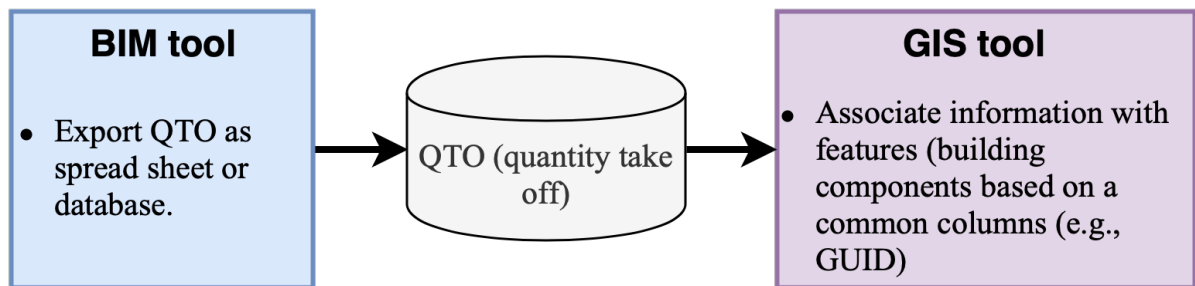


Figure 4.6: Process flow of exporting QTO from BIM tool to GIS tool.

4.5.2 Module 2: Route planning and hauling (RPH)

4.5.2.1 Objectives of module 2:

- Identifying the safest and shortest route between two points.
- Estimating the number of trucks required for hauling and moving operations.

4.5.2.2 Prerequisites of module 2

- The transportation network including roads and routes for the construction site and its surroundings should be available.
- Information such as volume, building material (e.g., concrete, steel, wood, glass, etc.), material condition (i.e., recyclable, reusable, and total loss), building component (wall, window, door, floor, etc.), and weight need to be available in features in the ArcMap.
- Land use including health, governmental, educational, industrial, residential, services, etc.

4.5.2.3 Route planning:

In this module, the network analysis capabilities of GIS will be used to determine the most efficient (safest and shortest) route between two different points. Users will identify the supply point (e.g., for tasks, materials, or waste generated onsite) and the demand point (e.g., storage, a landfill, or recycling facility) and using the Network Analyst tool in ArcMap they can identify the shortest route available as shown in Figure 4.7. In case of a restriction occurring (e.g., a road accident, road maintenance, or vulnerable facilities such as schools, hospitals, or highly populated areas in case hazardous materials are being transported) one or multiple restriction points can be applied on the road to simulate what occurs in reality and the model will be used to identify an alternative best and safest route. After identifying the most efficient routes, the selected routes can be merged into a layer called "Roads" to be used by the DCD module in the process of conflict detection.

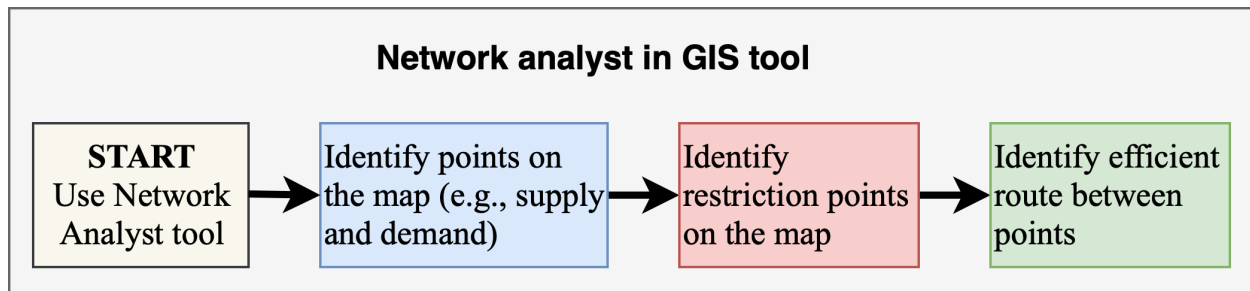


Figure 4.7: Process flow of route planning in module 2 (RPH)

As shown in Figure 4.8, the proposed model can assist in locating, estimating, and categorizing the building components and or demolition and renovation (D&R) waste based on three categories: building materials (e.g., concrete, steel, etc.), building components (e.g., door, window, slab, floor, etc.), and material/component condition (i.e., recyclable, reusable, and total loss); which will help in identifying suitable locations for supply and demand points. Also, all the different sorting categories could be further filtered based on locational and functional attributes (e.g., certain building components exist on certain floors on a specific area or building/s).

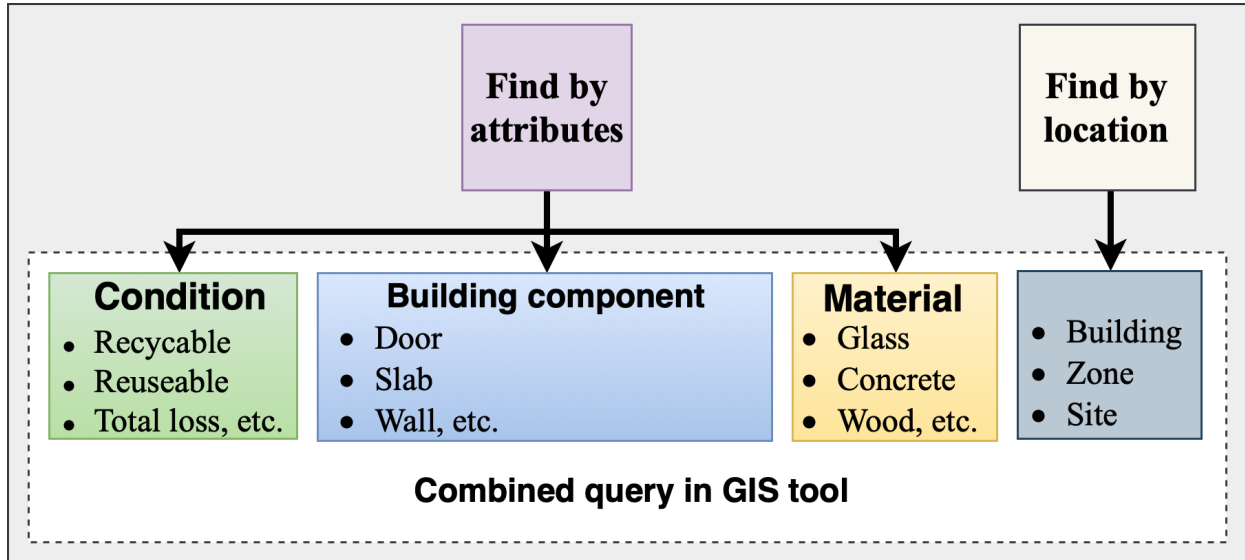


Figure 4.8: Process flow of using spatial analysis in module 2 (RPH)

This is achieved by leveraging GIS spatial analysis capabilities (find by location and find by attributes). If the information mentioned in the second point of the module’s prerequisites does not exist, it needs to be associated with corresponding features in GIS. After associating the information imported (e.g., from a spreadsheet) with their corresponding features, the statistical analysis capabilities in the model can be used to estimate the potential amounts of materials and or waste generated onsite. The proposed model can be used to produce tables and reports for the aforementioned three categories by using the data management capability available in GIS tool.

4.5.2.4 Estimating the number of trucks:

After identifying the most efficient route between the two points, the number of trucks required for hauling and moving operations can be calculated by using Equation 4.1 and identifying the maximum number of trips that can be performed by one truck during one business day. Then, users will be able to estimate the number of trucks required for hauling and moving operations and the period (e.g., days) they are required for. For example, if 90 trips are required to move material X and the maximum number of trips per day performed by 1 truck is 10, then 9 days are required to

completely move material X. To decrease the number of days required to completely move a certain material, users can increase the number of trucks according to their preferences. This is the traditional methodology (i.e., number of loads/ trips) used in the literature to estimate the required number of trucks (e.g., Cheng and Ma 2013).

$$\text{Estimated number of trips} = \text{Total volume} \div \text{Truck loading capacity} \quad [4.1]$$

4.5.3 Module 3: Execution schedule time entry (ESTE)

4.5.3.1 Objectives of module 3:

- Facilitate 4D modelling for users by assisting them in adding and editing Actual Start Time (AST), Actual Finish Time (AFT), Estimated Start Time (EST) and Estimated Finish Time (EFT) in an easy and fast manner.

4.5.3.2 Functions of module 3:

- Allocating time information for a single object or multiple features based on locational and attribute queries.

4.5.3.3 Prerequisites of module 3:

- A detailed execution schedule for the project's construction should already be available at this point.
- All layers should be located within the same Geodatabase.

This module will facilitate allocating the start time and/or finish time based on locational and attribute queries for a single object or multiple features or activities (e.g., ifcColumn) in a feature class (layer) in the 3D model. For example, selecting all the columns on the first and second floors with a specific width and length or based on a specified component's number or a global unique

identifier (GUID) or choosing objects within a specific range (e.g., TAG number 1234 to 1345). The Process flow of the Execution schedule temporal data entry (ESTE) tool is illustrated in Figure 4.9. Modelbuilder, which is a visual programming language that is part of the ArcGIS desktop package, will be used to develop the toolbar extension and UI for the ESTE module.

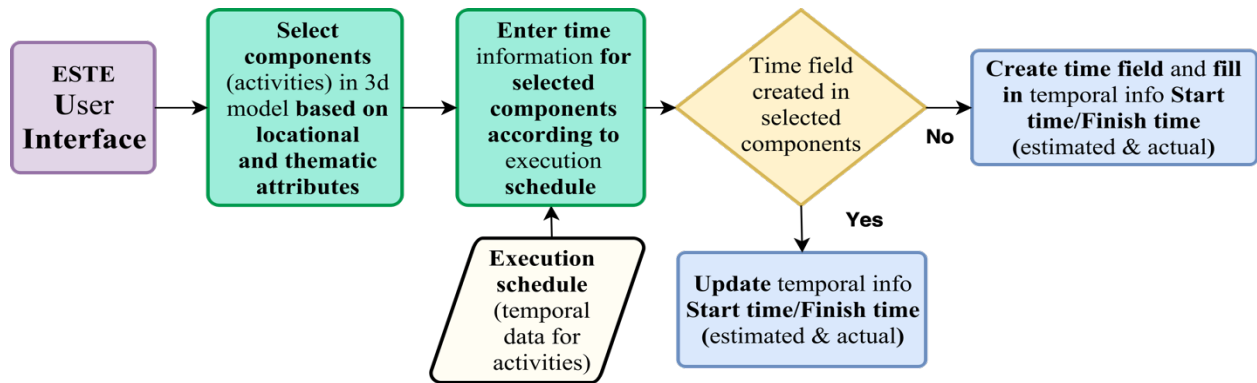


Figure 4.9: Process flow of Execution schedule temporal data entry (ESTE) tool

This module will also be used to enter the durations for the temporary facilities (TFs). As shown in Figure 4.10, the 4D simulation and the detailed execution schedule for the construction will help users to identify required TFs to support the construction and based on that users can calculate the estimated time required for each TF then enter that time using this module.

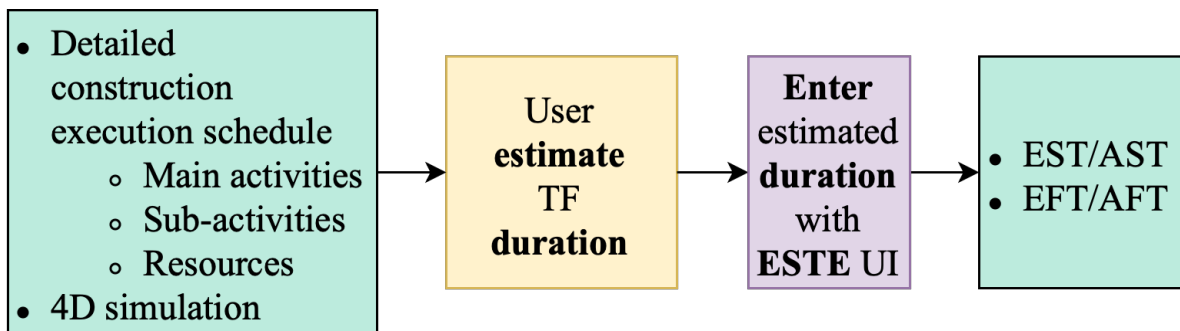


Figure 4.10: Process flow of entering temporal info for TFs using the ESTE tool

4.5.4 Module 4: 4D visualization

4.5.4.1 Functions of module 4:

- Simulate the construction process by showing the chronologically sequence of the 3D model.
- Allow features (building components or temporary facilities) to be shown incrementally or momentarily for the time they exist onsite.

4.5.4.2 Prerequisites of module 4:

- All the feature classes should have at least one field of time (i.e., Estimated Start Time).
- Other time fields can be optional (i.e., Actual Finish Time, Estimated Finish Time, and Actual Start Time).

The 4D simulation can be set up using the time representation function in ArcMap (Timeslider). As shown in Figure 4.11, the Timeslider enables setting different and separate display output for the different layers to show the contained site objects either incrementally over time or just for the time they exist onsite. In this module, 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 in the floor layer. This allows to identify and manipulate only the features of concern along with their associated data.

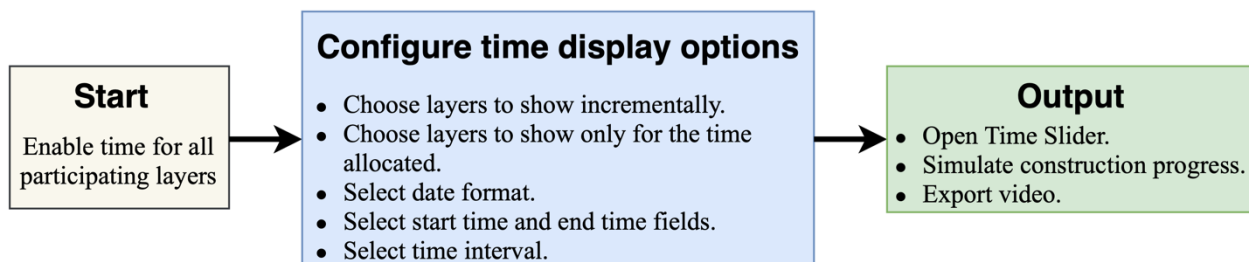


Figure 4.11: Process flow of module 4 (4D module)

As shown in Figure 4.12 , this module allows to conduct spatial-temporal analysis such as “How many objects (e.g., floors, windows, slabs, walls, etc.) will be done after the first 3 months?”; “How many site objects will be covered by the jib radius of the tower crane 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?”

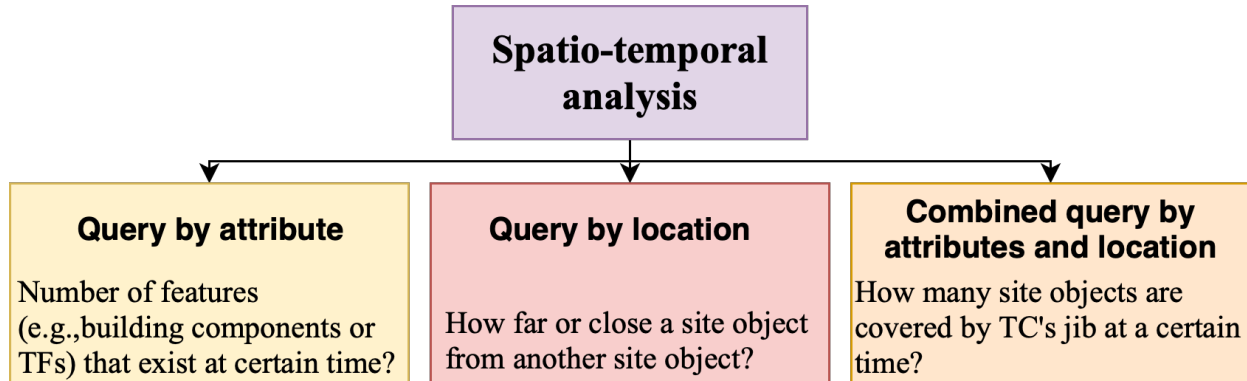


Figure 4.12: Spatial-temporal analysis that can be conducted in module 4 (4D module)

The presented 4D module is a result of the methodology of integrating the BIM tool (i.e., Revit) with the GIS tool (i.e., ArcMap) in a way that allows users to visualize the construction progress of the project in a dynamic manner as shown in Figure 4.13. The IFC 3D model exported from Revit provides a detailed 3D model that helps in visualizing the facility components dynamically (floor by floor); while ArcMap enables the visualization of the construction process through time.

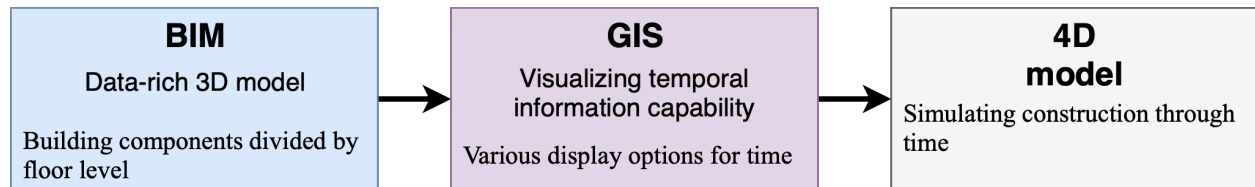


Figure 4.13: Data flow of module 4 (4D module)

4.5.5 Module 5: Temporary facility library (TFL)

This section explains the methodology to develop the TFL module.

4.5.5.1 Objectives of module 5:

- Aid users in planning the site layout by enabling them to select and place the different temporary facilities (TFs) that are required for the construction process.
- Attributes found in the TF's database must be sufficient, usable, and recognizable by the DCD tool, which means that the output of the TFL in this study is considered as an input in the proposed DCD module and will work seamlessly with it.

The TFL module will mainly consist of a geodatabase (GDB) and a user-friendly user interface (UI). This is achieved by preparing a GDB containing the actual physical (geometrical) representation and associated attributes for all the types of the temporary facilities (TFs), which will be connected to an intuitive user interface (UI) with texts, illustrative pictures and floating messages that facilitates the process of selecting and placing TFs on the map. ArcGIS provides the capability of developing custom tools using programming languages such as VB and Arc objects library (based on the C# programming language), which is used to develop the user interface and logic of the TFL module.

The TFL that will be developed in this study will have the following characteristics: 1) it is built within a GIS environment as a File Geodatabase that is complemented with a user-friendly UI; 2) the customized representation for TFs based on their shape and functions. This allows for an easy selection and placement of TFs on the map and automatically sets up the real-world coordinate system of the imported TF to match the coordinate system in the current file users are working on. Also, the TFL in this study will contain 2D and 3D information about the different TFs. This module will be developed with the aim to be fully compatible with and work seamlessly with the DCD model, which will enable detecting potential time-space conflicts in 2D as well as 3D.

4.5.5.2 TFL data collection, preparation and representation

Figure 4.14 shows the development methodology of the TFL.

Data collection: the dimensional or physical information (shape) along with all the functional information (e.g., safety distance) of the TF will be based on data collected from manufacturers and vendors for those TFs, literature and published data, guidelines, and regulations (e.g., from municipality, OSHA, etc.), and can be updated and or adjusted, if needed.

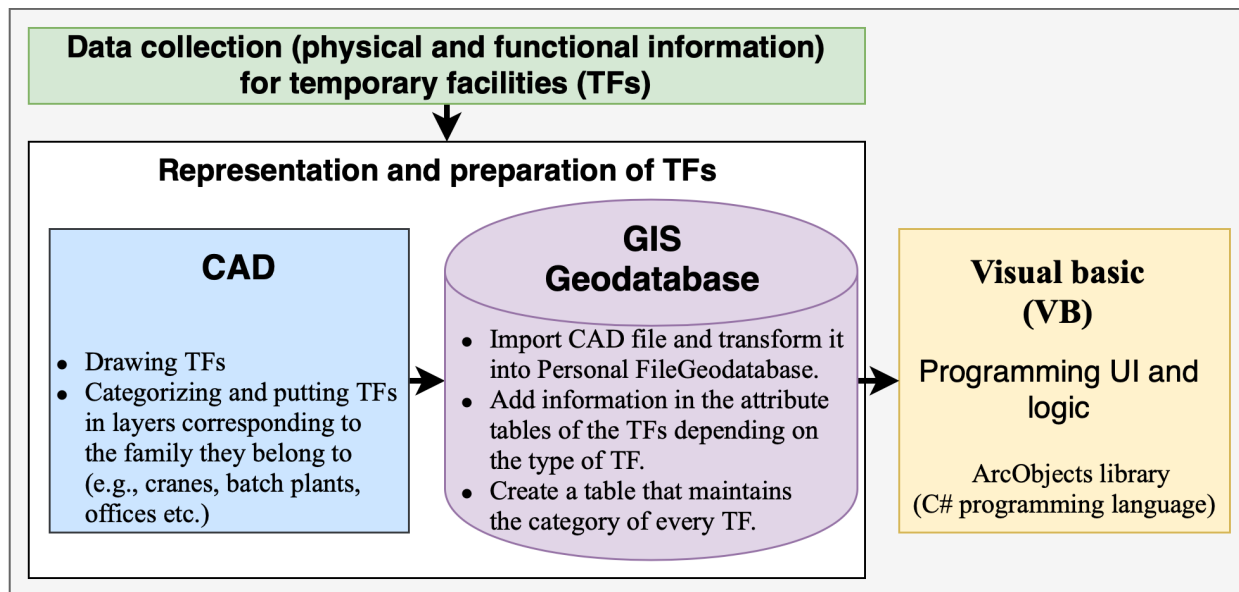


Figure 4.14: Development methodology for module 5 (TFL module)

Preparation: to achieve accurate shape representation, all TFs will be first drawn in AutoCAD. For CAD geometric information to be successfully imported into GIS it must be in compliance with the kinds of geometric information that are recognized by GIS (i.e., polygons, lines, points, and annotations). After that, they will be imported into the GIS tool and stored in a geodatabase where thematic information will be included in their associated attribute table.

The attributes maintained in the TFL geodatabase will include, depending on the shape of the TF, the length, width, height (thickness), area, spatial requirements (e.g., safety distance and or operation distance). In addition, some essential information about the TFs contained in the TFL are the main category of the TF, such as family, type, sub-type, the feature ID (FID) and TF ID,

and the RGB values for the thematic colour of the type the TF in question belongs to. Also, a table preserving the logical hierarchy of the different TFs will be included in the geodatabase as a reference that will be used by the UI to organize and display the TFs included in the geodatabase.

Representation: TFs vary in shapes and functions thus, in this study, the methodology used to present the different types of TFs varies in accordance to the type and function of the TF as shown in Figure 4.15. Figure 4.16 provides an illustration for the methodology used for representing TFs.

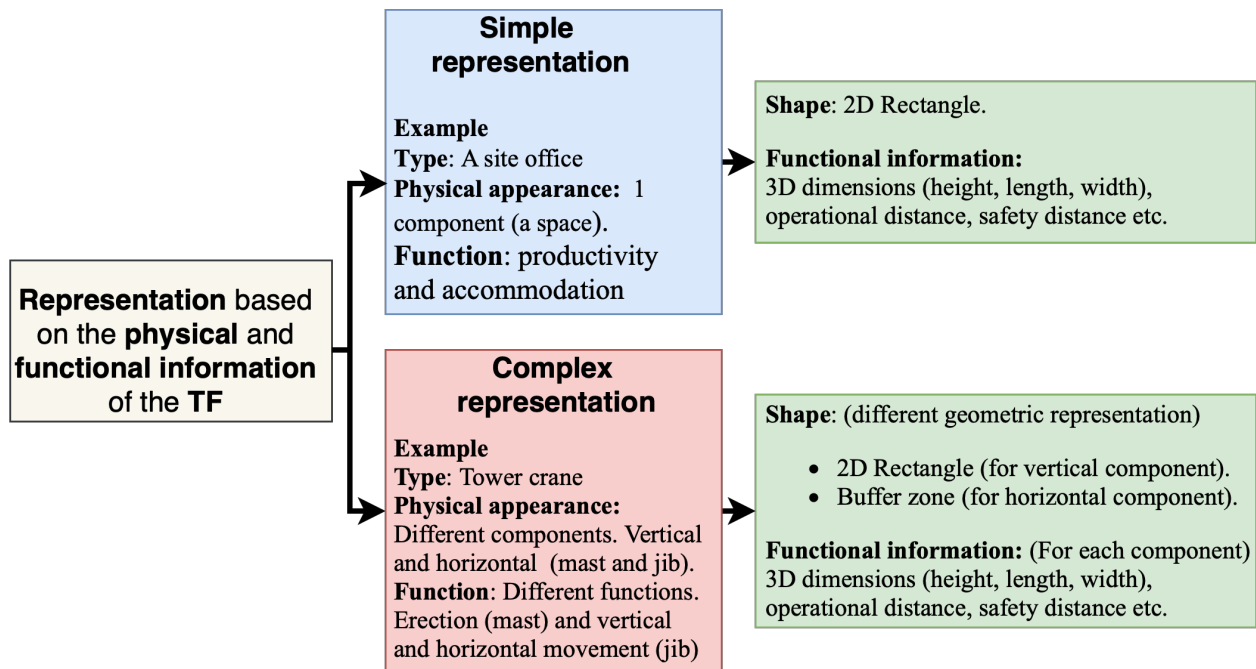


Figure 4.15: Methodology of representing TFs in the TFL module.

This means that an office that provides a space for work and productivity that is normally rectangular in shape will be modelled as a simple 2D polygon shape (rectangle) with the height value included in its attribute table, whereas, a tower crane (T.C.), for instance, typically consists of several parts including the main two parts, which are the tower mast and the jib. Both of those have different dimensions, directions and functions; for instance, the tower is vertical and fixed, whereas the jib is normally horizontal and moving in a circular motion with a radius that is equal to its length.

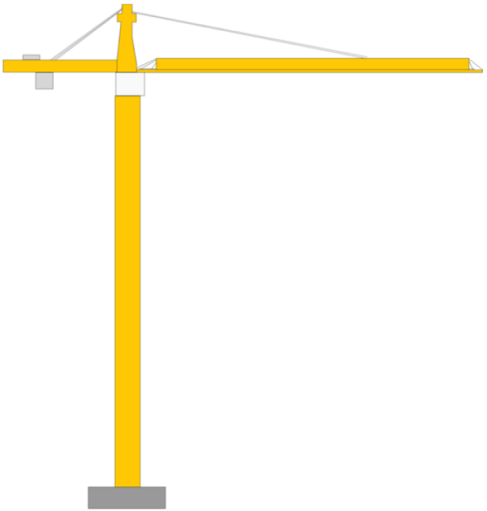
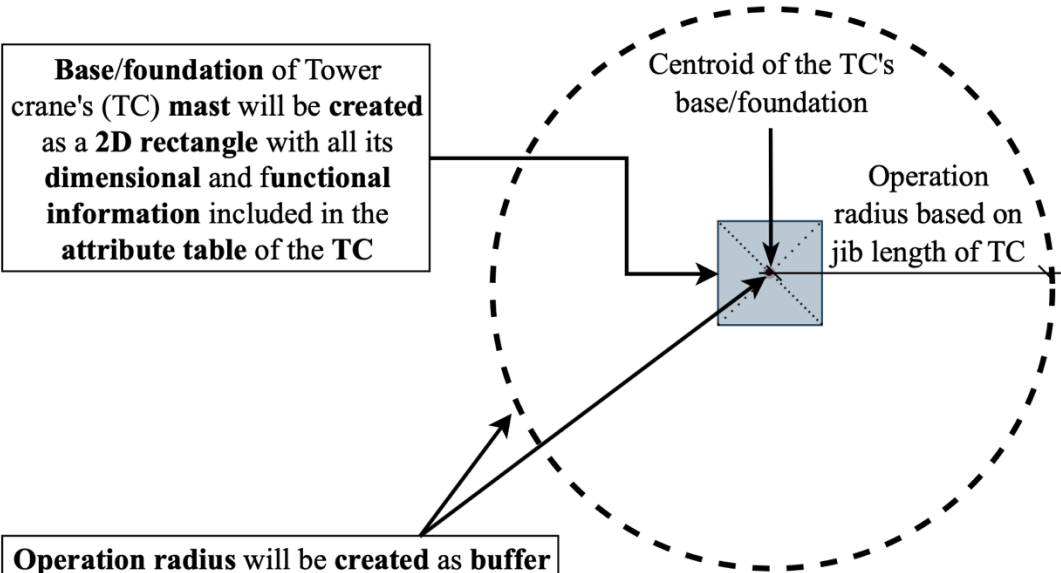
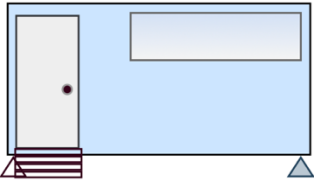

| | Elevation view for the TF | Plan view for the TF |
|-------------------------------|---|---|
| Complex representation |  <p>Temporary facility (Tower crane)</p> | <p>Base/foundation of Tower crane's (TC) mast will be created as a 2D rectangle with all its dimensional and functional information included in the attribute table of the TC</p>  <p>Centroid of the TC's base/foundation</p> <p>Operation radius based on jib length of TC</p> <p>Operation radius will be created as buffer zone from the centroid of the TC's base with all its functional information included in the attribute table of the TC</p> |
| Simple representation |  <p>Temporary facility (Site office)</p> |  <p>Office will be created as a 2D rectangle with all its dimensional and functional information included in the attribute table of the Office</p> |

Figure 4.16: Illustration for the methodology of representing TFs in the TFL module

Also, both have different spatial requirements (operation distance and safety distance), therefore, they must to be presented separately in order to satisfy their individual requirements. Accordingly, both components (jib and tower mast) must be represented separately in order to satisfy their individual requirements. This means that some TF types, such as tower cranes, will require special data processing and spatio-temporal data analysis. The TFs created by the TFL module will have different colour themes depending on the TF family that a certain TF belongs to.

The process flow for using the Temporary Facilities Library (TFL) is shown in Figure 4.17, users will select the reference GDB and the output GDB.

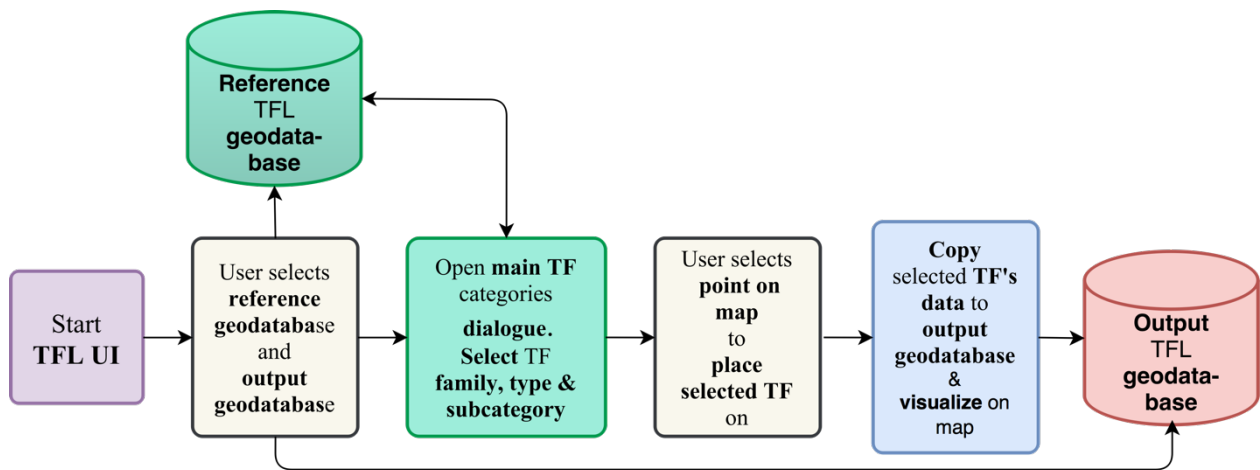


Figure 4.17: Process flow of TFL module

Figure 4.18 shows the methodology for categorizing the TFs and their hierarchy in the TFL module. All TFs in the presented module will be categorized under 3 main categories as per the categorization mentioned in chapter 2: 1) Operation and Processing facilities (OPTF); 2) Storage facilities (STF); and 3) Residence facilities (RTF). Under each main category there will be different families (e.g., Cranes); under each family there will be different types (e.g., Tower Cranes or TCs); under each type, depending on the type, there will be different sub-types (e.g., different sizes of TCs). The TFL will adopt the tree-hierarchy approach in presenting the different TFs it contains. The TFL will use thumbnails, texts, and tip texts, when hovering on the required TF, to

facilitate the TF selection process for users and to make it more intuitive and user friendly. All TFs with their relevant attributes will be stored in the form feature classes in a Geodatabase.

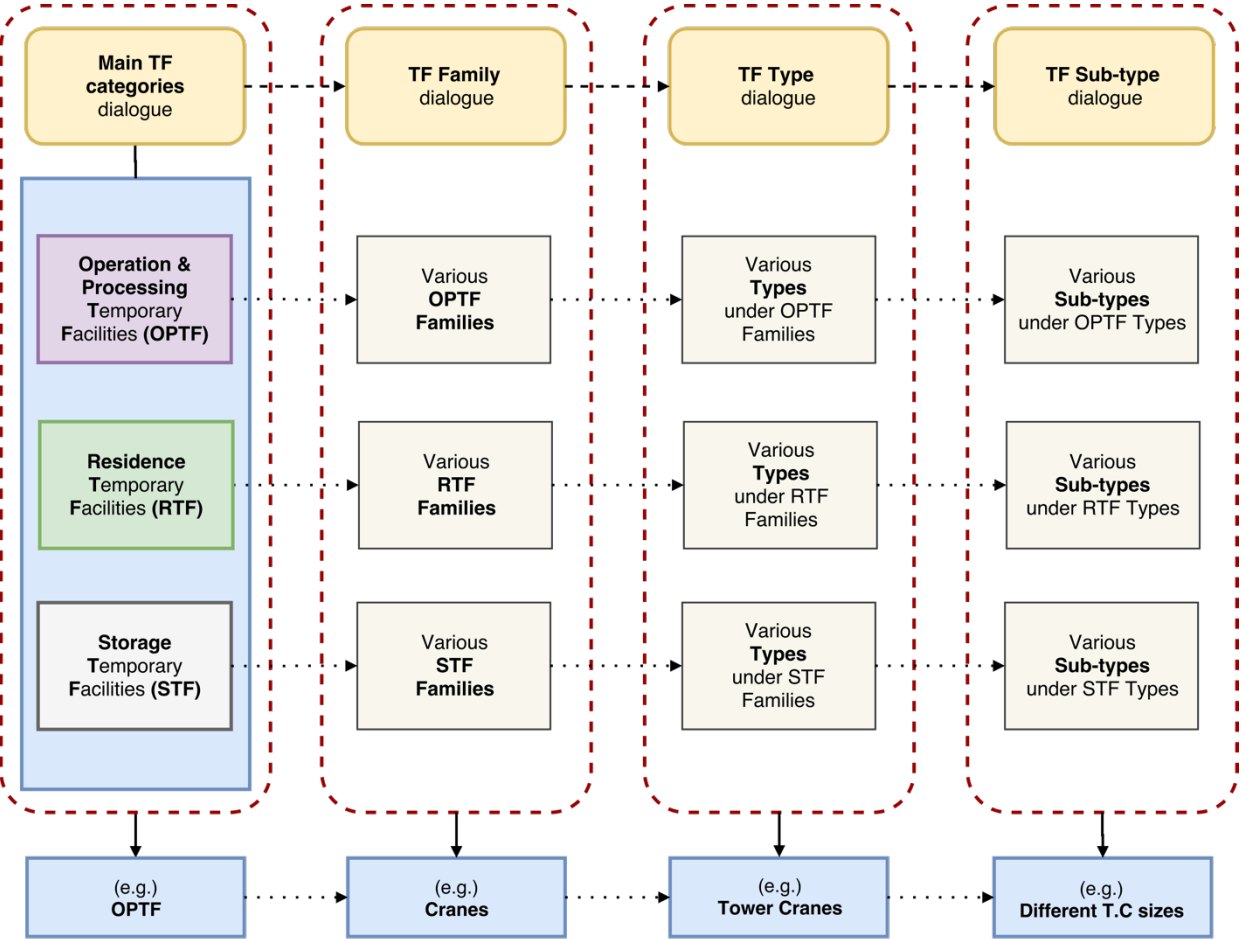


Figure 4.18: Methodology of categorizing TFs and their hierarchy in the TFL module

Color codes, based on the family (e.g., cranes) the TF belongs to, and labels (displaying the TF’s name) will be allocated to the TF that is created and placed on the site plan. This will make it easier to distinguish between all the different TFs on the site plan.

4.5.5.3 Temporary facilities that will be developed in this module:

As illustrated in Figure 4.14, the TFL will be created as a personal FileGeodatabase which has a capacity of 2GB. This should be large enough to store hundreds of different TF families with hundreds of types (subcategories), which should be sufficient to cover the requirements of any

type of construction project. This study focuses on the TFs required for the construction of building projects. Table 4.1 illustrates the selected TFs in this study to be created in the TFL module for testing and verification purposes. The number of different types of temporary facilities (TFs) included in the TFL module presented in this study is 12; however, as shown in Table 4.1, the total number of the different TFs including their subtype is 21. In this study, the TFs will have different colour themes depending on the TF family that a certain TF belongs to. These colours are as illustrated in Table 4.1.

Table 4.1: The selected TFs to be created for the model development and verification

| TF No. | TF type | Category | Family | Color code | Sub-types No. |
|---|--------------------|-----------------|----------------|-------------------|----------------------|
| 1 | Batch Plant | OPTF | Batch Plants | Grey | 3 |
| 2 | Tower Crane | OPTF | Cranes | Yellow | 3 |
| 3 | Geotechnical lab | OPTF | Labs | Purple | 1 |
| 4 | Carpentry | OPTF | Workshops | Beige | 1 |
| 5 | Rebar workshop | OPTF | Workshops | Beige | 1 |
| 6 | Landscape workshop | OPTF | Workshops | Beige | 1 |
| 7 | Bricks depot | STF | Storage | Brown | 1 |
| 8 | Gravel depot | STF | Storage | Brown | 1 |
| 9 | Storage | STF | Storage | Brown | 3 |
| 10 | Laydown Area | STF | Storage | Brown | 1 |
| 11 | Office | RTF | Offices | Blue | 3 |
| 12 | Site washroom | RTF | Sanitary units | Light blue | 1 |
| Total number of temporary facilities included in the TFL | | | | | 21 |

4.5.5.4 Identifying suitable area (SAI)

To facilitate placing the temporary facilities (TFs) that users select from the temporary facilities library (TFL) on the map, the proposed BIM-GIS model will help to identify the available and suitable area on the construction site by using a tool called suitable area identifier (SAI) that will be developed in this study. The SAI will generate the available and suitable area on site and add it as a separate layer on the map. The workflow of the suitable area identifier is shown in Figure 4.19. The SAI will be developed using the ModelBuilder that is part of the ArcGIS desktop package.

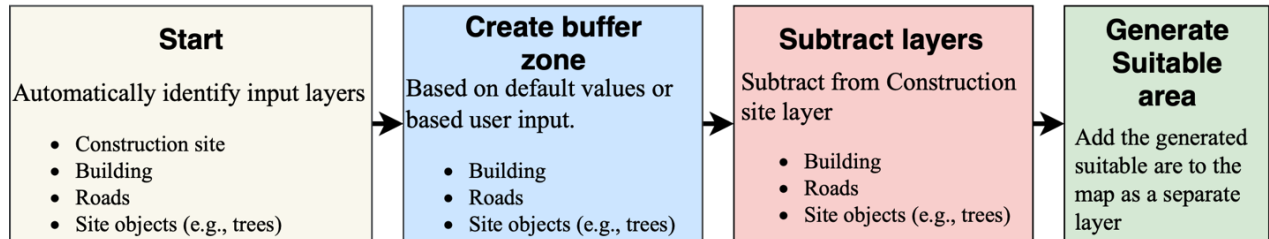


Figure 4.19: Workflow for the suitable area identifier.

As illustrated in Equation 4.2, the proposed model will basically subtract the areas of the building, roads, and site objects from total area of the construction site. Also, the model will consider the spatial requirements (i.e., safety distance and operational distance) for the previously mentioned areas that will be subtracted from the total area of the construction site.

$$SA = ACS - (AB + AR + ASO) \quad [4.2]$$

Where SA is the suitable are; ACS is the total area of the construction site; AB is total area of building; AR is the total area for roads including the spatial requirements required by roads; and ASO is the total area of site objects (e.g., trees) including the spatial requirements required by site objects.

The proposed model will allow modifying the values of the safety distance and operation distance for the roads, building, and other site objects. It will provide the available area that is suitable for

placing the TFs and will display it on the map. In this study, the proposed model will generate the available and suitable area, as opposed to an available and suitable location, as found in most of the previous studies on SLP. After that, the selected TF can be placed on any specific point on the map by using the TFL module.

4.5.5.5 Identify suitable area for tower cranes (SAITC)

This section will explain the development methodology of a tool “suitable area identifier for tower cranes (SAITC)” that will help to identify the suitable area for placing tower cranes (TCs) on the map. GIS can help in identifying a feasible area for locating TCs on the construction site (Sebt et al., 2008). The development methodology of the proposed model (the modularity and flexibility) will allow for accommodating solutions that were presented in the literature on SLP. The methodology for determining the suitable area for tower cranes is based on a study by Irizarry and Karan (2012). In general, TCs are used on construction sites for transporting resources (e.g., materials, equipment etc.) between two points a supply point (SP) and a demand point (DP). As shown in Figure 4.20, a circle which its radius is equal to the jib length of the TC selected for the project and its center is the SP will be generated by the presented model for the SP. The same process will be done for the DP. The suitable area (SA) for the TC is the intersection area between the two circles of the SP and DP. The locations of the SP and DP on the map is determined by users. The workflow for identifying the suitable area for TCs is shown in Figure 4.21. This SAITC in the TFL module will be developed by using the ModelBuilder that is part of the ArcGIS desktop package. For tasks that are far away from each other and that a single TC cannot cover, a new group (layer) of SP and DP should be identified by users then the model can be used again to identify the SA for the new TC.

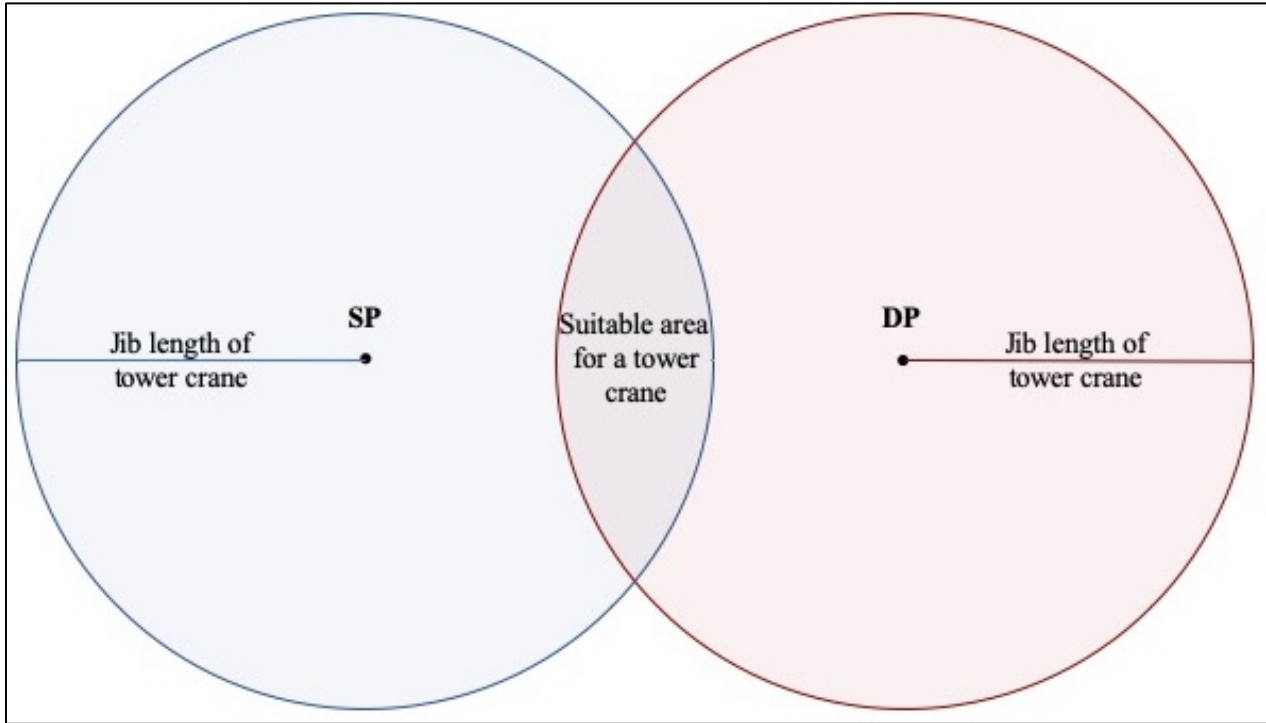


Figure 4.20: Illustration for the suitable area for tower cranes.

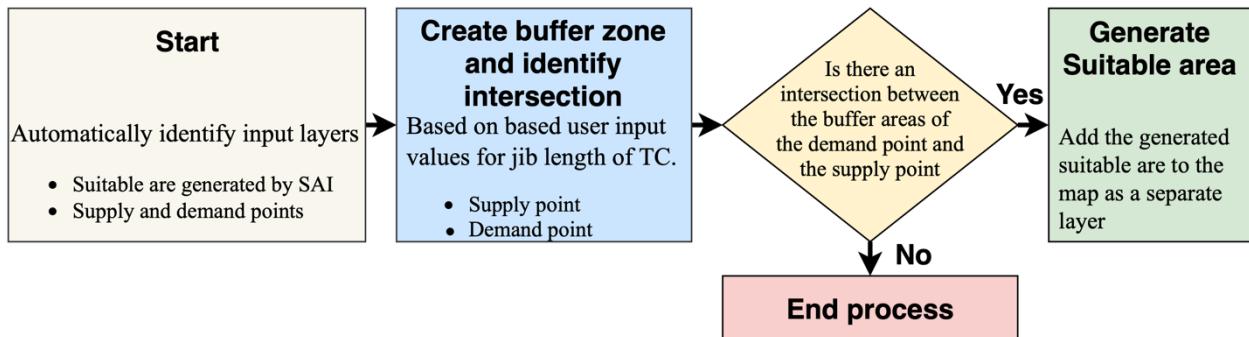


Figure 4.21: Workflow for the identifying the suitable area for tower cranes.

4.5.5.6 Data-rich environment to support users' decisions

The development methodology of the proposed model, which is based on the integration between BIM and GIS, enables providing data-rich environment to support user's decision on selecting suitable and safe locations for TFs and supply and demand points as shown in Figure 4.22. The proposed model will make topography and soil information of the construction site available, quarriable, and visualized for users along with the information of the transportation networks and the building information in one location. GIS can be used to help users estimate the suitability and

safety of a location for a certain task by including information about the ground surface, topography and the environment surrounding this location (Kumar and Bansal, 2016; Kumar and Bansal, 2019). In this study the soil information in the proposed model will provide users with detailed soil information including slope steepness, slope length, type of soil profile (agriculture or native), soil variation (e.g., bedrock substrate, clay substrate, gravel substrate), surface stoniness (including size and fragments of rock on the soil surface or protruding above ground), water table, and soil salinity etc. This detailed soil information was obtained in a form of polygons with a scale of 1:50,000 in a shapefile (.shp) from the detailed soil survey complications (DSS) by Agriculture and Agri-Food Canada (2013). Moreover, the proposed integrated model will provide information about the characteristics of the soil that was gathered from boreholes for the Ottawa-Gatineau area (in Canada), which was obtained from Agriculture and Agri-Food Canada (2019). In addition, GIS provides data management capabilities, which will allow creating and including own soil data that is either gathered from soil samples obtained from boreholes or any geotechnical field tests and make it available to inquire, analyze, and display it on the map. Furthermore, a contour of 5m, stored in an AutoCAD file, will be used in this study to create a TIN layer for the selected construction site area to help simulate and visualize the topography on the map. This will enable visualizing and enquiring about the difference in terrain and different elevations of the surface of the construction site.

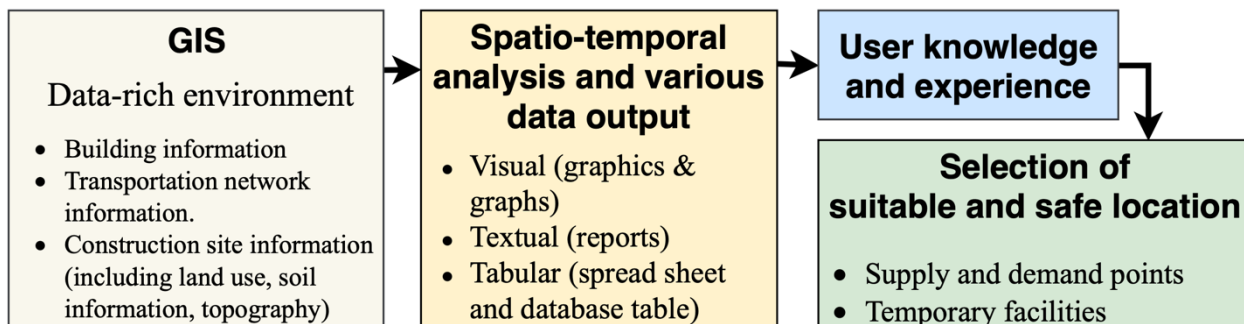


Figure 4.22: Workflow of supporting user's decision for selecting suitable and safe locations

4.5.6 Module 6: Dynamic conflict detection (DCD)

The methodology for developing a rule-based checking module for site layout planning is to assist users to dynamically identify the potential time-space conflicts in 2D and 3D with high accuracy in an intuitive and efficient manner as will be explained in this section.

4.5.6.1 Objective of module 6:

The DCD extension should assist users, in an easy and quick manner, to detect the potential conflicts in 2D and 3D between the different site objects for the project's whole duration; as well as making it easy to understand, to check, and to analyze the detected clashes and to assist users in making and applying the recommended corrections. Also, users should get feedback from the proposed module regarding the detected conflicts in various outputs (i.e., graphical, textual and tabular) and be able to document them.

4.5.6.2 Functions of module 6:

The dynamic conflict detection module will include some essential features to assist users in checking their site layout plan and identifying any potential conflicts and assess their risk level, such as:

- i. Visualize the detected time-space conflicts among site objects during the whole lifetime of the project. Visualization should be made easy and clear for users to understand in order for them to comprehend the gravity of the problem and to make the right corrective actions.
- ii. The module will generate alert messages to notify users of the number of conflicts detected or if there are no conflicts detected. In addition, users will get a report including detailed information regarding the site objects in conflict, which is also useful for project documentation purposes.
- iii. The DCD module should be efficient, easy to use, and automatically conduct the dynamic

conflict detection process to get results in a timely fashion. In addition, it should be flexible to apply modified information by users (geometric or functional) to match their preferences.

- iv. Seamlessly compatible with the site objects included in the TFL and the IFC 3D model components.

4.5.6.3 Prerequisite of module 6:

- All feature classes (layers) that need checking for potential conflicts including construction site, roads, site objects, etc., should be in the same Geodatabase.

Figure 4.23 shows the methodology for developing the DCD module. A data collection on the spatial constraints and relationships between temporary facilities will be conducted. After that, sets of rules to govern the different spatial relationships and constraints that exist between the different TFs and between TFs and PFs will be identified. Finally, those rules will be translated and developed as codes that convey the meaning of the identified rules. Figure 4.24 explains the process flow for the DCD module. ArcGIS provides the capability of developing custom tools using programming languages such as VB, and Arc objects library (based on the C# programming language), which will be used to develop the toolbar extension, user interface (UI), and functions for the DCD module. To identify time overlap between two objects for all the different cases of time overlap, the DCD module will use the formula shown in Figure 4.25 that is adopted from (Stackoverflow, 2018).

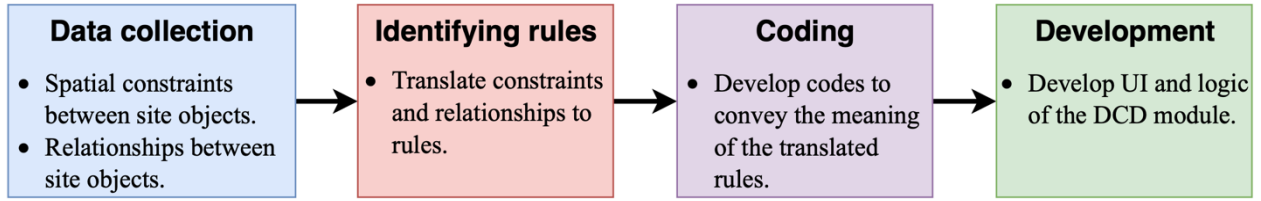


Figure 4.23: Development methodology of module 6 (DCD)

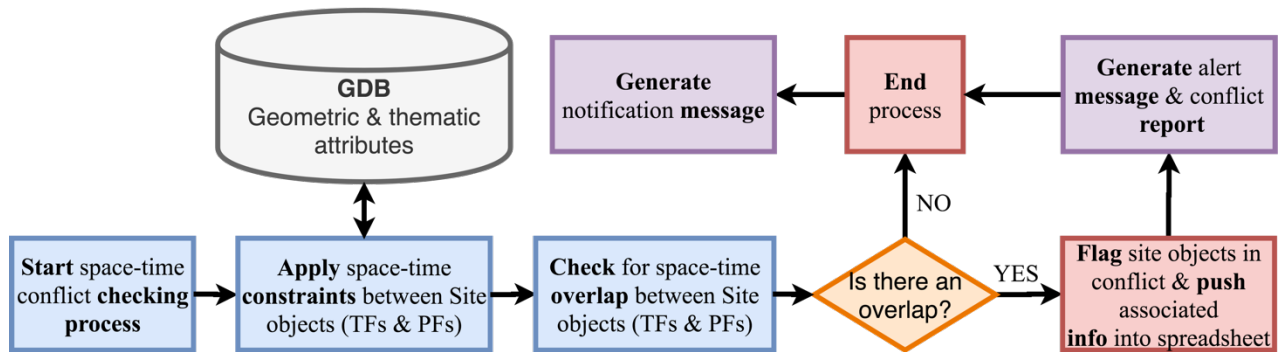


Figure 4.24: Dynamic conflict detection workflow

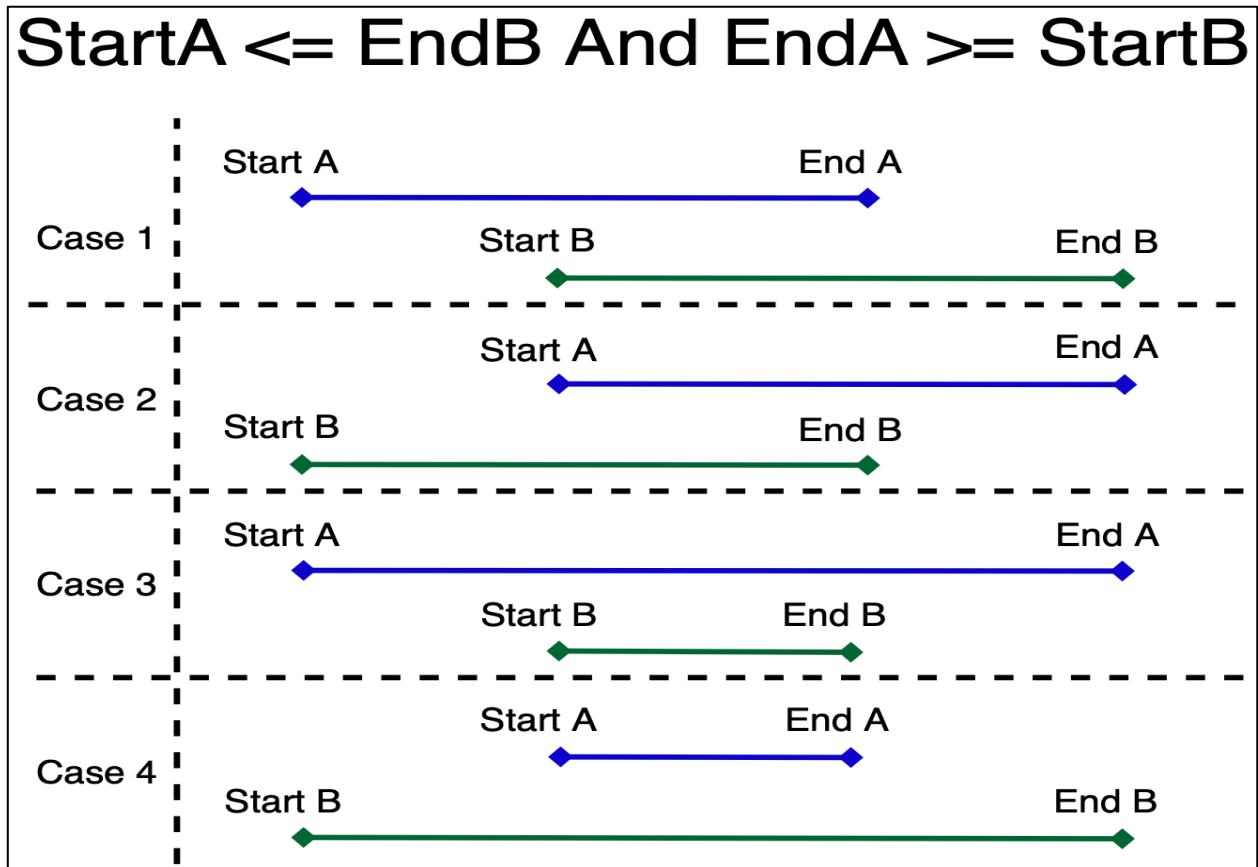


Figure 4.25: SQL formula for identifying time overlap between two objects

The DCD module will check all the different site objects against each other for potential time-space conflicts. First, the module will check for the values of spatial requirements (i.e., the operation distance and/or safety distance), which are stored in the attribute tables, for the site objects that have time-space conflict in order to create the spatial requirement area (SRA). The SRA is represented by the developed module as a buffer zone that surrounds the site object in question and follows the shape of its geometry (exterior boundary), which is calculated and created based on the values of the spatial requirements for each site object. Then, the module will run the required spatio-temporal analysis by considering all the developed spatial constraints or rules for each object on the site (TF and PF) depending on the type of that object, its function, and the special spatial relationship between an object and other objects if one exists. For instance, for some site objects (e.g., laydown areas), the module will check for time-space conflicts in 2D; whereas, for other site objects (i.e., Tower cranes) it will check for time-space conflicts in 3D. If there are no spatial requirements (i.e., operation distance or safety distance) in the attribute tables, the module will consider only the exterior boundary of the site objects that are in conflict. In case of any constraint or rule violation, an alert message will be shown to notify users about the number of conflicts while all the information for the site objects in conflict will be written into a spreadsheet and saved for later checking and documenting by users. The advantage of using GIS is that the site objects in conflict will be highlighted on the screen and only the attributes for the site objects in conflict will be highlighted in their associated attributes table. This saves time and effort for users to identify and conduct the required adjustments for the site objects (e.g., TFs) in conflict. First, users will check the site layout for any potential conflicts by using the DCD module, then they will adjust the layout accordingly and run the DCD module again. This process is repeated until no more conflicts are detected. The visualization and data manipulation

capabilities included in GIS make it easier for users to see the areas of conflict and to easily adjust the facilities of concern in accordance to what is displayed on the screen and found in the generated report. Finally, users, if required, can print the final output (layout). Spatial relationships and constraints between temporary facilities

4.5.6.4 *Spatial relationships and constraints between temporary facilities:*

The constraints and spatial relationships between the site objects included in the DCD module are “interference” and “dimensional”. Some spatial relationships and constraints will be applied as general rules to all site objects (i.e., interference) while others (i.e., dimensional) will be applied to certain site objects (e.g., site offices) as follows:

Interference:

There should never be an overlap between any two site objects while they are onsite at the same time. The overlap is defined, in this study, as the intersection that exists between the areas of the different site objects involved plus their distance requirements area as depicted by Equation 4.3.

$$OL = (SOA_x + SRso_x) \cap (SOA_y + SRso_y) \quad [4.3]$$

Where OL is overlap between site objects; SOA_x area for site object X; SRA_{SOx} is spatial requirement area for site object X; SOA_y area for site object y; SRA_{SOy} is spatial requirement area for site object y.

Dimensional:

There are different dimensional constraints considered in the DCD module (i.e., operation distance and safety distance). Safety distance is further divided into “minimum distance” and “within a distance”. In this study, the dimensional constraints will be applied to site objects differently depending on the type and function of each site object.

a) Minimum distance:

In case a site object requires a minimum distance from any other site object, the module will create a buffer zone around the exterior boundaries of that site object equivalent to that value stored in its attribute table (e.g., 5 meters). Then, the module will check all other site objects for any rule violation (i.e., overlapping) as described in Figure 4.24. In this study, this type of constraint will be applied to the following TFs: combustive material storage and batch plant. This will be applied in order to achieve a minimum distance between them and the site offices, as well as between them and the roads. In the case of storage, as shown in Figure 4.26, the module will check for the “stored material status”, which is found in the attribute table of the TF. If the status is “Combustive” then the module will apply the minimum distance constraint; otherwise, it will only consider the interference constraints.

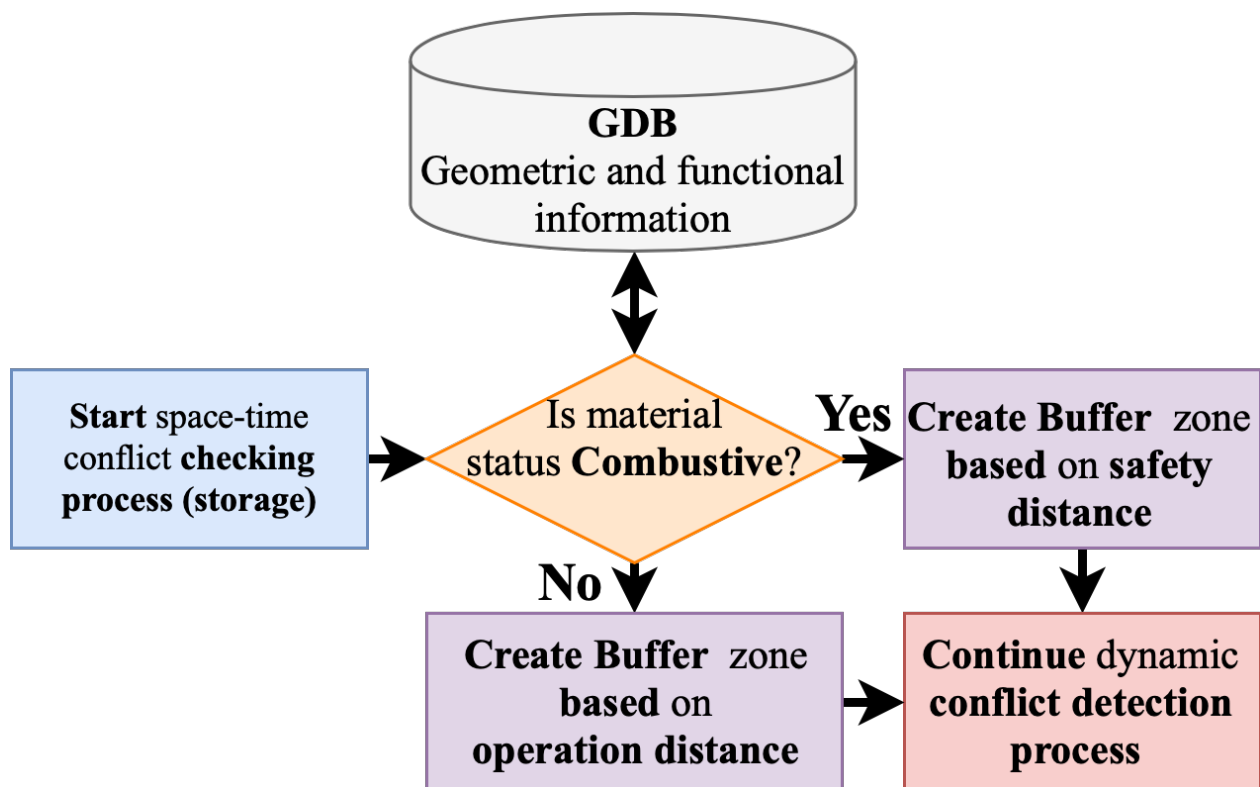


Figure 4.26: Workflow of applying minimum distance constraint (storage)

For some site objects, such as tower cranes, additional steps are considered to conduct especial spatial analysis requirements (in this case minimum distance requirements) in respect to height (z value) spatial analysis. In this module, for the case of tower cranes, the inherited checking rules will be for conflicts in height, which is classified under two main categories that are: a tower crane to a tower crane (TC-TC) relationship; and a tower crane to a building (TC-B) relationship. The process flow for the special spatial analysis (height) including these said two categories (TC-TC and TC-TB) is presented in Figure 4.27.

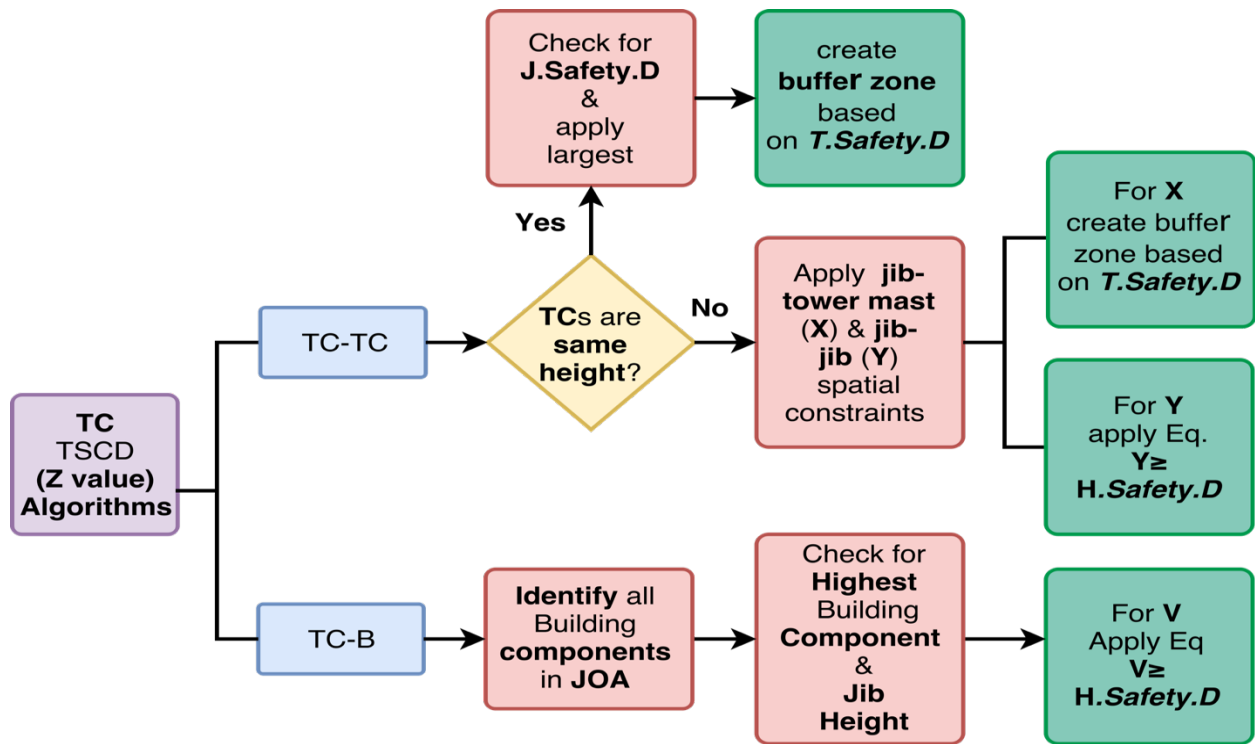


Figure 4.27: Flowchart for special spatial analysis (height) for specific TFs (TCs)

In the first category (TC-TC), when multiple TCs exist on the site at the same time, the module will check to see if the TCs in conflict have the same height or different height in order to identify the set of constraints that should be applied, according to the following:

- *The tower cranes (TCs) in conflict have same height:*

In this case, as shown in Figure 4.28, the module will use the minimum distance required between

the different jibs for the TCs in conflict and apply it in Equation 4.4.

$$H \geq L.JSD \quad [4.4]$$

where; H is the minimum distance required between the jibs of the two different TCs in conflict; L.JSD is the largest J.Safety.D (minimum jib safety distance requirement) value between the two J.Safety.D values stored in the attribute tables of the two tower cranes (TCs) in conflict. The value for the minimum jib safety distance requirement (J.Safety.D) will be stored in the tower crane's attribute table. In case TCs have different minimum distance value requirements, then the larger value is the one to be applied. Also, users can override any stored information and apply any value for all TCs if needed.

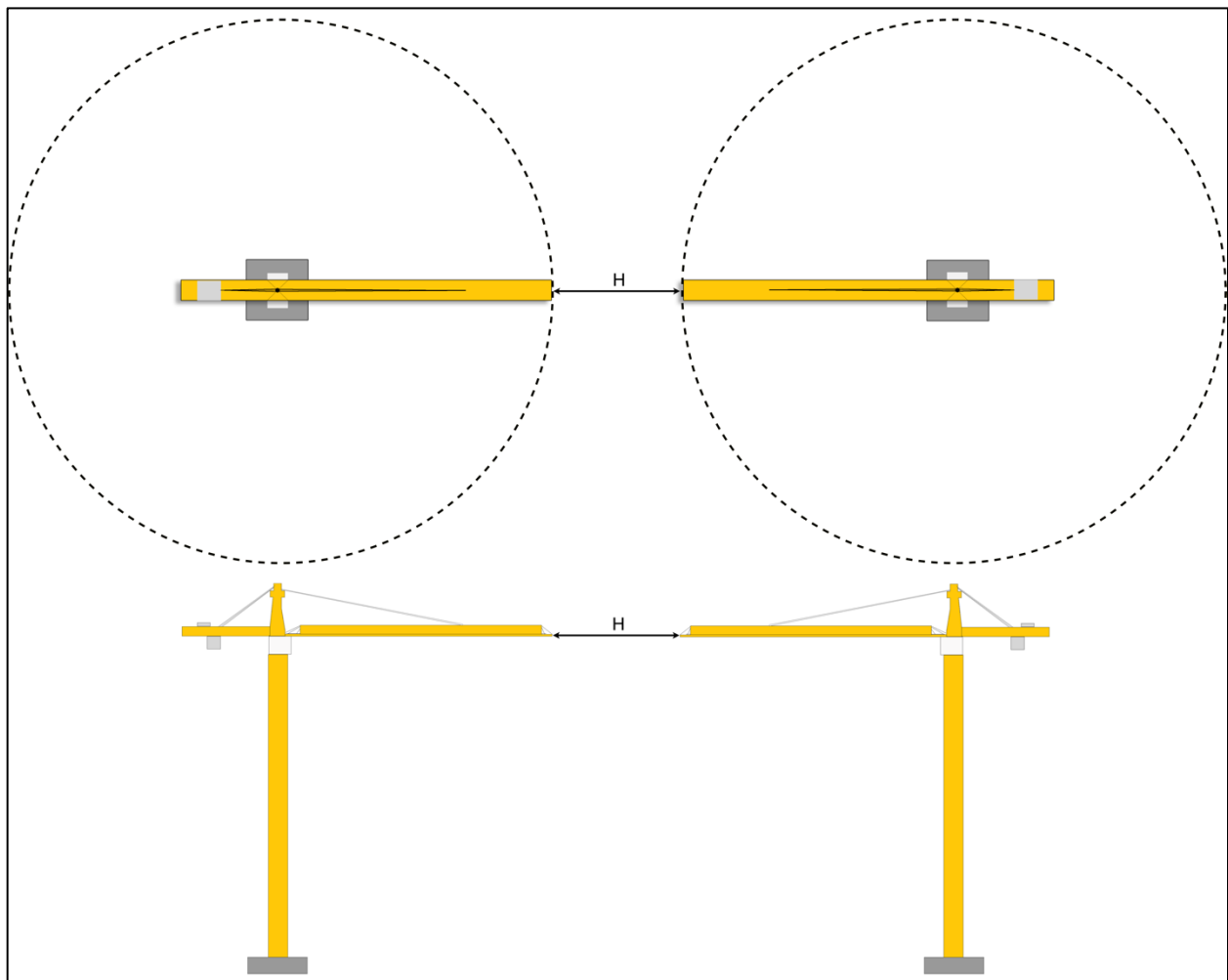


Figure 4.28: Illustration of the spatial relationship between two TCs with same height

- *The tower cranes (TCs) in conflict have different heights:*

In this case, the module will check for the minimum distance values required for the two different spatial constraints that govern the spatial relationships between jib-to-tower mast (X) and jib-to-jib (Y) relationships, as illustrated in Figure 4.29, for the different TCs in conflict. The two spatial constraints, X and Y, are described as follows:

- For constraint X, the DCD model will create a buffer zone around the exterior boundaries of the tower mast of the tallest TC to check for potential spatial conflicts between the jib of the shortest TC and the tower mast of the tallest TC. The buffer zone is based on the value of T.Safety.D, which is the value of the tower mast safety distance that is stored in the TCs' attribute tables.
- For constraint Y, the module will use Equation 4.5,

$$Y \geq H. \text{Safety}. D \quad [4.5]$$

where, Y is the distance between the jib of the shortest TC and the tower mast of the tallest TC, as presented in Figure 4.29; and H.Safety.D is the height safety distance value stored in the TC's attribute table. The height of each TC is stored in its attribute table as well.

It should be noted that the case of the two TCs with different heights as shown in Figure 4.29 is not practical and should be avoided in real life however, in this study the two constraints X and Y are developed in the presented model to be applied in case they were needed in extreme cases.

In the second category (TC-B), the module will identify all the building components that are covered by the Jib Operation Area (JOA). JOA is calculated by using Equation 4.6. Then, the module will identify the highest building components in the JOA of the TC and apply the minimum distance constraint calculated by Equation 4.7. Figure 4.29 shows the distance (V), which is the height difference between the jib of the TC and the highest building components in the JOA of the

TC. The module will determine the value of V and will check for the value of H.Safety.D that is stored in the attribute table of the TC, then it will apply the distance constraint shown in Equation 4.7. For all other building components that lie beyond the JOA there is no need to run spatial analyses to identify conflicts as they are already in the safe zone. The process flow for the height spatial analysis, for tower cranes, in the DCD module is illustrated in Figure 4.27.

$$JOA = J.L + JSD \quad [4.6]$$

where J.L is Jib length and JSD is jib safety distance.

$$V \geq H.Safety.D \quad [4.7]$$

where V is the distance between the jib and the highest building component identified within the JOA of the TC, as presented in Figure 4.29, and, H.Safety.D is the height safety distance value stored in the TC's attribute table.

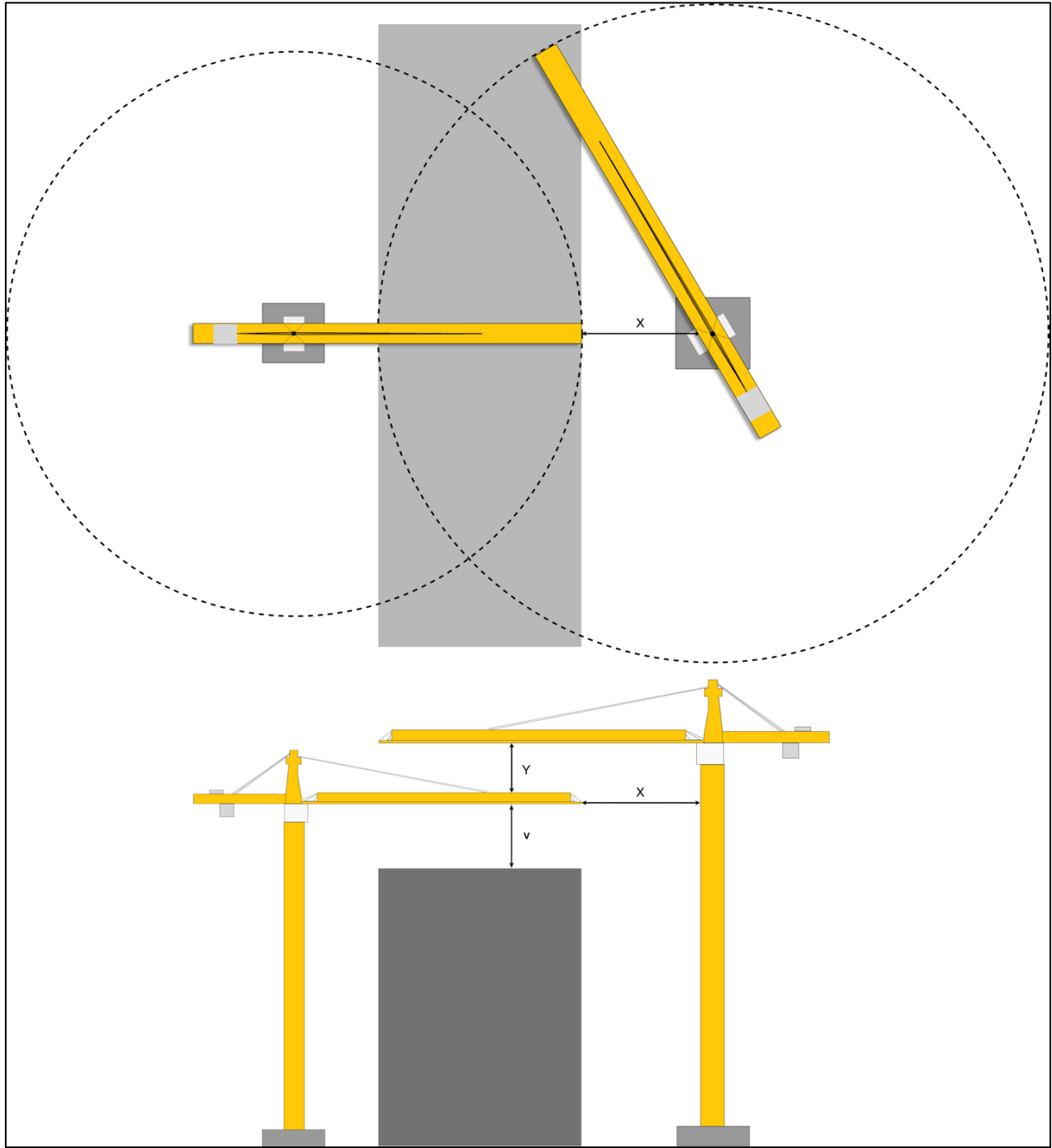


Figure 4.29: Illustration of the spatial relationship between two TCs with different height

b) within a distance

Generally, some site objects need to be placed within a certain distance from each other in order to have a more efficient construction workflow (e.g., a site office and a site washroom). In this case, the distance constraint will be stored in the attribute table of the main site object (MSO), such as a site office that requires the other dependent site object (DSO), such as a site washroom to be placed within a certain distance from it. This distance constraint will be stored under the field 'Within.D' in the attribute table of the MSO. In case there are multiple, different site objects that need to be within a certain distance from a specific site object, then multiple 'Within.D' fields are required, which should be made unique for each site object to be stored in the attribute table of the MSO. The module will create a buffer zone equal to the value of the Within.D stored in the attribute table of the MSO. Then, it will identify how many DSOs, if any, are within the boundary of the created buffer zone. As shown in Figure 4.30, if there are no DSOs within the Within.D boundary, then the constraint is considered violated. If at least one DSO is identified within the boundary of the associated Within.D then the relationship is considered valid. In case multiple DSOs (e.g., site washrooms) are all within the buffer zone (within a distance) of the MSO (e.g., site office), the closest DSO will be selected and associated with the MSO and the rest will be reported as they are not associated to any MSO. The module will determine the closest DSO by measuring the distance from the centroids of the multiple DSOs to the centroid of the MSO, then the DSO with shortest distance to the MSO will be selected. Due to the flexibility of the module, users can modify the Within.D as required and whenever is needed.

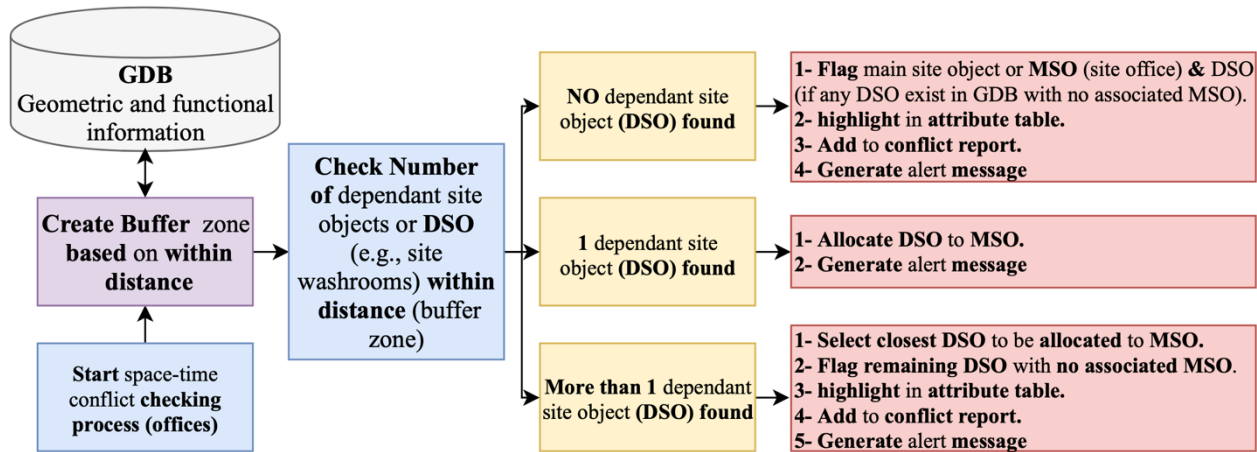


Figure 4.30: Workflow of applying within distance constraint (offices)

c) Operational distance

It is known that some site objects require an operation distance to function properly. The module will create a buffer zone around the exterior boundaries of the site objects equivalent to that value that is stored in its attribute table for the operation distance. The module will run the spatio-temporal analysis to check for any overlap. Users can modify the values for the operation distance for all site objects if needed.

For modifying the TFs' parameters, users can modify their values in the attribute tables of the associated TFs or in the main GDB that is linked to the TFL module, which would be included automatically the next time they create a TF using the TFL. As for the IFC (building) components, a dialogue named "Set IFC safety distance" that exists in the DCD module will be developed to modify the values of the safety distance for each IFC component. The workflow of applying safety distance for IFC components is shown in Figure 4.31. Each spatial relationship (constraint or rule) between site objects is hard coded and included in the DCD module.

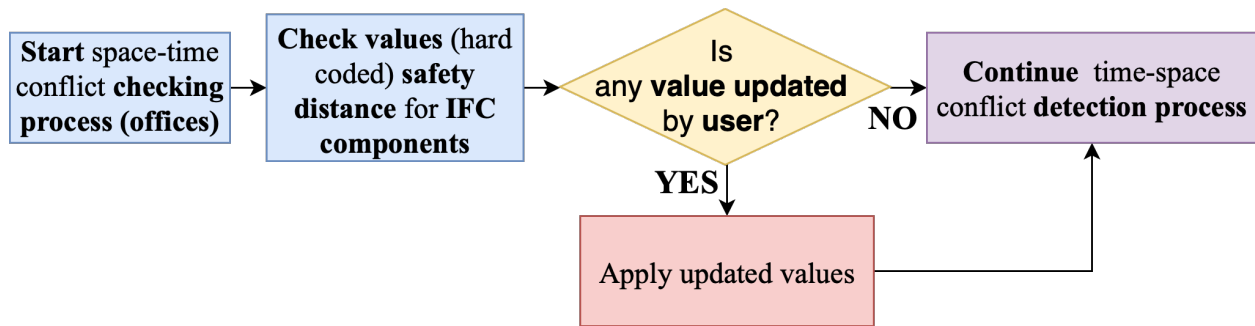


Figure 4.31: Workflow of applying safety distance for IFC components

4.5.6.5 Risk/hazard assessment:

The DCD module will also run a generic risk assessment that will inform users through visualization and text (report) about the level of the potential hazard that is involved with the conflicts detected between the different site objects in their site layout plan. The proposed checking rules that will be included in the DCD module are categorized as follows:

- Urgent, which is associated with high risky site objects (i.e. Tower Cranes and combustive material storage). If any TC has a conflict with any site object (including TFs and PFs) the DCD module will consider the risk level to be high, since such conflicts can result in immediate fatality, and will display those conflicts in a red color on the map. The same process will be applied when a site office or a road has a conflict with a combustive material storage.
- Very important, which is associated with medium risky site objects (i.e., batch plants). Such a facility produces hazardous fumes and if human beings are exposed to it can endanger their health over the long term. When such a conflict is detected between that facility and any vulnerable site object (e.g., site offices or roads) the DCD module will consider the risk level as medium, since such conflicts will not result in immediate fatality, and will display those conflicts in an orange color on the map.

- Important, which is associated with all the time-space conflicts between site objects. In case a conflict is detected between different site objects (including TFs and PFs) the DCD module will consider the risk level as important, since such conflicts can lead to a decrease in the efficiency on the construction site and a delay in the construction process. such conflicts are displayed in a yellow color on the map.

All the risk levels will be included in both the attribute table of the site objects in conflict and the conflict report, while the cells in the spreadsheet will be highlighted in the color corresponding to the risk level (i.e., red, orange and yellow for the risk levels urgent, very important and important, respectively). In case a facility has more than one level of risk detected (e.g., very important and important) the highest level governs and will be displayed on the map and included in the attribute table of that site object under the field “Risk level” (which will be automatically generated and updated by the DCD module depending on the detected conflicts). Furthermore, the multiple risk levels detected, however, will be included in the conflict report generated by the DCD module. It should be noted that the presented model in its current state only considers how urgent/intense a hazard is but does not take into account the probability of occurrence for hazards (how often a hazard occurs).

4.5.6.6 Conflict Report Generation

Figure 4.32 shows process flow of feedback for every detected conflict. When a time-space conflict is detected by the DCD module, all the necessary information about site objects (TFs and PFs) in conflict will be saved into a spreadsheet and a notification message (alert message) will be displayed to ask users to review the conflict report generated. If a site object (A) is in conflict with site object (B), all the aforementioned information will be saved for both site objects (A and B). If a site object is in conflict with multiple site objects, each conflict in the report will be represented

in a separate row in the table of the generated spreadsheet, showing the aforementioned information for the site object and each of the other site objects with which it has conflict separately.

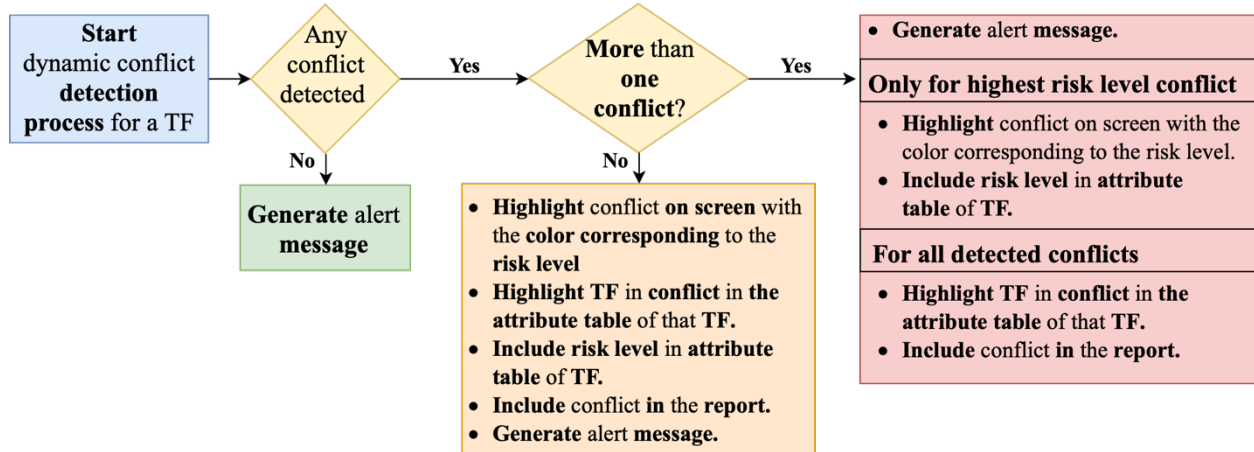


Figure 4.32 Process flow of feedback for every detected conflict.

The conflict report will include descriptive texts in the field “Type of conflict” that varies depending on the type of the detected conflict in order to explain to users the nature of it. This includes space conflict, minimum distance conflict, within distance conflict, same height tower cranes (TCs) conflict, different height TCs conflict, tower crane and building conflicts. The texts will be; space conflict; hazard within range (name of the TF family) and Vulnerable TF within range (name of the TF family); required facilities not within range (name of the TF family) and Main TF is not assigned (name of the TF family); same height TCs conflicts; different height TCs conflicts (Jib-Jib or Tower Mast-Jib); TC and building component conflicts, respectively.

The information included in the conflict report is as follows: Number of site objects in conflict; the main TF category of the site object; TF family; TF type; TF Name (sub-type), starting date and finishing date of the conflict between site objects; conflict duration in days. Position of the site objects onsite at the time of conflict (The X,Y coordinates, based on the objects’ centroids); a description for the type of conflict the site object is having; the risk level of the detected conflict,

which will be written in the report and the color associated with the risk level will be shown in the background of the associated cell in the report (spreadsheet).

4.5.6.7 The equations used to identify the time information used in the conflict report.

One piece of information included in the conflict report is the duration of the conflict between the site objects and the durations of the site objects onsite. The following equations show how the calculations for the different required durations of site objects onsite.

$$\text{Estimated Activity Duration} = \text{Estimated Finish Time (EFT)} - \text{Estimated Start Time (EST)}. \quad [4.8]$$

$$\text{Actual Activity Duration} = \text{Actual Finish Time (EFT)} - \text{Actual Start Time (EST)}. \quad [4.9]$$

$$\text{Conflict Duration} = \text{Duration of TF onsite} \cap \text{Duration of TFc onsite}. \quad [4.10]$$

Where TF is the primary temporary facility; and TFc is the temporary facility that has a time overlap with the primary temporary facility.

4.5.7 The layers that will be used in the proposed model.

- 1) For Building (IFC) components time-space conflicts, the following feature classes are used: a) IfcWall_Surface; b) IfcWallStandardCase_surface; c) IfcCovering_surface; d) IfcSlab_surface; e) IfcColumn_surface; f) IfcWall_Line; g) IfcWallStandardCase_line.
- 2) All the TFs created by the TFL will be checked for potential conflicts by the proposed model.
- 3) Time-space conflict will be checked for the following permanent facilities: a) Traffic signals; b) Tree; c) Roads.
- 4) For Tower Crane to Building (TC-B) constraints the following building feature classes will be used to check for height conflict: a) IfcWall_Surface; b) IfcWallStandardCase_surface; c) IfcCovering_surface; d) IfcSlab_surface; e) IfcColumn_surface.

4.6 Summary

The methodology for the development of the integrated BIM-GIS model for site layout planning (SLP) was discussed in this chapter. The intent of the research presented in this thesis is to assist site layout planners at the preconstruction phase as well as the construction phase to plan a safer, more efficient, and close to conflict-free site layout taking into consideration users interaction and applying their knowledge and experience, the space requirements and relationships and constraints between site objects (TFs and PFs). The proposed SLP model will be developed based on the BIM-GIS integration and will be designed in a modular format to assist users during the process of site layout planning in an efficient, effective, intuitive and timely manner. This approach for development and design will make the proposed model versatile to tackle a variety of issues related to SLP and flexible enough to include additional modules and functions that will be required for solving further SLP issues in the future. This is achieved by the successful implementation of six modules which are a 3D modelling module; a route planning and hauling (RPH) module, an execution schedule time entry (ESTE) module; a 4D visualization module; a temporary facilities library module; and a dynamic conflict detection (DCD) module. Details about each module including its objective, functionalities and requirements, preconditions, and workflow were discussed. Some functions required by certain modules (i.e., 3D modeling, 4D visualization, and RPH) will be realized by taking advantage of the existing functions in both tools for GIS and BIM while new functions had to be developed for other modules (i.e., ESTE, TFL, and DCD). These functions will be achieved by using Visual C#, and ArcObjects programming environment, which is part of MS Visual Studio©, which will also be used for developing the plugin to open ArcMap (GIS tool) from within Revit (BIM tool). In addition, Modelbuilder, which is a visual

programming language that is part of the ArcGIS desktop package, will be used to develop the ESTE module and suitable area identifiers under TFL.

The proposed SLP model facilitates the process of creating a 4D model, implementing the concept of virtual review of the construction sequence and site layout, by providing a tool (ESTE) that makes adding temporal information to single or multiple building components (by direct selection or based on locational and functional parameters) an easy and fast process, which decreases the intimidation and frustration of users during the creation of 4D models and saves time. The 4D capability of the proposed model will be a result of the successful integration between a BIM tool and a GIS tool in a way that visualizes the construction progress dynamically. Furthermore, in an intuitive manner, users get to select from a wide inventory of temporary facilities (TFs) that represents the physical properties (shape and dimensions) and the functional information for the TF (constraints and spatial requirements). Also, the TFL module will help users with identifying the suitable and available area for placing the TFs they select from the TFL on the map. Through the development of a parametric temporary facilities library (TFL) and a rule-based dynamic conflict detection (DCD) tool that is compatible with both the TFL and the imported IFC 3D model, the proposed model will assist practitioners in checking their site layout plan for potential conflicts in 2D and 3D for the whole project duration. Furthermore, the DCD module will assess the risk level of detected conflicts and gives feedback in various formats including graphical, textual, and tabular. The proposed model will facilitate site layout planning for professionals by enabling them to apply their knowledge and experience in the planning process and insuring that their design is safe and conflict free to get optimal results in an efficient and timely manner, which will contribute in achieving an optimal site layout that provides an efficient and safer work environment onsite and will reduce the overall cost of the construction project.

CHAPTER 5

Model development

5.1 Introduction

This chapter discusses the development of the proposed BIM-GIS integrated model for site layout planning. All of the six modules that are part of that model will be developed and explained in a way that gives a clear idea on how each module will look, the steps for using it, and its functions. The implementation of those modules will be realized by using some built-in functions in both tools of BIM (i.e., Autodesk Revit) and GIS (i.e., ArcGIS desktop) and by creating new functions either as an application/extension with a user interface (within the BIM or GIS tool), or as plugins that will be linked to the associated tool (BIM or GIS).

5.2 Development of the 3D modelling module

In this module, as shown in Figure 5.1, the proposed BIM 3D model for a new project should contain all the required information for the facility and should be reviewed by users before exporting the project file from BIM tool (Revit) as IFC file format (i.e., IFC 2x3) then importing it into GIS tool (ArcMap), and then transforming it into the File Geodatabase format by using the Data Interoperability Extension in ArcMap. As shown in Figures 5.2 and 5.3, the user will open the IFC export dialogue from the main menu in Revit. Then, he/she will configure the different IFC export options (e.g., IFC version). The most important thing is to select the option for separating the walls and columns by level. This will ensure that these building components will be exported with the level information stored in their attribute table. That will serve the functionalities

in the model such as 4D visualization which will display the different building components individually and independently.

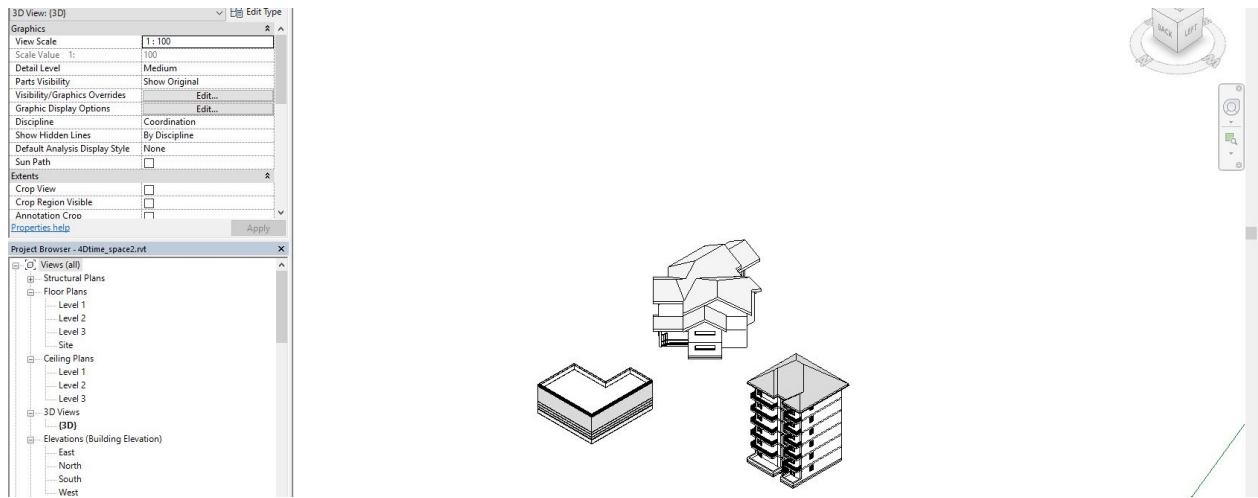


Figure 5.1: Created BIM 3D model in Revit

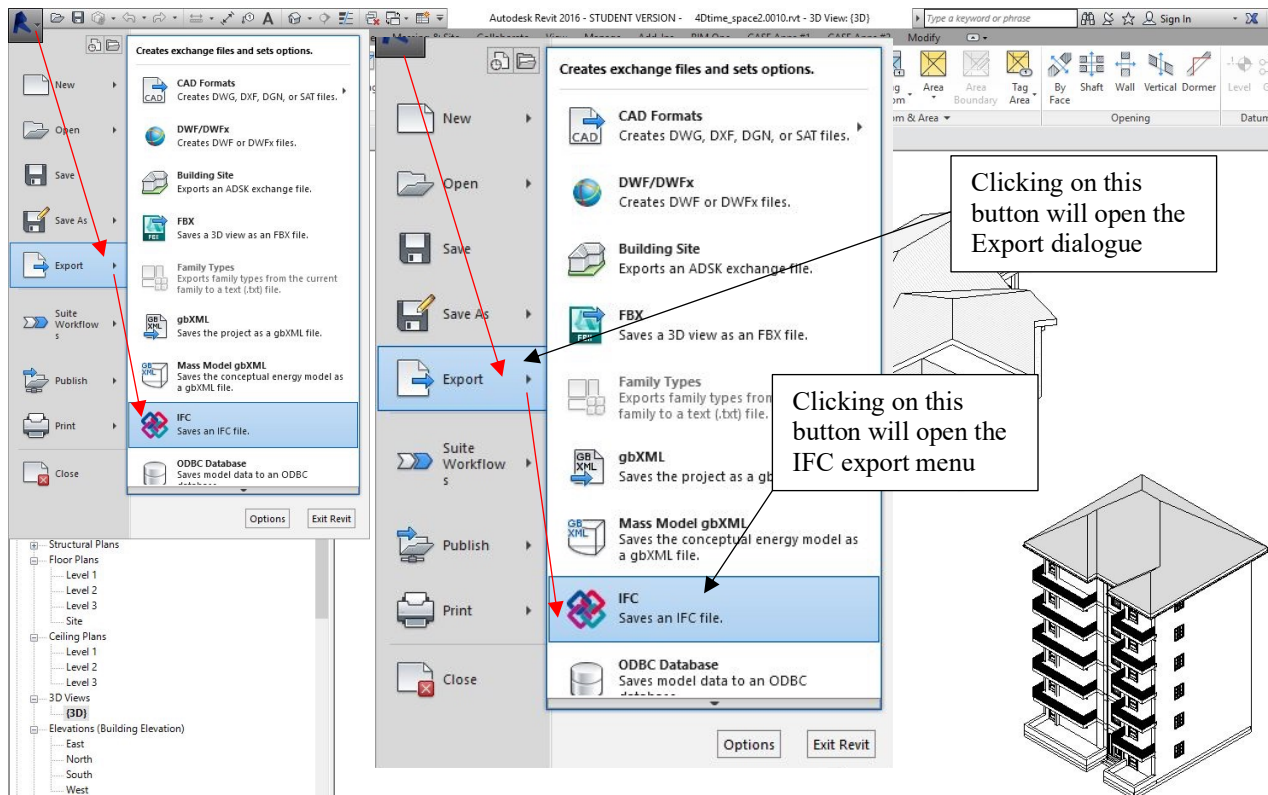


Figure 5.2: The IFC export option from main menu

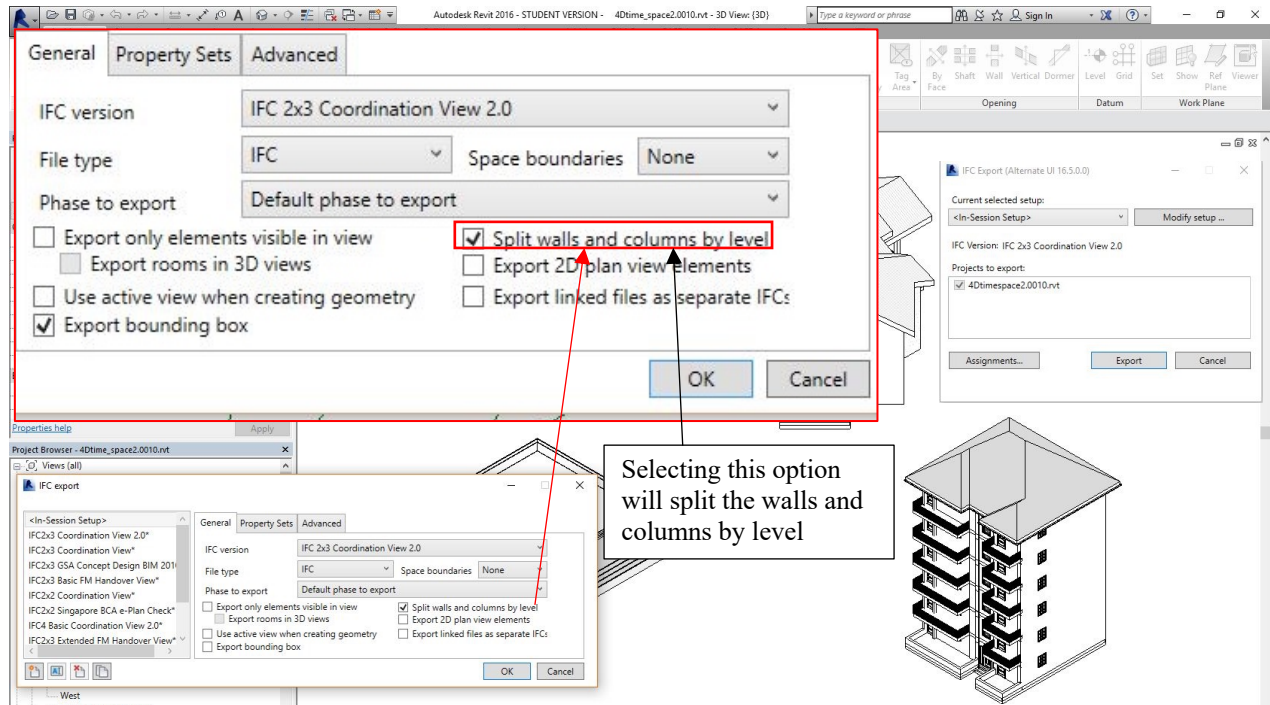


Figure 5.3: Configuring the IFC export menu to serve the model requirements

If needed, users can prepare a material quantity take off (QTO) using the “Modify Schedule/Quantities” option in the main menu, as shown in Figure 5.4. before exporting the BIM 3D model as an IFC file. If this step of preparing the QTO is missed, users can export the QTO as a spreadsheet to be associated with the 3D BIM model in the GIS tool later. A plug-in is developed and linked to the BIM tool to help users to seamlessly open the GIS tool from within the BIM tool as shown in Figures 5.5. This step gives users of the model the sense of a unified environment and seamless transition from one application to another. Portion of the development code of the plugin is shown in Figure 5.6. As shown in Figure 5.7, users will use the Data Interoperability extension in ArcMap to transform the IFC file exported from Revit into a Personal File Geodatabase (GDB) format. After this, the GDB is imported into ArcMap including the 3D model for the new project with its associated attributes. Users will also import all the different layers required for the project including the transportation network, topographical and soil information, the construction site, etc.

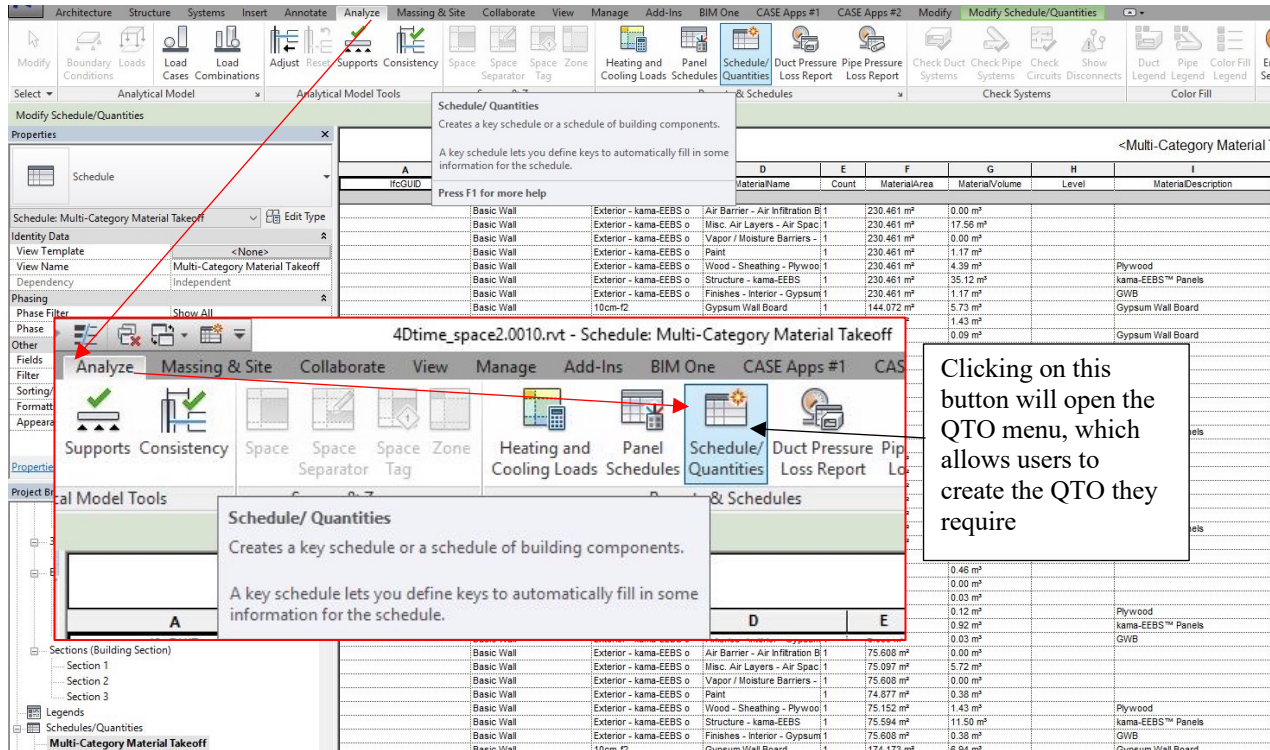


Figure 5.4: Material QTO made by Revit (BIM tool)

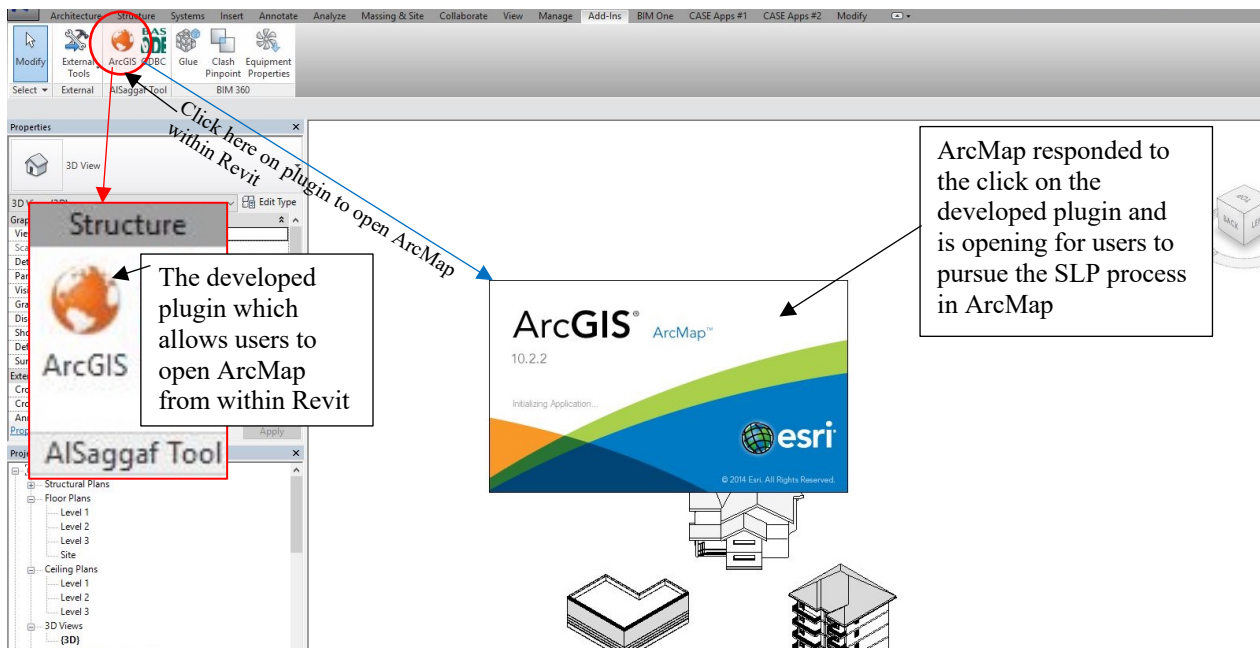


Figure 5.5: The plugin to open ArcMap within Revit

```

1  [Ribbon]
2  Name = AlSaggaf Tool
3  [Image]
4  Name = C:\\BIM-GIS plugin\\images\\m.ico
5  [ToolTip]
6  Name = Run ArcGis
7  [Application]
8  Name = C:\\Program Files (x86)\\ArcGIS\\Desktop10.6\\bin\\ArcMap.exe
9  [ArcGIS]
10 Path = C:\\Program Files (x86)\\ArcGIS\\Desktop10.6\\bin\\ArcMap.exe
11 ToolTip = ArcGIS

1  echo off
2  rem Copy plugin to revit directory
3  rem -----
4  Copy "C:\\BIM-GIS plugin\\ArcGISExt.addin" "C:\\ProgramData\\Autodesk\\Revit\\Addins\\2020\\ArcGISExt.addin"

```

Figure 5.6: Development code for the plugin to open ArcMap within Revit

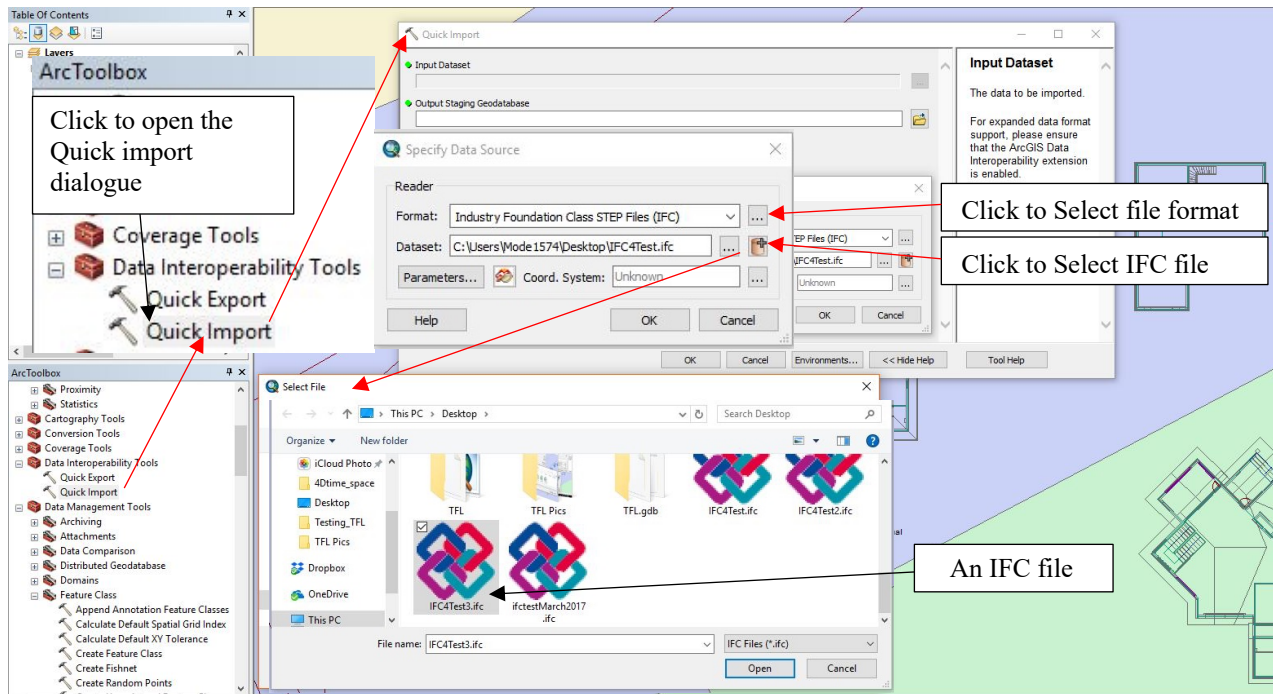


Figure 5.7: Using the data interoperability extension to import IFC files

The 3D model will be imported into ArcMap as different layers (feature classes) that represent the different building components (e.g., floor, slabs, windows, doors, etc.) in accordance with the IFC schema. Each feature class will contain the geometrical and functional information for the building

components. However, the shape and functional information included in its attribute table will vary depending on the building component. Users have various options to examine the imported 3D model as shown in Figure 5.8. They can select the inquiry option and click on the building component they would like to inquire about or they can select the layer (feature class) that represents certain building components (e.g., ifcDoor_Surface) and open that layer's attribute table to find all the information about these building components. If users need more information than what is automatically transformed with the imported IFC 3D model, they can associate the information QTO they prepared or they prepare a new one, which they export as a spreadsheet with the imported IFC building components. This is done by using the "join table" option in ArcMap, which will enable users to enrich the feature classes (layers) of the imported 3D model with the information they want.

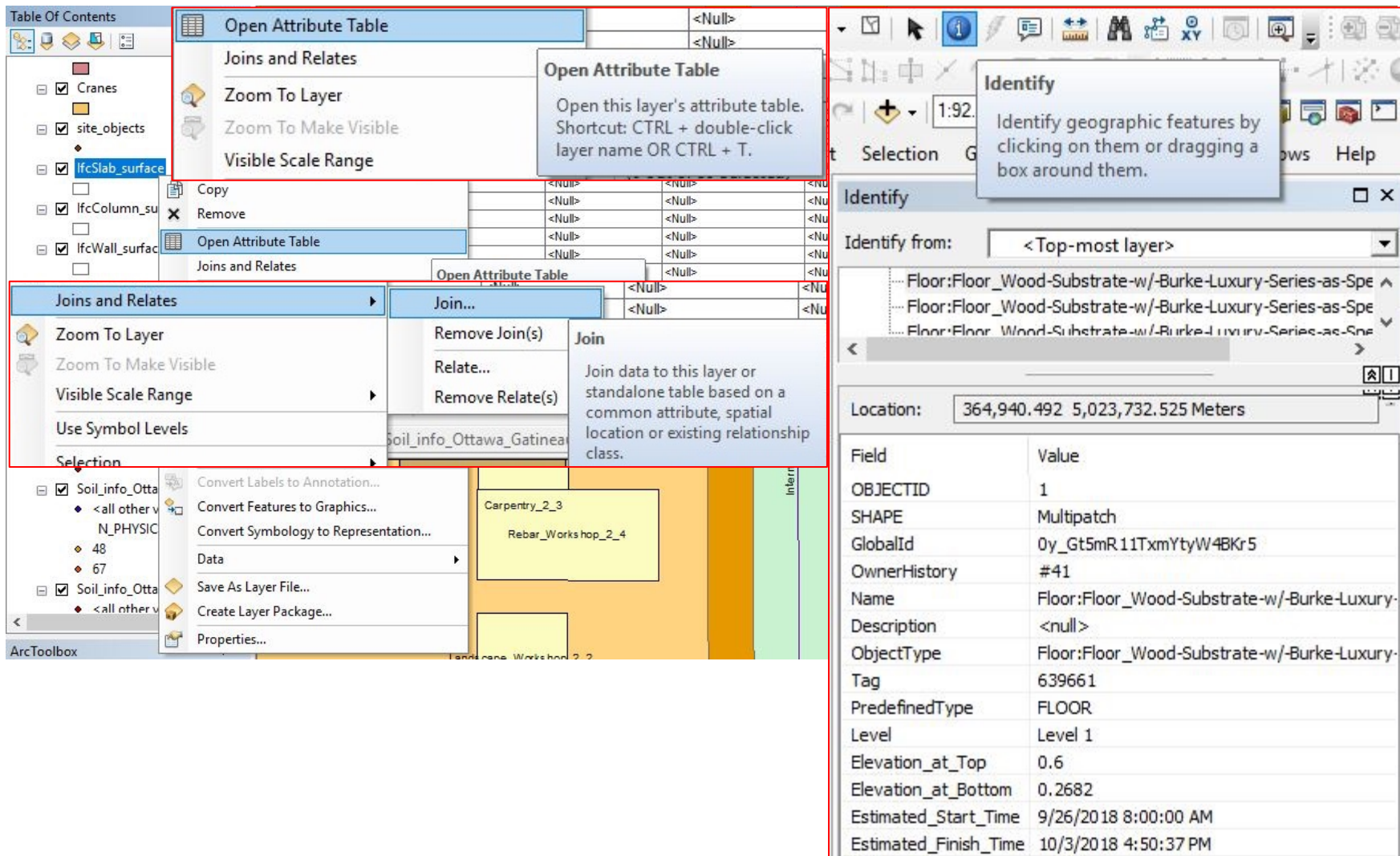


Figure 5.8: Options to examine the imported 3D model

5.3 Development of the route planning and hauling (RPH) module

In this module, the Network Analyst tool in ArcMap will help users to identify the most efficient (safest and shortest) route between two points. First, users will identify the supply and demand points (for instance, for the materials/waste needed for loading and hauling) by using the “identify locations” button as shown in Figure 5.9. In case hazardous materials are being transported, users can identify restriction points on the map (e.g., schools, hospitals, or highly populated areas) by using the same button “identify locations”. Then, users will calculate the most efficient route by clicking on the solve route button as shown in Figure 5.9. In addition, the model will assist users in choosing a suitable location for the supply and demand points by supplying information related to the transportation network, the quantities and volumes of building components and materials, and helping users with estimating and categorizing the potential waste that is generated onsite based on the three waste categorization approaches (i.e., building component, type of material, and material’s condition). As shown in Figure 5.10 users can use the “summary” option when they open the attribute table of the layer of the building components they like to get information about (e.g., ifcDoor_Surface) and produce tables that contains information about the quantities, volume, names of the different building components included in that layer. Also, users can do this based on functional and locational attributes, which is possible because of the spatial analysis capabilities of GIS, which will assist users in identifying the information or objects, such as quantities of building components, based on functional and locational attributes. By knowing the quantities of materials to be transported, truck capacity, average speed of the truck, and the distance of the trip, the total trip time users can estimate the number of trucks needed for loading and hauling operations.

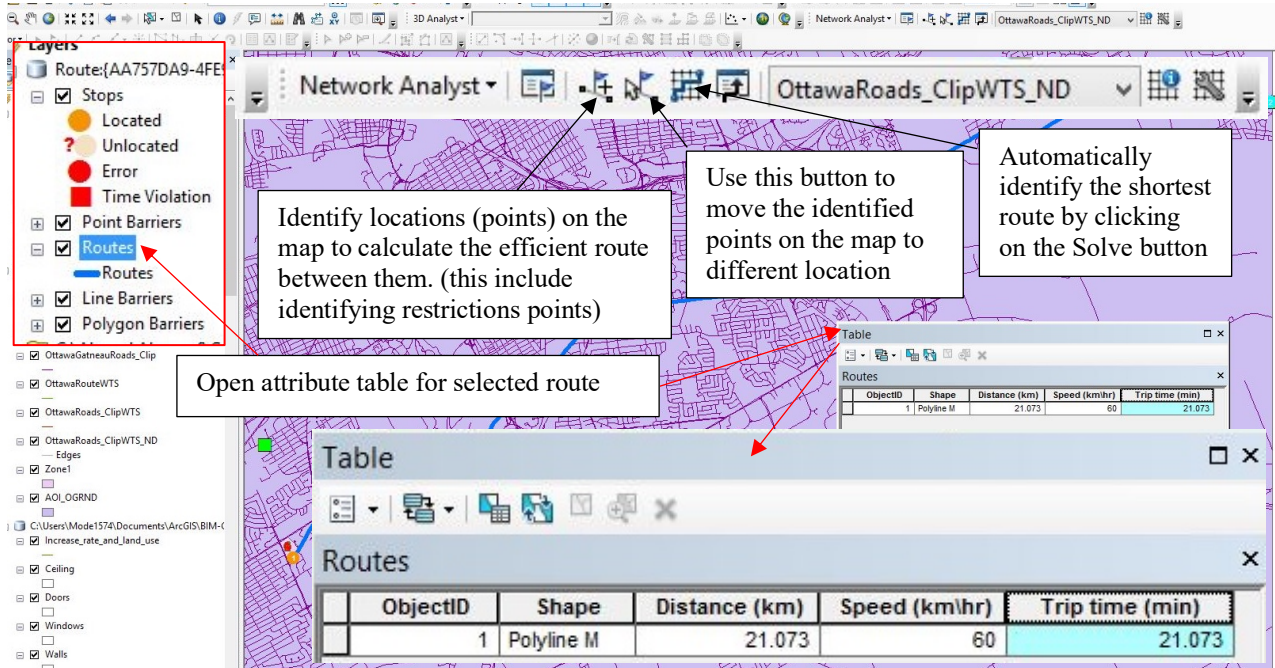


Figure 5.9: Selecting the shortest route between two points

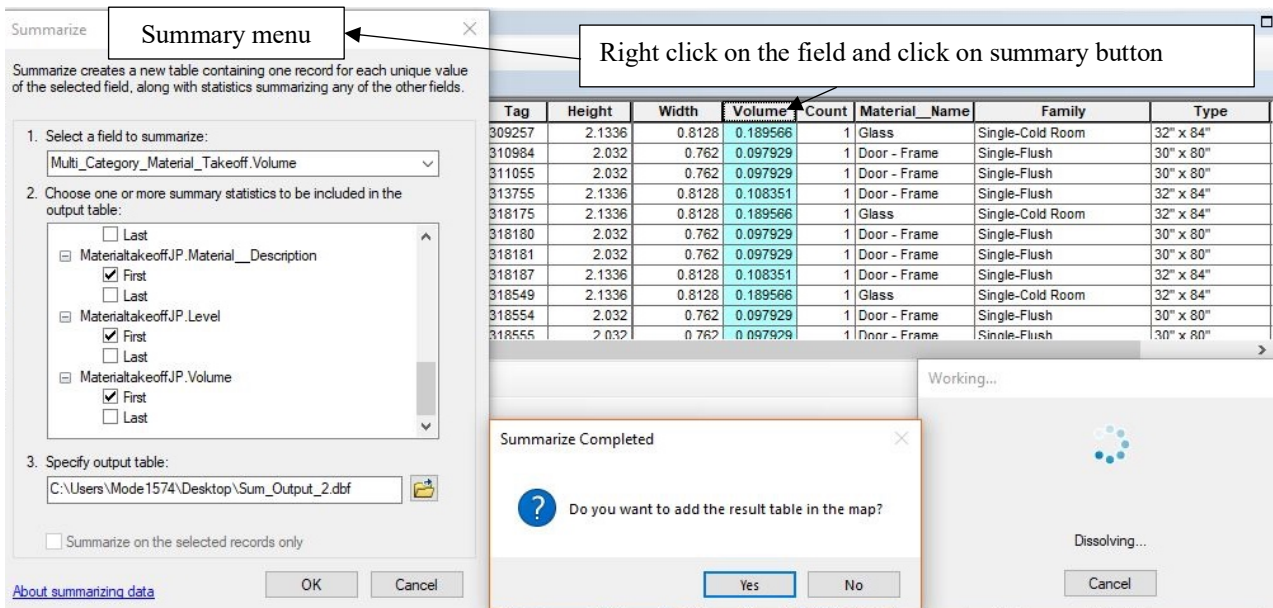


Figure 5.10: Selecting the shortest route between two points

Information such as volume, building material (e.g., concrete, steel, wood, glass, etc.), material condition (i.e., recyclable, reusable, and total loss), building component (wall, window, door, floor, etc.), and weight need to be associated with corresponding features in the ArcMap to enable

locating, estimating, and categorizing the materials and or potential waste generated onsite. However, not all information related to a facility that is found in the 3D BIM model is included within the IFC schema. Also, due to the interoperability issues between BIM and GIS limitations and information loss in the data transformation for both geometrical and functional attributes is inevitable. This causes an issue in associating some of the required information to its corresponding layer as it cannot be found in the transformed file. Thus, in this study some data from the spreadsheet could not be associated with corresponding components. Accordingly, the available data within the geodatabase (transformed from IFC) and the added data (from joining the information spreadsheet with the corresponding layers) such as length, width, volume, floor level, material name, GUID, and component description is used; and other information (i.e., material/component condition) was entered manually for the purposes of testing and verifying the presented model.

It should be noted that developing an automated model for waste management is beyond the scope of this research and is not part of it. The reasons for introducing such methodology (for estimating and categorizing the building components and potential waste generated onsite) in this study that is discussed in this section are: a) knowing the locations and quantities of materials and or waste generated onsite is a topic interrelated with the route planning process, identifying accessibility, and site logistics planning where this will help users to more accurately identify suitable locations for supply and demand points as was discussed in the literature review; b) to demonstrate the versatile capabilities and expandability potential of the presented BIM-GIS model to perform and include other analytical tasks that go beyond the scope of the site layout planning process but are related to the AEC industry; c) integrating the concept of sustainability with the SLP process,

which is an overlooked area in most of the previous studies; which have only incorporated material procurement and site layout planning and did not consider D&R waste.

5.4 Development of the Execution Schedule Time Entry (ESTE) module

To facilitate the use of the proposed model, all the user interfaces developed for the ESTE, TFL, and the DCD modules are included in a single toolbar, called “ArcSPAT”, which is available in the toolbar menu of ArcMap. The name ArcSPAT consists of the two parts: Arc is an abbreviation used in the field of engineering and is associated with drafting, while SPAT is an abbreviation for Site Planning Assisting Tool. Figure 5.11 shows the main toolbar called ArcSPAT, which contains the main extensions (applications) that are developed in this study to help users plan the site layout for construction. By clicking on the ESTE extension as shown in Figure 5.11, the user interface (UI) that is developed for the ESTE module will open as shown in Figure 5.12. The ESTE module facilitates the creation process of 4D models for users. It allows users to enter the information for EST, EFT, AST, and AFT individually or simultaneously for a single or for multiple building components based on locational and functional attributes.

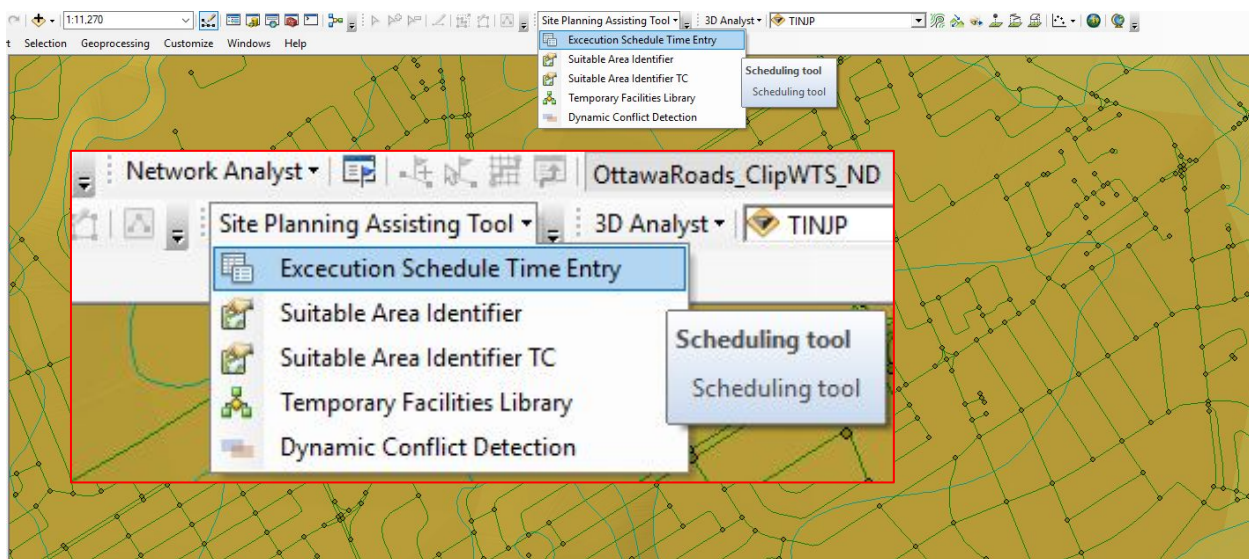


Figure 5.11: Opening the ESTE extension from the developed ArcSPAT tool bar

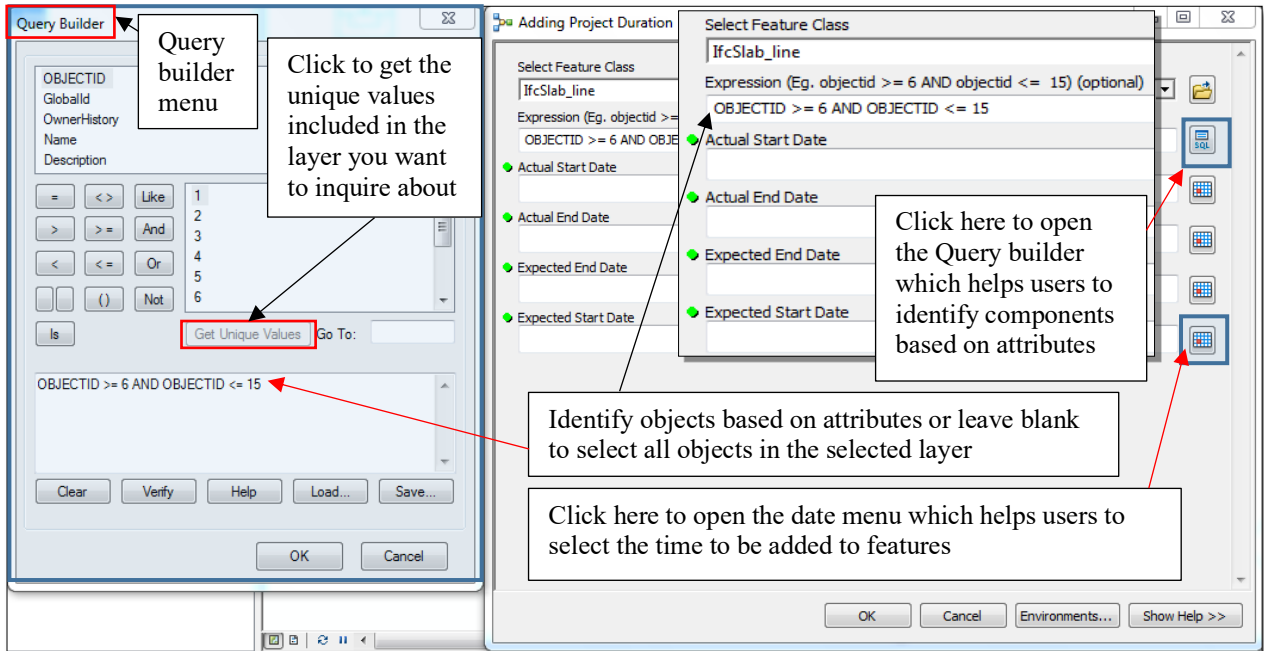


Figure 5.12: UI of the ESTE extension and features selection via query builder

Users can select the layers (feature classes) where they want to enter the temporal information to, and they can specify the exact date and time based on the information found in the construction schedule for the project. The ESTE module at the back end will add two time-fields (four in total) for the Start Time and Finish Time (Estimated and Actual for each) and fill the column value with dates entered by users for the selected objects in the specified Feature class or layer (e.g., ifcWall). The module is configured to ignore the fields that are not specified (entered) and accordingly decide how many fields it will create. If time fields already exist, the ESTE will not recreate them and instead it will just fill them out or update previous values with the new entries. Users will select the date and time information to be allocated to the selected features (building components or activities) from the date menu as shown in Figure 5.13. Users can identify the features based on locational and thematic attributes using the BIM-GIS model. For example, using the query builder, as shown in Figure 5.12, users can select, based on thematic attributes, a certain column or a certain slab on a specific level or floor. In addition, users can combine both locational and thematic queries

to identify the activities they seek to allocate time to. For instance, users can select all walls with a specific area that are located on a certain location or a certain part of the site. If users, while allocating time information to activities, need to quickly review the values for a certain field in the attribute table for a layer, they can do that using the “Get Unique Values” option highlighted in Figure 5.12. This helps users to check for a certain value (e.g., a certain wall) they want to include in the query process. This module will be used to enter the time information for the TFs as well.

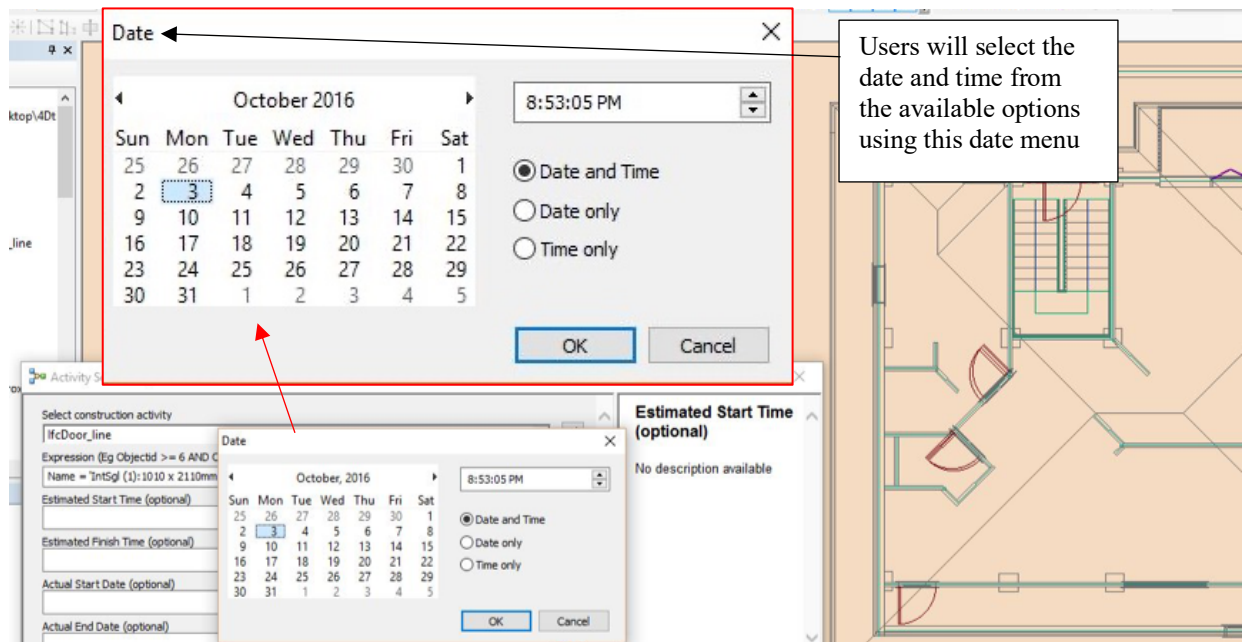


Figure 5.13: Selecting time to be added to features using the date menu in the ESTE module

5.5 Development of the 4D Visualization module

In this module, users will have to enable the time for the layers that contain the building components that they would like to display on screen before they use the Time Slider tool in ArcScene as shown in Figure 5.14. Users will have to set up the available options according to their needs, which include selecting the corresponding time fields, and time intervals for the sequence display on screen, whether to display feature classes cumulatively or just for the time they are onsite, etc. For example, some feature classes like walls and flooring have only Start Time;

thus, users should be able to get an option to skip the end date as some building components will always be there once the building is installed, unlike, for instance, tower cranes that will be removed after their job is done. Figures 5.15 and 5.16 show the options available in the Time Slider tool where users get to configure and set up the way they would like to review the 4D model and how it will be displayed on the screen. This include time interval and date and time format. Furthermore, by using this module, users can review the construction progress and, accordingly, confirm or make modifications to the construction execution plan and they can assign or modify the number of TFs required for an efficient construction process. In addition, users can select different start time and finish time fields such as estimated time or actual time and run the module to compare between the different scenarios of actual time construction simulation and estimated time construction simulation.

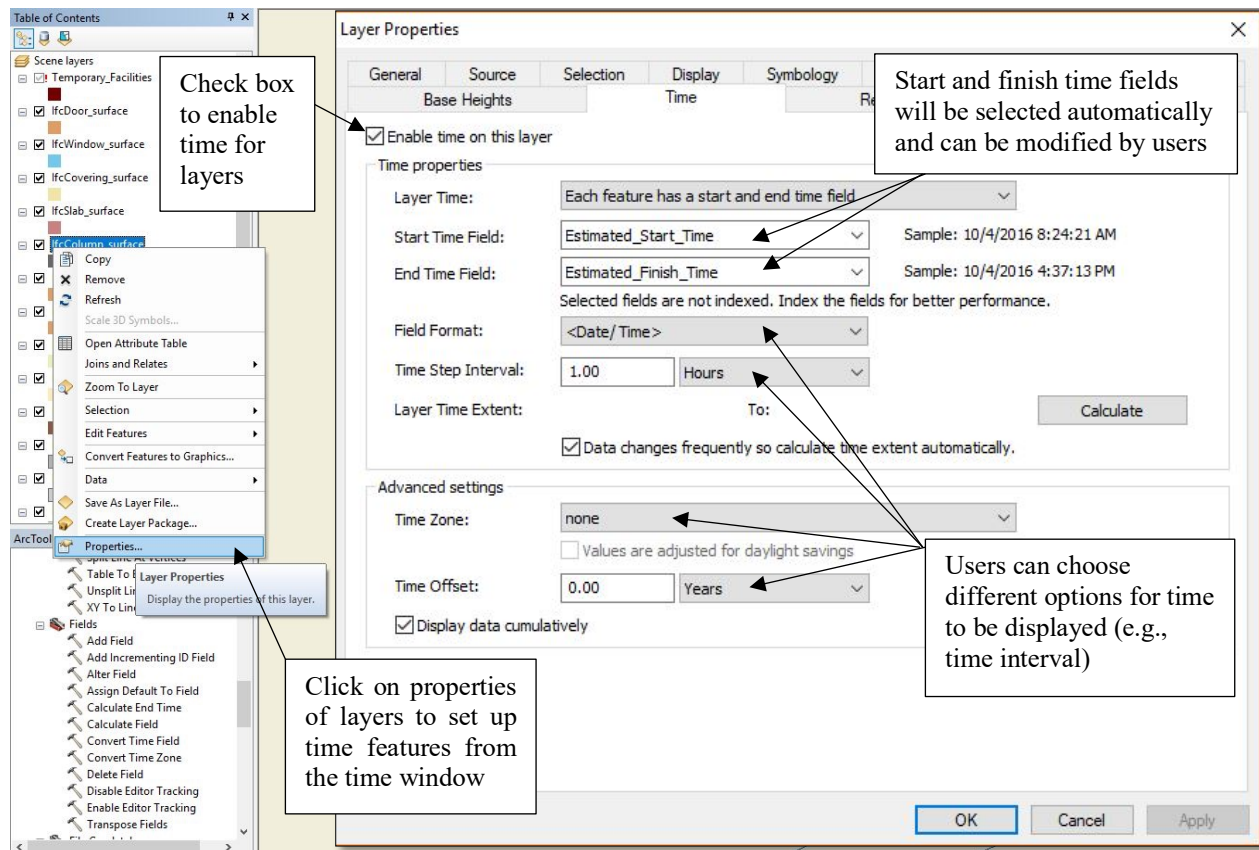


Figure 5.14: Enabling and configuring options of time for layers in GIS.

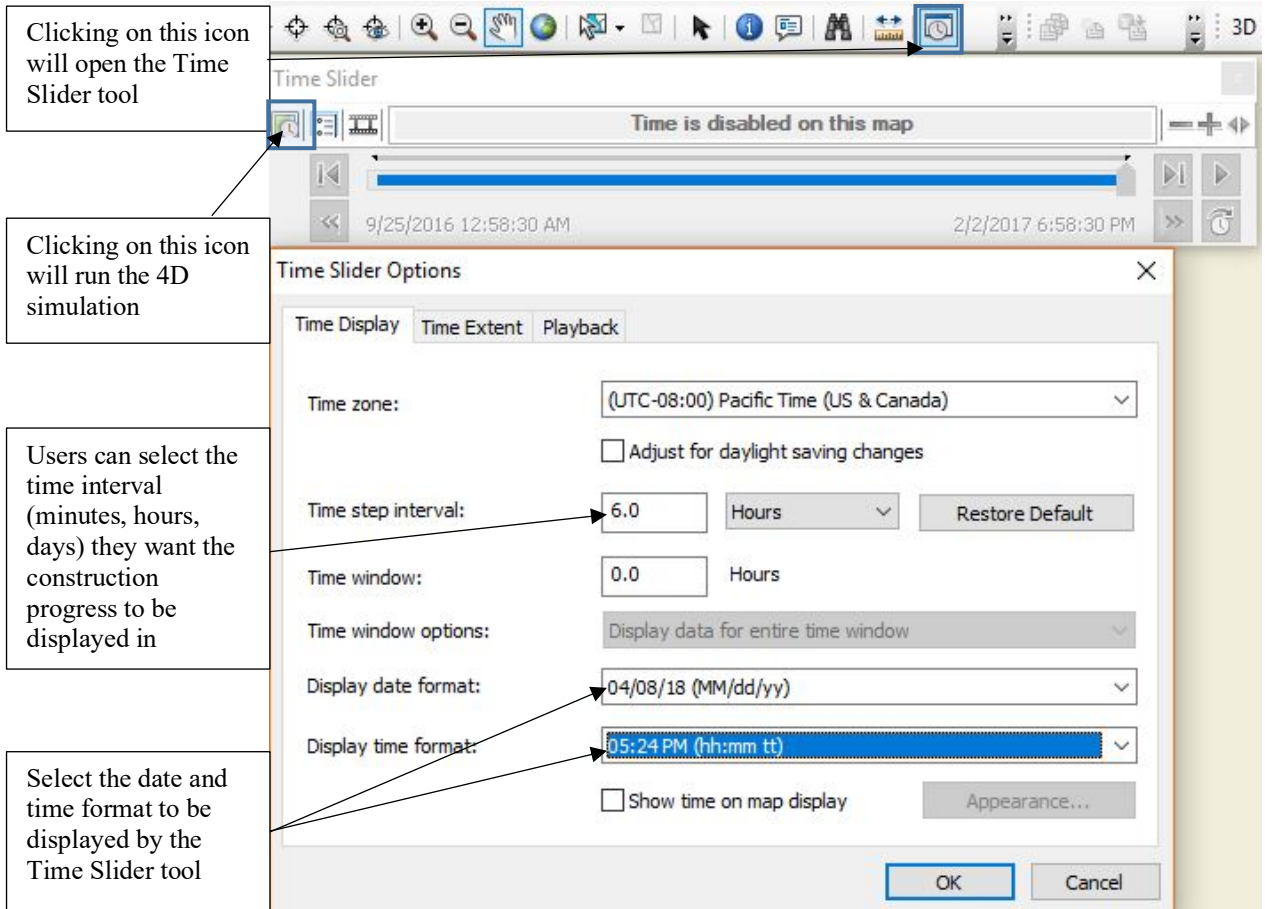


Figure 5.15: Options in the time slider tool

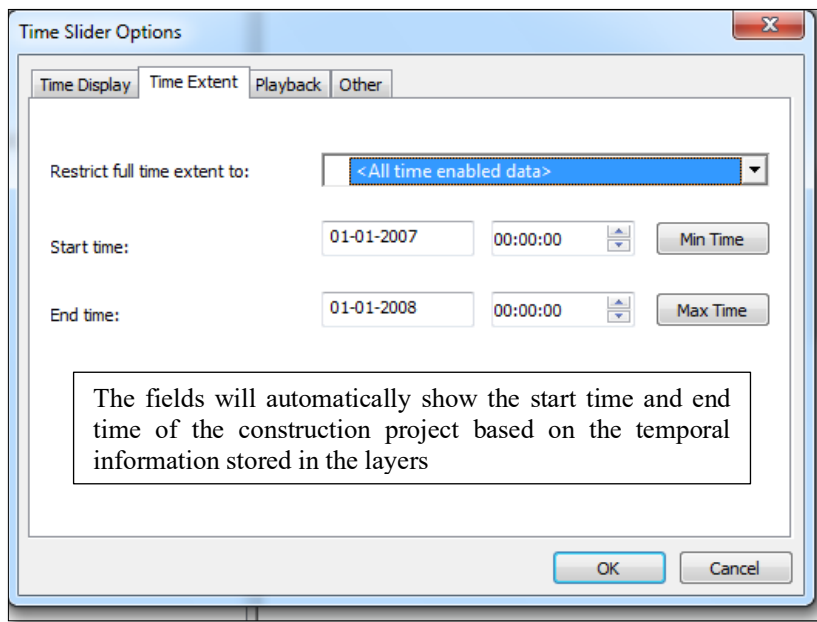


Figure 5.16: Time extent of the construction project

5.6 Development of the Temporary facilities library (TFL) module

Users will open the TFL from the created ArcSPAT tool extension as shown in Figure 5.17. Figure 5.18 shows the developed user interface (UI) of the temporary facilities library (TFL) and the tree hierarchy for the TFs it contains. When users use this module for the first time, they have to select the reference GDB for TFL and the output GDB for the site they want to plan as shown in Figure 5.19.

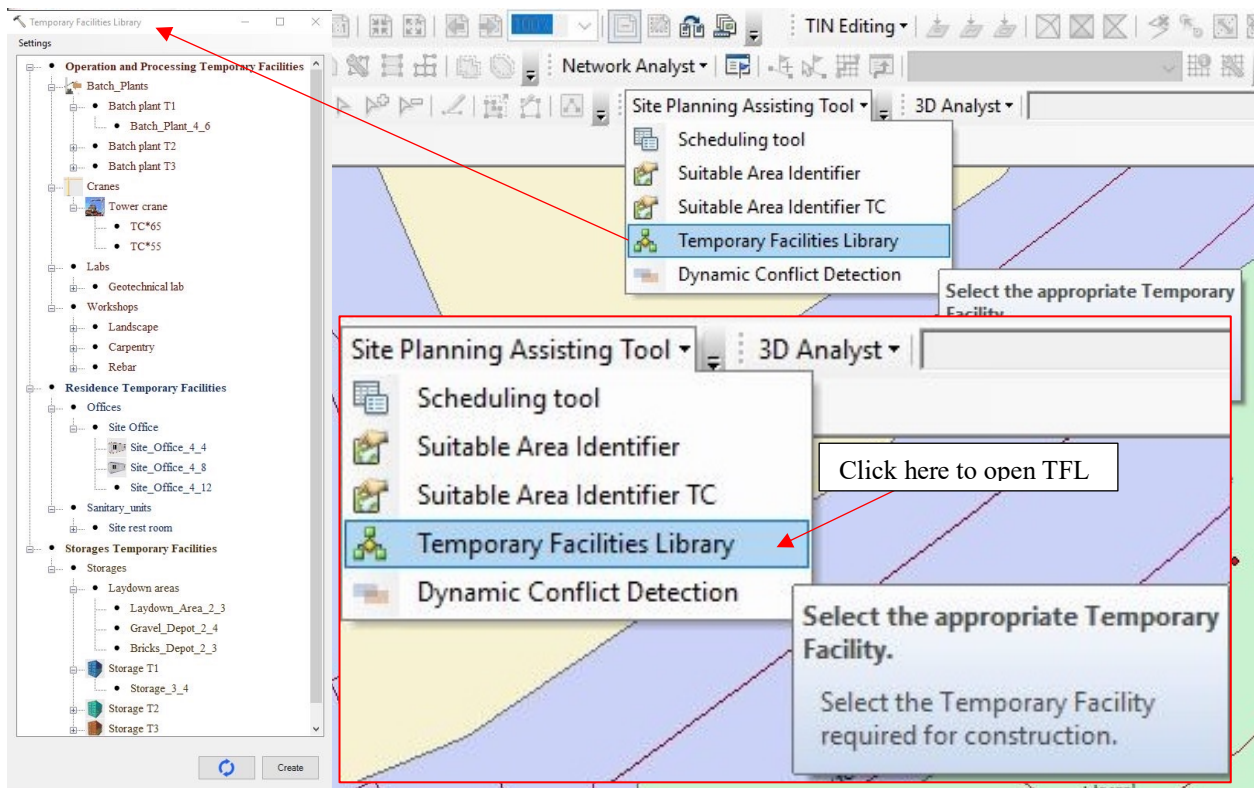


Figure 5.17: User interface (UI) for the TFL

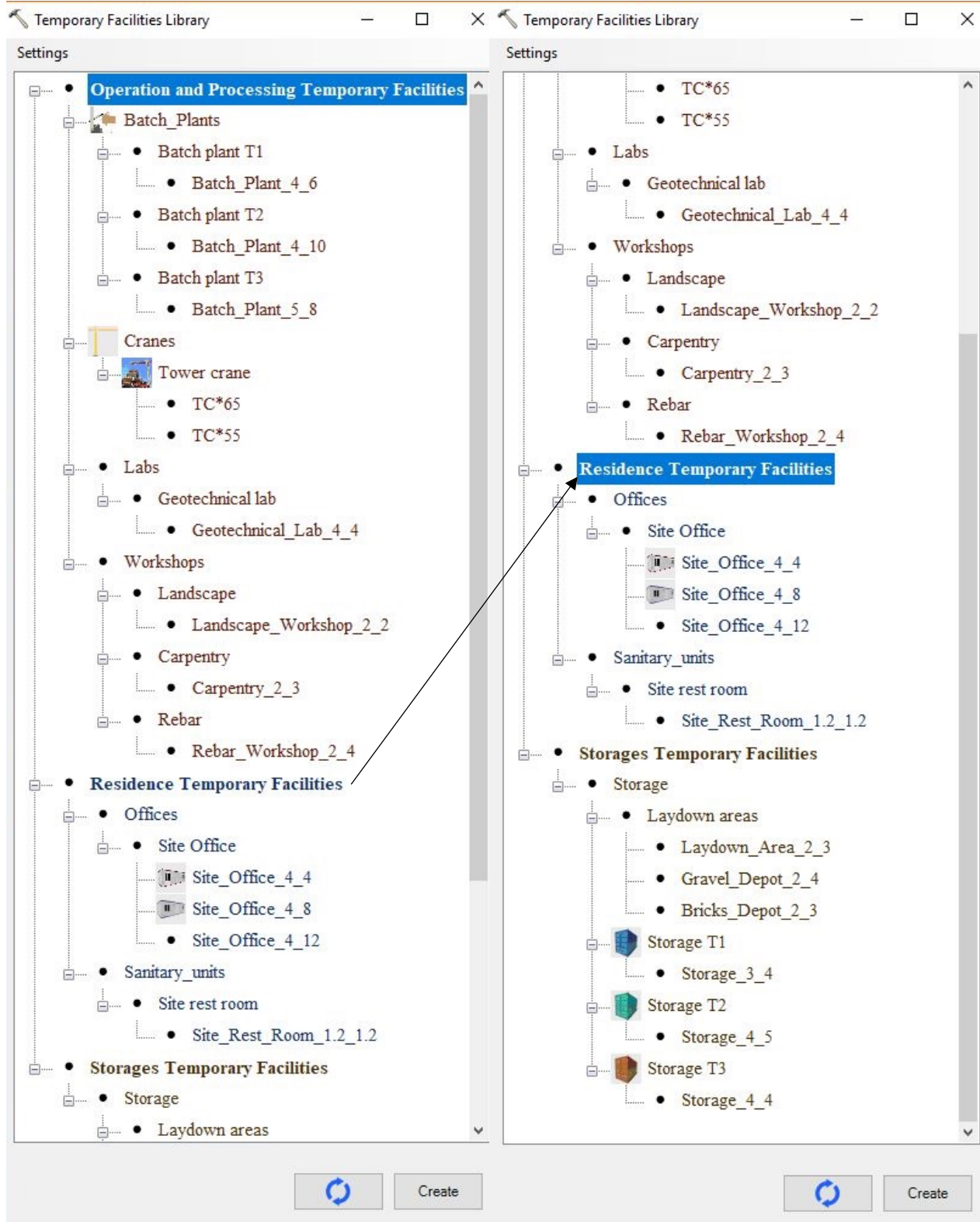


Figure 5.18: The developed user interface (UI) for the TFL

When users use this module for the first time, they have to select the reference GDB for TFL and the output GDB for the site they want to plan as shown in Figure 5.19. The selected path for reference GDB will be stored permanently in the UI of the TFL; however, the output GDB will be temporarily stored in the TFL main dialogue so that this step will not be repeated for the same project or during the same session of the planning process and this step is required for new projects (or planning process).

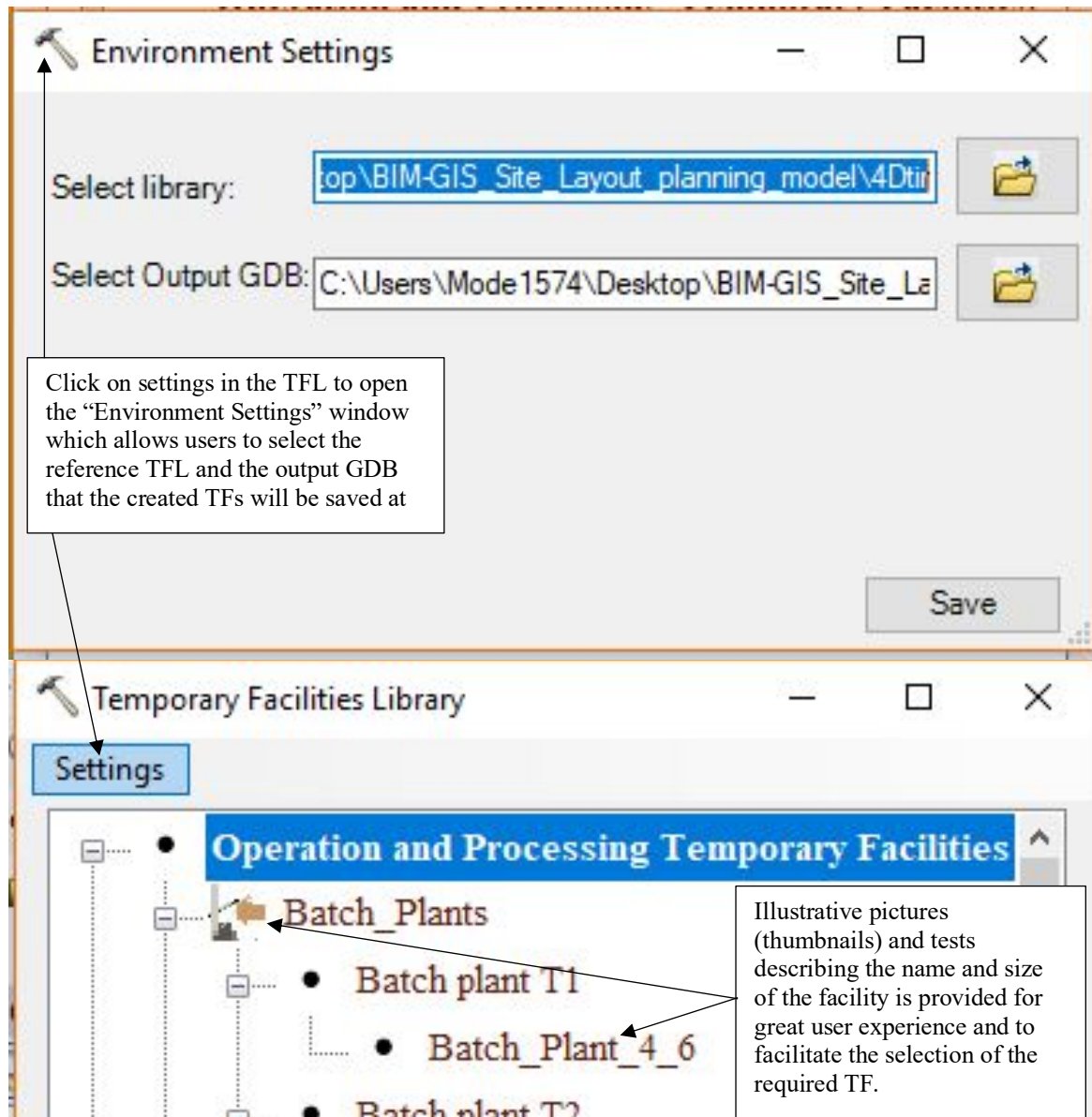


Figure 5.19: Selecting the reference GDB for TFL and the output GDB

Afterwards, users will follow the tree hierarchy in the TFL's UI to select the TFs required for the construction process, choose the location for the selected TFs onsite, and create them after clicking on the chosen place on the map where they want to position the selected TF (e.g., an office) as shown in Figure 5.20. At the back end, the selected TF from the reference GDB will be pasted in the output GDB along with its associated attributes. The centroid for the selected TF will be placed on the exact selected point on the map. Once users click on the save button, features (TFs) will be permanently stored in the output GDB under the related feature class (layer or family). The coordinate system for the placed TF will match the coordinate system of the file users are working on. There are two cases for allocating the coordinate system for the placed (imported) TF: 1) if there is no layer previously created, the model will create a layer (family) and add the selected TF to this family and allocate the same coordinate system of the reference GDB for the TFL; 2) if a layer exists, the model will add the selected TF to that layer and copy the coordinate system of that layer so that all the TFs contained within it have the same coordinate system. All this is done automatically.

Figure 5.21 shows the geometry of the TFs included in the TFL while Figures 5.22 and 5.23 show the information included in the attribute table of every TF included in the TFL. Users can edit the geometries of the TFs as needed without compromising the functionality of the presented SLP model in predicting time-space conflicts. Also, users can save the modified TF to be used for other prospective projects. Users will also have an option to modify the existing parameters (e.g., safety distance, etc.) for any of the TFs included in the TFL.

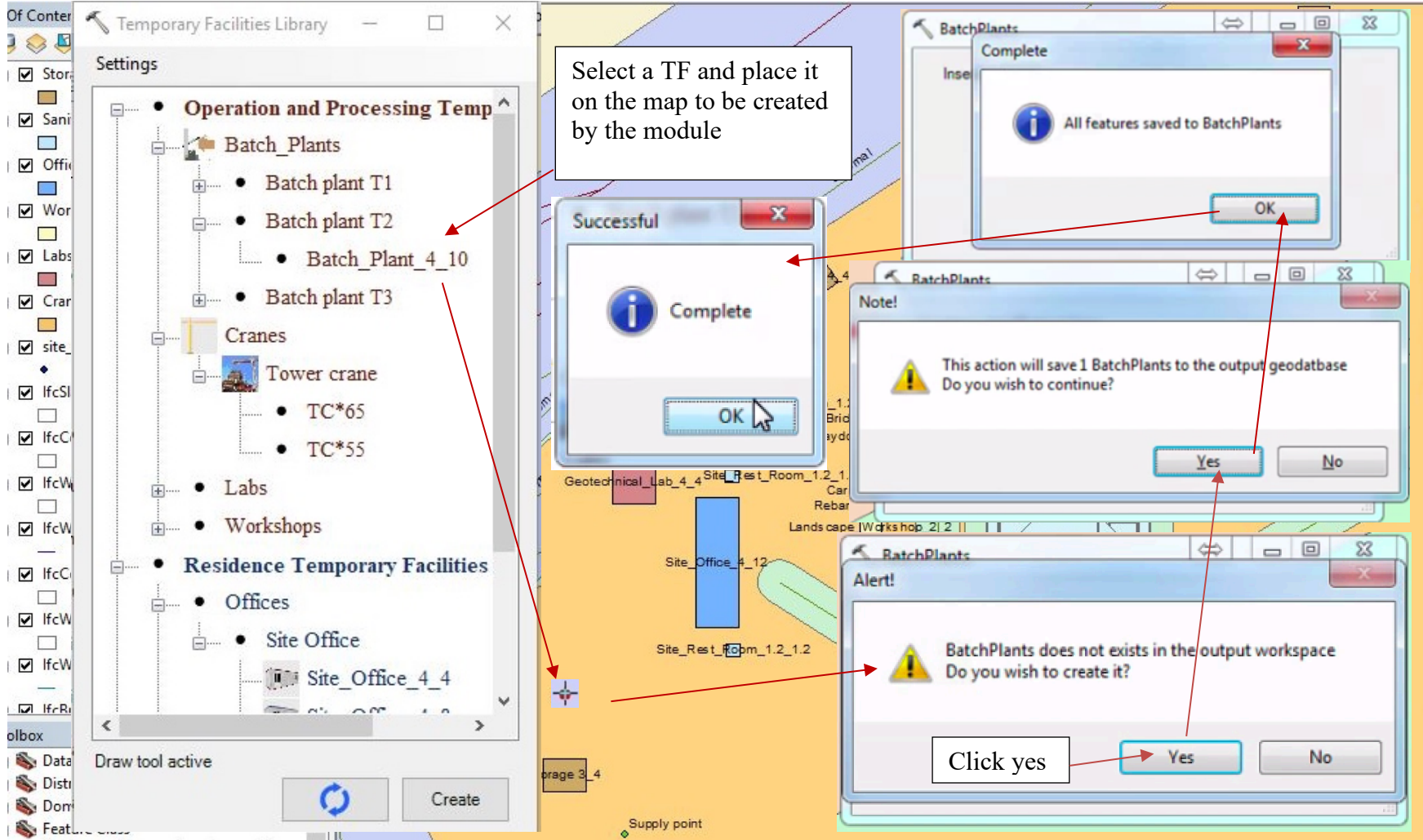


Figure 5.20: Creating temporary facilities using the TFL model

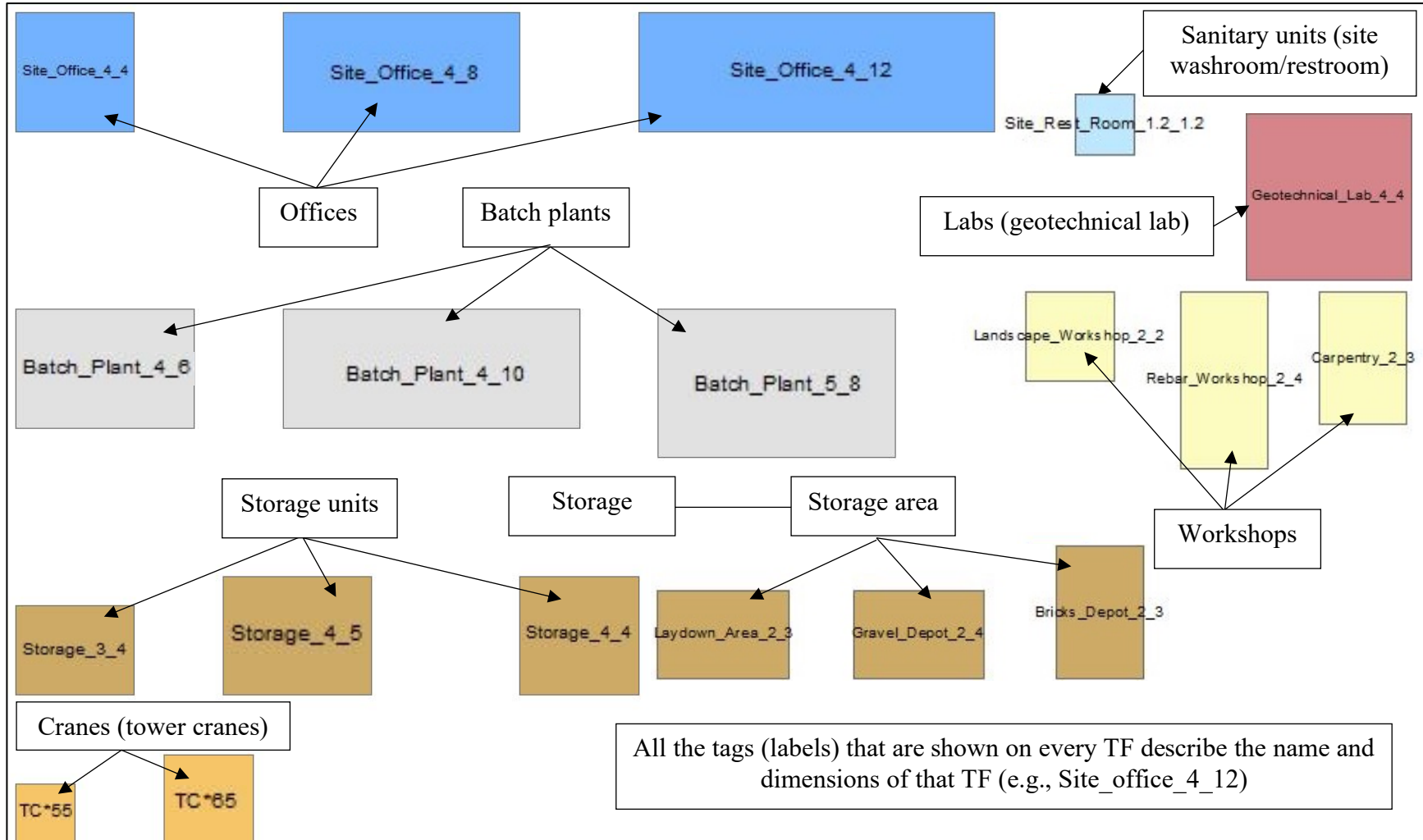


Figure 5.21: Temporary facilities (TFs) included in the temporary facilities library (TFL)

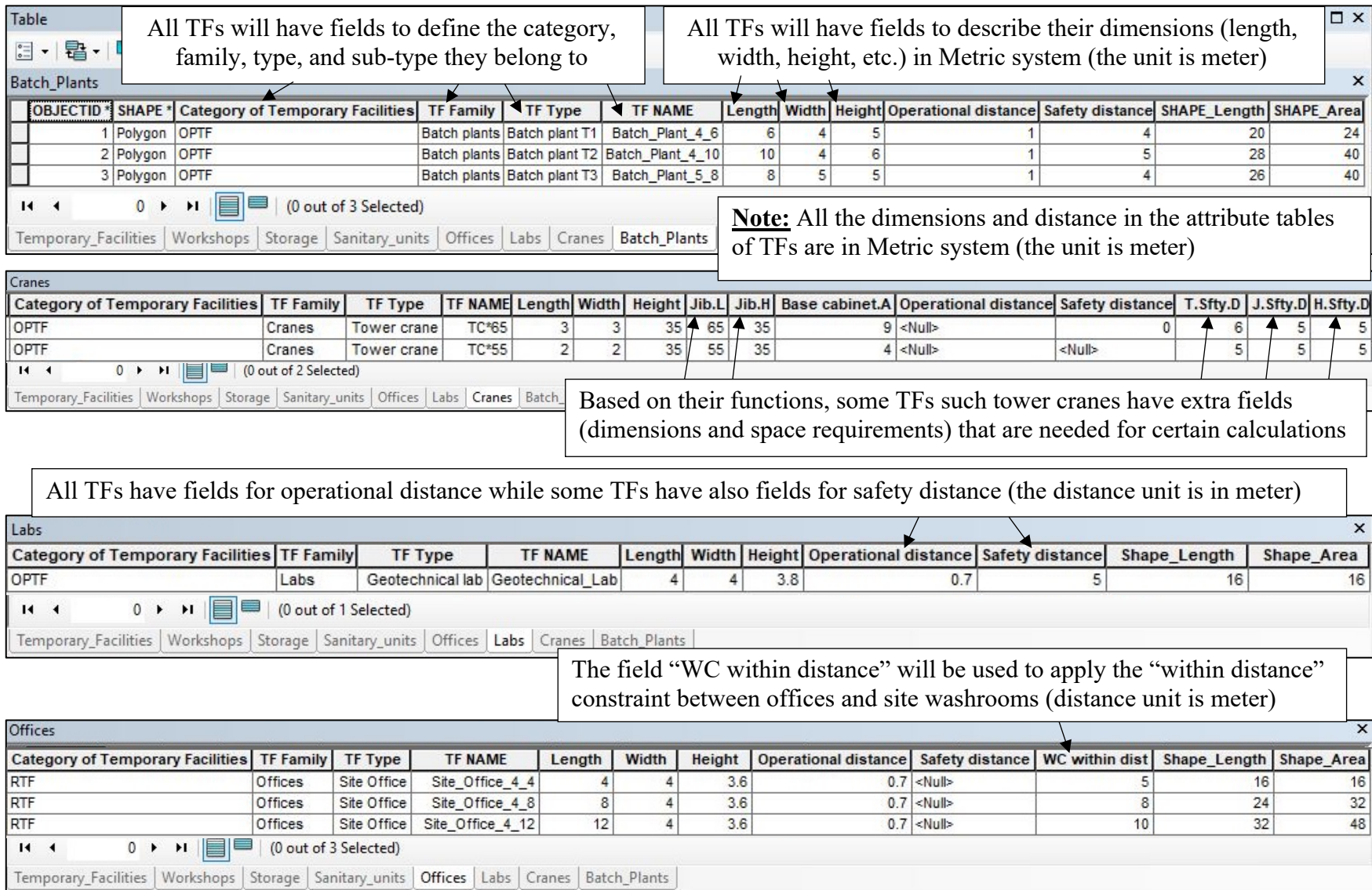


Figure 5.22: Attribute tables of the TFs included in the TFL (1 of 2)

| Category of Temporary Facilities | TF Family | TF Type | TF NAME | Length | Width | Height | Operational distance | Safety distance | Shape_Length | Shape_Area |
|----------------------------------|----------------|----------------|------------------------|--------|-------|--------|----------------------|-----------------|--------------|------------|
| RTF | Sanitary_Units | Site rest room | Site_Rest_Room_1_2_1_2 | 1.2 | 1.2 | 2.2 | 0.7 | 0 | 4.8 | 1.44 |

Note: All the dimensions and distance in the attribute tables of TFs are in Metric system (the unit is meter)

The field “Material status” will be used by the DCD module to determine the whether or not the stored materials are combustive and based on that status the module will select appropriate field to participate in applying the “minimum distance” constraint between combustive storage and offices as explained in chapter 4

| Category of Temporary Facilities | TF Family | TF Type | TF NAME | Length | Width | Height | Operational distance | Safety distance | Material status | Sfty.D frm ofcs | Shape_Length | Shape_Area |
|----------------------------------|-----------|--------------|------------------|--------|-------|--------|----------------------|-----------------|--------------------------|-----------------|--------------|------------|
| STF | Storages | Laydown area | Laydown_Area_2_3 | 3 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 |
| STF | Storages | Laydown area | Bricks_Depot_2_3 | 4 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 |
| STF | Storages | Laydown area | Gravel_Depot_2_4 | 3 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 |
| STF | Storages | Storage T1 | Storage_3_4 | 4 | 3 | 3.6 | 0.7 | 15 | Combustive materials | 15 | 14 | 12 |
| STF | Storages | Storage T2 | Storage_4_5 | 5 | 4 | 4 | 0.7 | 0 | Non-combustive materials | <Null> | 18 | 20 |
| STF | Storages | Storage T3 | Storages_4_4 | 4 | 4 | 3.6 | 0.7 | 0 | Non-combustive materials | <Null> | 16 | 16 |

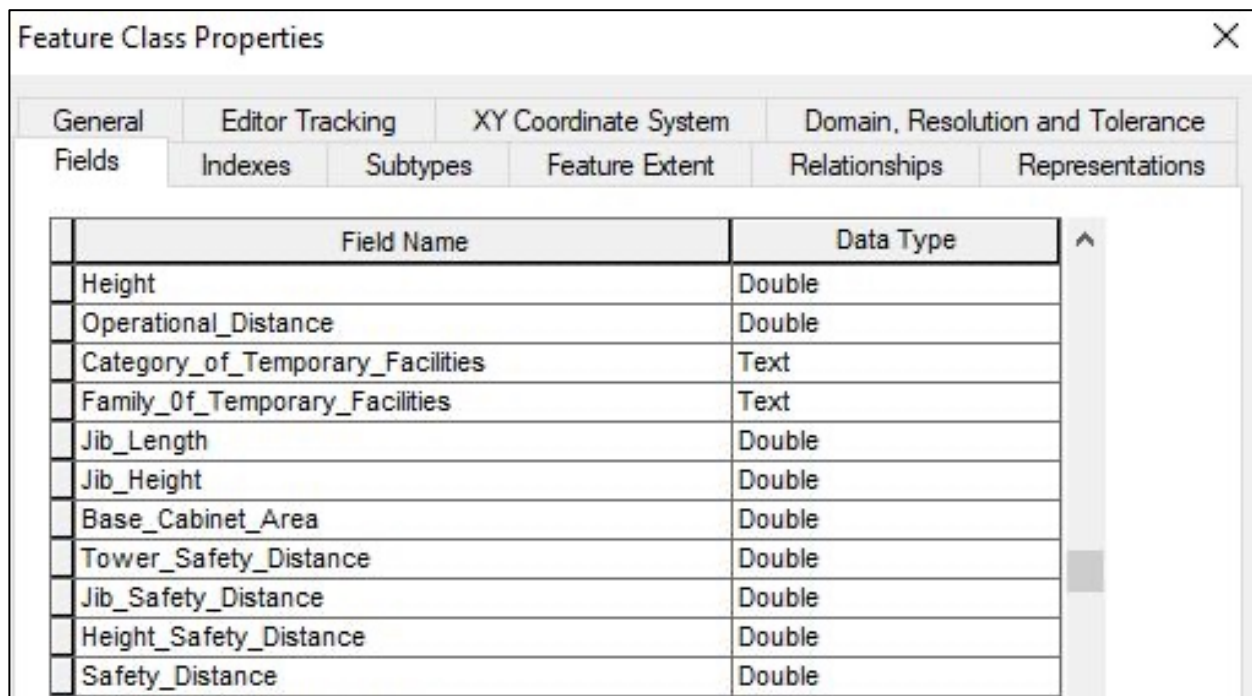
In case the material status is “combustive materials”, the field of “safety distance from offices” will be selected otherwise, the “safety distance” field will be selected

The fields for shape length (perimeter) and shape area will be updated automatically in case users modified the TF’s geometry. Any modification to the geometry will not affect or impede the functions of the DCD module

| Category of Temporary Facilities | TF Family | TF Type | TF NAME | Length | Width | Height | Operational distance | Safety distance | Shape_Length | Shape_Area |
|----------------------------------|-----------|-----------|------------------------|--------|-------|--------|----------------------|-----------------|--------------|------------|
| OPTF | Workshops | Landscape | Landscape_Workshop_2_2 | 2 | 2 | 1.8 | 0.7 | 0 | 8 | 4 |
| OPTF | Workshops | Carpentry | Carpentry_2_3 | 3 | 2 | 1.8 | 0.7 | 0 | 10 | 6 |
| OPTF | Workshops | Rebar | Rebar_Workshop_2_4 | 4 | 2 | 1.8 | 0.7 | 0 | 12 | 8 |

Figure 5.23: Attribute tables of the TFs included in the TFL (2 of 2)

The data type of every field in the attribute is depending on the function of that field. For instance, for names (e.g., the name of the category or the family of a certain TF that belong to) the data type of the associated fields is selected as “Text”, while for some fields it will be used for calculation, such as safety distance or operational distance, the data type of the associated fields is selected as “Double”, which is a numerical type of data. This organization is used for all the TFs that are categorized under one family (feature class or layer). Figure 5.24 shows the data type for some of the fields created for the family (layer) of cranes. All the values for operational distance and safety distance can be modified by users and will be used by the DCD module when applying the predefined rules for constraints and constriction between site objects.



| Field Name | Data Type |
|----------------------------------|-----------|
| Height | Double |
| Operational_Distance | Double |
| Category_of_Temporary_Facilities | Text |
| Family_Of_Temporary_Facilities | Text |
| Jib_Length | Double |
| Jib_Height | Double |
| Base_Cabinet_Area | Double |
| Tower_Safety_Distance | Double |
| Jib_Safety_Distance | Double |
| Height_Safety_Distance | Double |
| Safety_Distance | Double |

Figure 5.24: Data type of the created fields in the attribute table of the TFs

In addition, in this module users can identify a suitable and available area on the construction site by using the developed tool called SAI (suitable area identifier). Figure 5.25 shows the development of the SAI using the ModelBuilder in ArcGIS while Figure 5.26 shows the developed UI for the SAI, which will use the input layers (i.e., roads, building, and site objects).

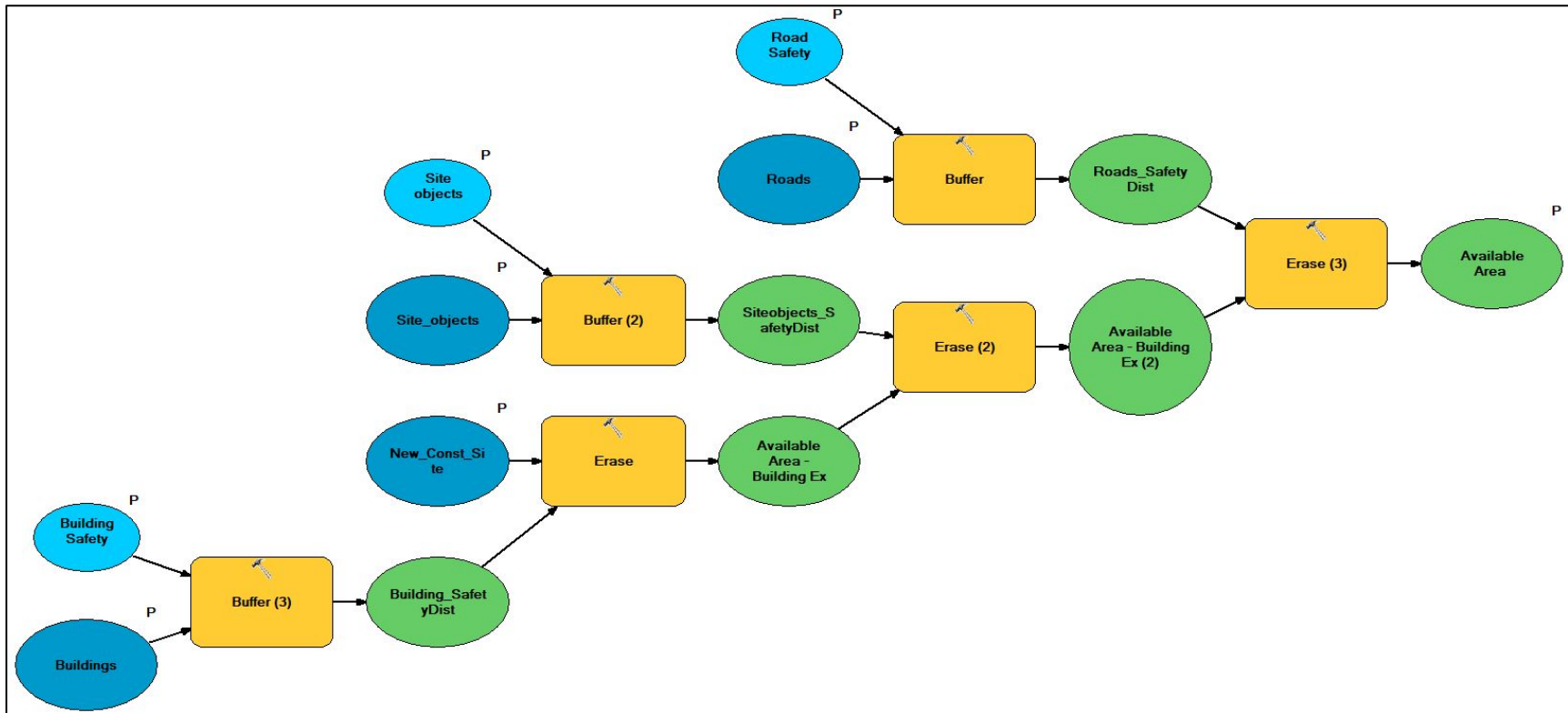


Figure 5.25: Development of the SAI using the ModelBuilder in ArcGIS

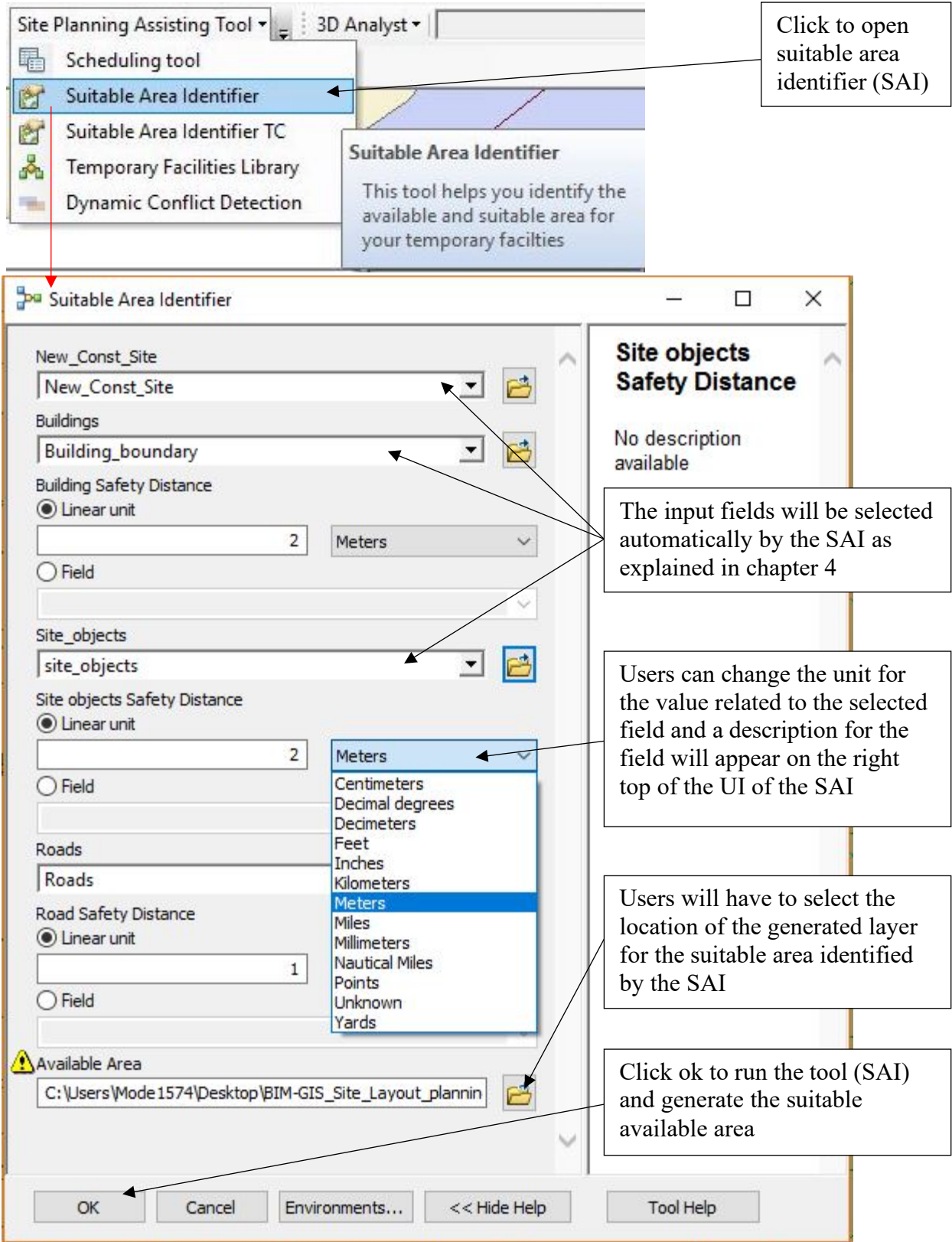


Figure 5.26: UI for the suitable area identifier (SAI).

The developed SAI tool will automatically identify the required input layers (i.e., building area, roads, and site objects) required by the tool for the process to generate the suitable area. Users can check and modify, if needed, the values assigned for the safety distance required for the different input layers and then click ok to generate the suitable area onsite. Users will select the default path for the file (e.g., geodatabase) where the layer for the generated SA will be saved.

Moreover, in this module, users can identify the suitable area for specific TFs such as tower cranes (TCs) by using the developed tool called SAITC (suitable area identifier for tower cranes). Figure 5.27 shows the development of the SAITC using the ModelBuilder in ArcGIS.

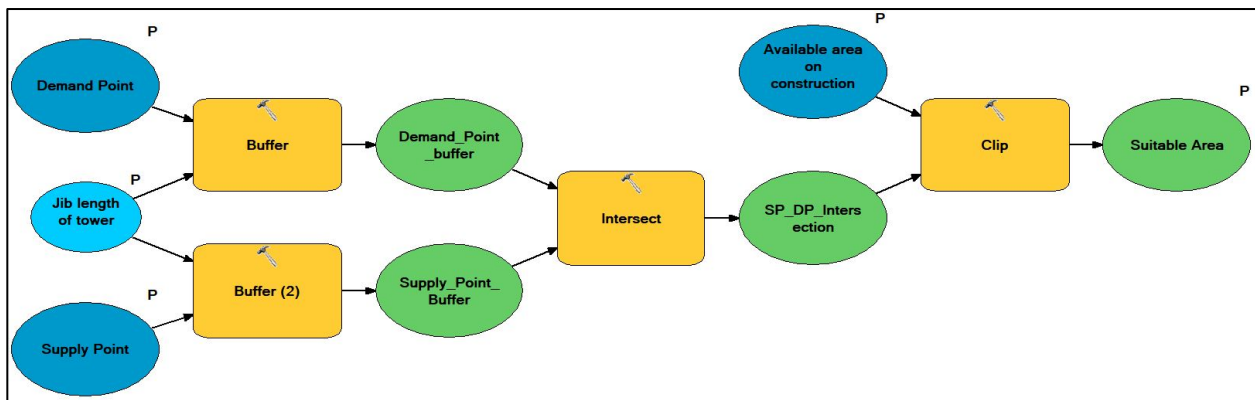


Figure 5.27: Development of the SAITC using the ModelBuilder in ArcGIS

Figure 5.28 shows the created UI for the developed tool, which will automatically identify the layers required for this process (i.e., suitable area and the supply and demand points). Afterwards, users will enter the jib length of the TC they want for the project and click “ok” to identify the suitable area (SATC) for that tower crane. The generated suitable area for TC can be too large depending on the length of the jib for the selected TC. This will give users an indication that the TC they selected for the project is larger than what might actually be needed for the construction process, in this case, users can select a smaller TC and use the module again to identify the new suitable area for the smaller TC. Also, the lifting capacity for a TC changes based on the length of the jib as it increases as the jib length gets shorter and vice versa. Users can identify the suitable

area for a TC, not only based on the maximum jib length, but also based on any length they decide is appropriate, such as the minimum jib length, for finishing the task for which they need the TC and generate the suitable area based on that length. In addition, it is possible that the module does not generate a suitable area for the selected TC based on the maximum jib length, this gives users an indication that one TC is not enough to cover the target tasks and accordingly a bigger TC or more than one TC may be required to cover those tasks. This shows that the module can also help users decide and select the number and type or size of some of the TFs that they require to support the construction process such as tower cranes.

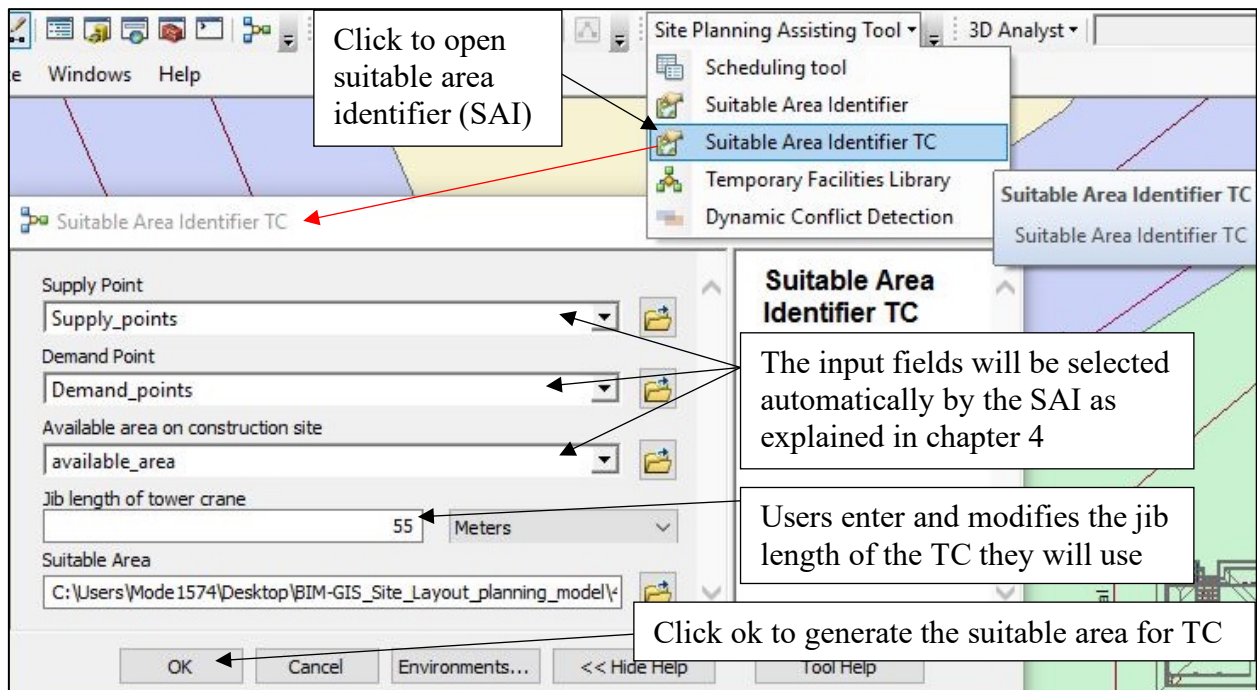


Figure 5.28: UI for the suitable area identifier for tower cranes (SAITC).

Furthermore, the presented BIM-GIS SLP model can provide users with various information such as topographical and soil information, which will help users to make better judgments on locating the supply and demand points as well as some of the TFs (e.g., storage areas, laydown areas, etc.) on a construction site. Figure 5.29 shows the boreholes conducted for the Ottawa-Gatineau area in Ontario, Canada.

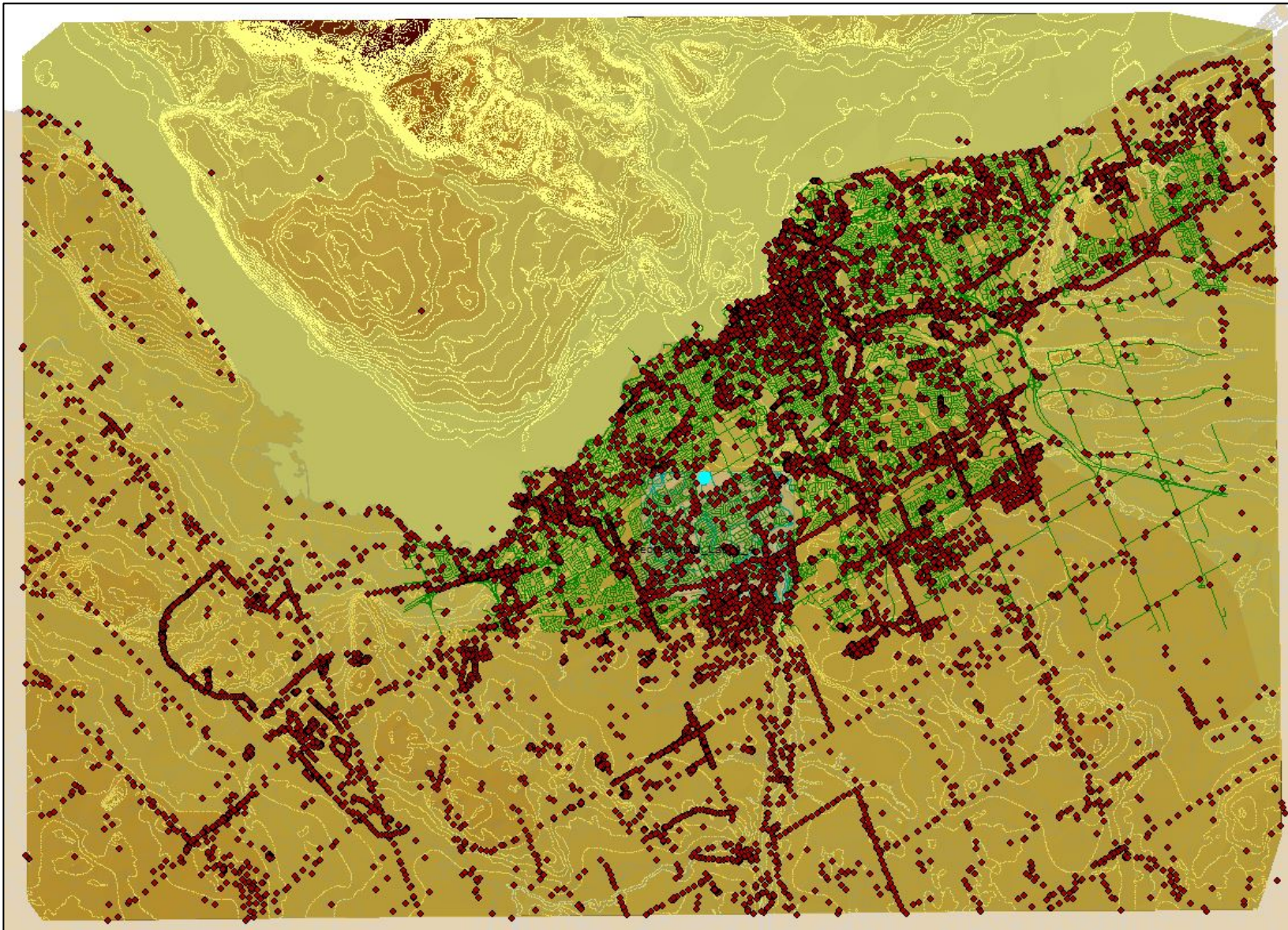


Figure 5.29: Boreholes conducted for the Ottawa-Gatineau area

Figures 5.30 and 5.31 shows soil information gathered from selected boreholes that are close to the Ottawa area (Agriculture and Agri-Food Canada, 2019), which can be used by users to make efficient choices on the aforementioned task. In addition, Figure 5.32 shows some of the soil information for the Ottawa-Gatineau area (in Canada) from a detailed soil survey (DSS) (Agriculture and Agri-Food Canada, 2013) that also can be used by users to make informed decisions on the previously mentioned task. This includes information about the surface slope degree, water table, drainage, types and names of the existing soil, etc. Moreover, Figure 5.33 shows the TIN layer, which visualizes the topographical information for the site to show the difference in terrain and elevation. Users can use topographical and soil data gathered from authorized and specialized sources such as the sources used in this study (i.e., Agriculture and Agri-Food Canada, 2013; Ontario Ministry of Energy, 2017; and Agriculture and Agri-Food Canada, 2019) and provided in the integrated model or they can add their own soil data to the map. The integrated model enables users to visualize, retrieve and query the topographical and soil information they require about the different locations and points on the construction site, which allow them to choose more appropriate locations to place the TFs selected from the TFL on the map. Furthermore, users can use the model to export the soil information they require in multiple output types including report (textual), MS access database (tabular), and graphical (graphs), as shown in Figure 5.34. This is one of the model's capability to provide users with a data-rich environment that includes information about the building, transportation network, and topographical and soil information that will support their decision while planning the site layout and locating the supply and demand points and selecting the appropriate temporary facility for supporting the construction process. Also, the integrated model provides a unified environment where users can import and use available GIS data and/or create and include their own data.

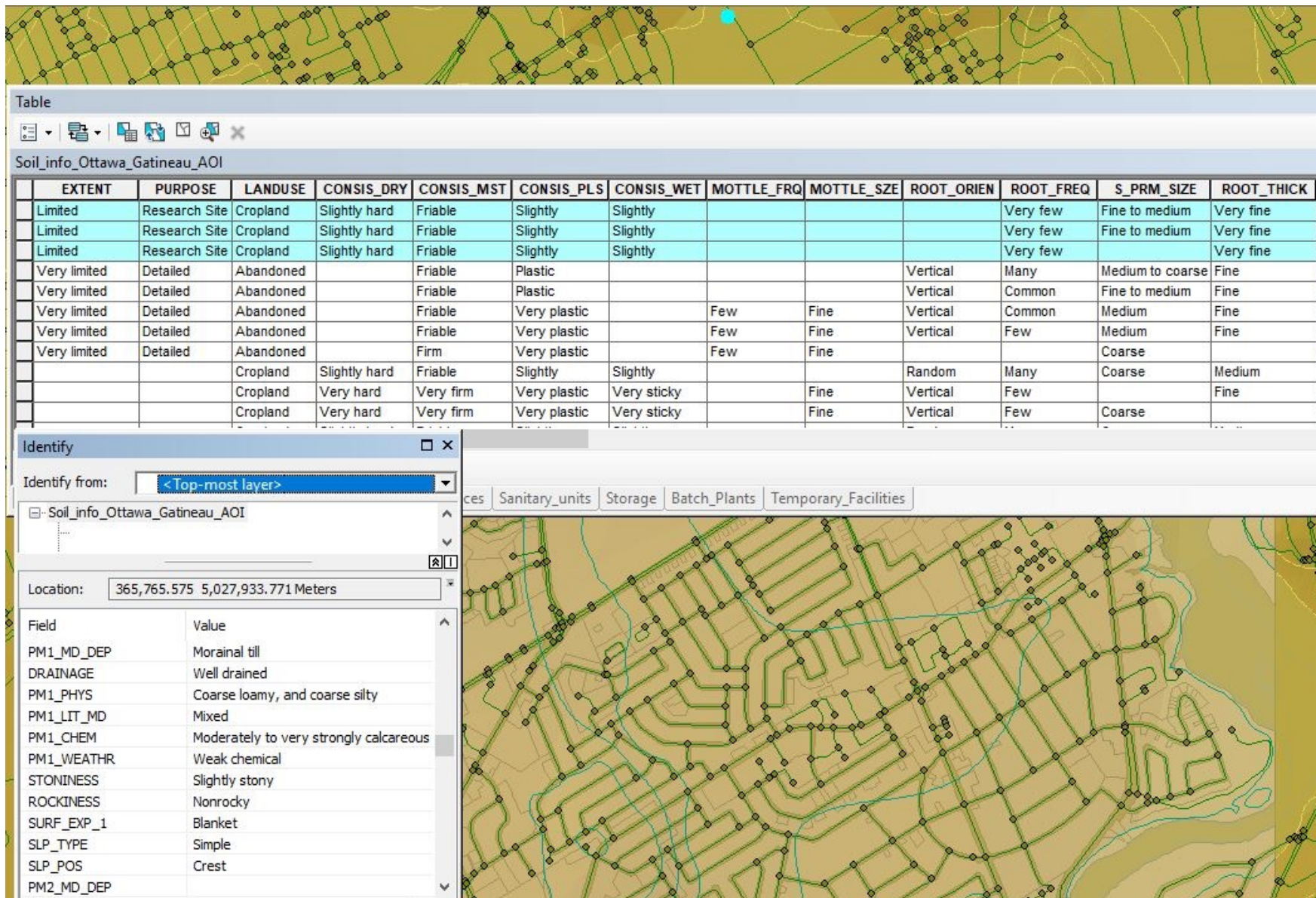


Figure 5.30: Some of the soil information included in the boreholes

| Soil_info_Ottawa_Gatineau_AOI | | | | | | | | | | | |
|-------------------------------|----------------|----------------------------|--------------------------------------|------------------------------|---------------|-----------|----------|------------|----------|---------|-------|
| PM1_MD_DEP | DRAINAGE | PM1_PHYS | PM1_LIT_MD | PM1_CHEM | PM1_WEATHR | STONINESS | ROCKINES | SURF_EXP_1 | SLP_TYPE | SLP_POS | SLP_A |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |

Figure 5.31: Some of the soil information included in the boreholes

| Table | | | | | | | | | | | | | |
|---------------------------|--------------|---------|---------|-----------|-----------|----------|----------|-----|-------|-------|-------|----------|--|
| dss_v3_on_Ottawa_Gatineau | | | | | | | | | | | | | |
| SURVEY | SOILNAME | PROFILE | SLOPE_P | SLOPE_LEN | STONINESS | WATERTBL | DRAINAGE | CLI | CLI_1 | CLI_2 | HYDRO | ATEXTURE | |
| OTTAWA CARLETON | UNCLASSIFIED | N | -9 | -9 | - | YU | - | | | | - | - | |
| OTTAWA CARLETON | UNCLASSIFIED | N | -9 | -9 | - | YU | - | | | | - | - | |
| OTTAWA CARLETON | JOCKVALE | A | 1.2 | -9 | 0 | NO | W | 3 | F | | A | LFS | |
| OTTAWA CARLETON | CARSONBY | A | 1.2 | -9 | 0 | YB | P | 2 | W | | C | SIL | |
| OTTAWA CARLETON | UNCLASSIFIED | N | 1.2 | -9 | 0 | YU | P | 2 | W | | D | SIL | |
| OTTAWA CARLETON | MILLE ISLE | A | 3.5 | -9 | 0 | NO | W | 4 | F | M | A | LS | |
| OTTAWA CARLETON | ERODED | N | 37.5 | -9 | 1 | YU | W | 7 | T | | - | - | |
| OTTAWA CARLETON | DALHOUSIE | A | 3.5 | -9 | 0 | YU | I | 2 | D | T | D | SICL | |
| OTTAWA CARLETON | UNCLASSIFIED | N | -9 | -9 | - | YU | - | | | | - | - | |
| OTTAWA CARLETON | CARLSBAD | A | 7 | -9 | 0 | NO | W | 4 | F | M | A | LS | |
| OTTAWA CARLETON | DALHOUSIE | A | 3.5 | -9 | 0 | YU | I | 2 | D | T | D | SICL | |

Figure 5.32: Some of the soil information included in the DSS

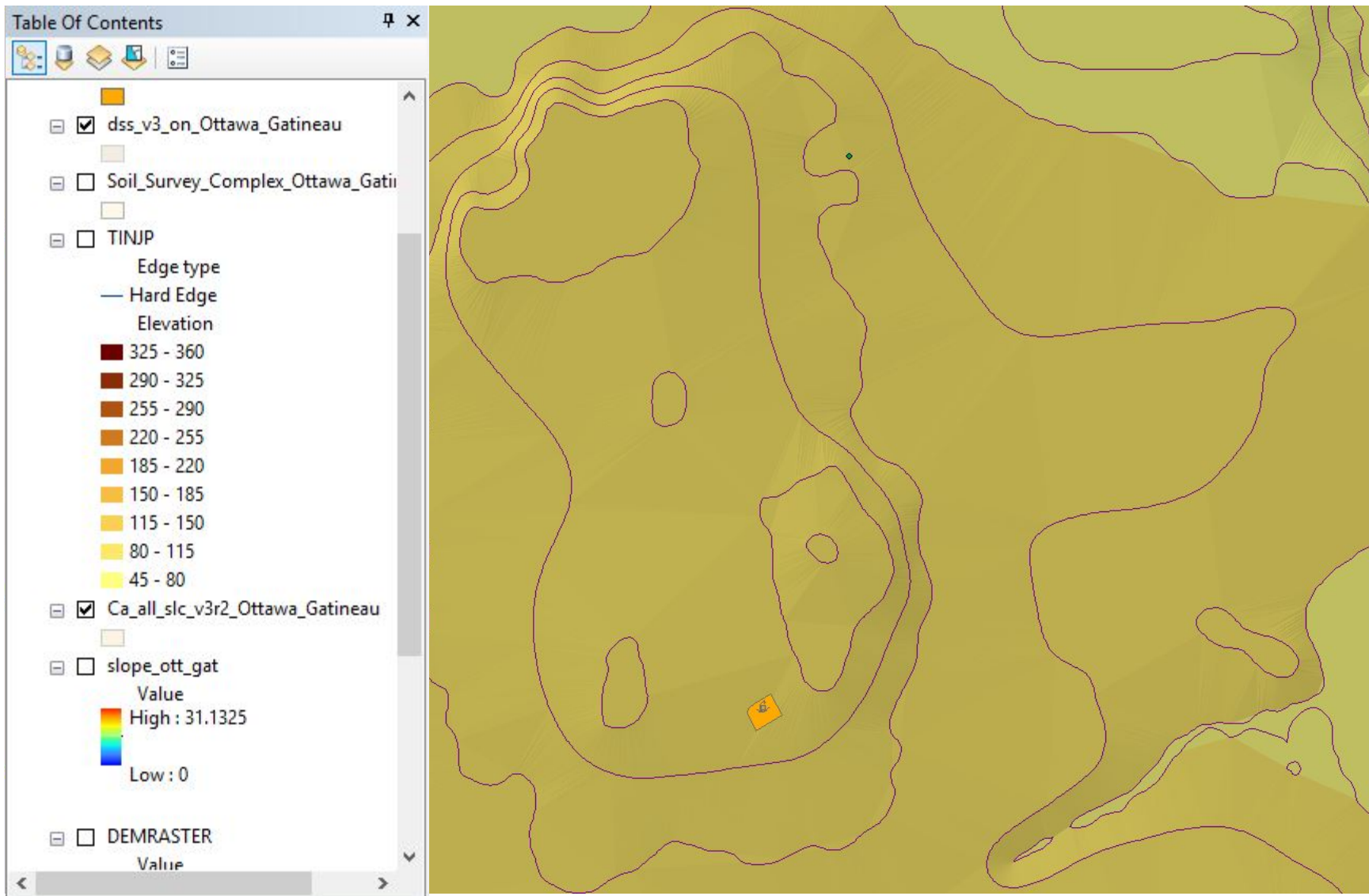


Figure 5.33: TIN layer for the construction site shows the difference in terrain and elevation

The screenshot displays a GIS application window with a 'Table' of soil data. The table has columns for various soil properties. A 'Table Of Contents' window is open at the top left. A 'Table' window is open in the center, showing a list of soil samples with their attributes. A 'Table' toolbar is visible above the table, and an 'ArcToolbox' is open on the left side. Three callout boxes provide instructions on how to use the 'Create Graph', 'Reports', and 'Export' tools.

| PROVINCE | CAL_YEAR | PURPOSE | CON SIS_DRY | CON SIS_MST | CON SIS_PL S | CON SIS_WET | MOT TLE_FRQ | MOT TLE_SIZE | ROO T_FREQ | ROO T_LOCTN | ROO T_ORIEN | ROO T_THICK | S_PR M_GRAD | S_PR M_KIND | S_PR M_MOD | S_PR M_SIZE | DRAINAG |
|----------|----------|---------------|-------------|-------------|--------------|-------------|-------------|--------------|------------|-------------|-------------|-------------|-------------|----------------|------------|----------------|--------------|
| tario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| tario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| tario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| tario | 1975 | | Very hard | Very firm | Very plastic | Very sticky | Many | Fine | Common | Exped | Vertical | Fine | Moderate | Angular blocky | | | Poorly drain |
| tario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Common | Exped | Vertical | Fine | None | | | | Moderately |
| tario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Few | Exped | Vertical | Fine | None | | | | Moderately |
| tario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| tario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| tario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| tario | 1976 | Research Site | Very hard | Firm | Plastic | Sticky | | | | | | | | Angular blocky | Pseudo | Fine to medium | Moderately |

Click to produce charts (e.g., vertical charts or pie charts)

Click to produce reports

Click to export the attribute table as a new table that can be opened by database software such as MS Access

Figure 5.34: Different outputs for soil information can be generated by the integrated model

5.7 Development of the Dynamic Conflict Detection (DCD) module

The developed user interface (UI) for the developed DCD tool/application is shown Figure 5.35. Users will open the DCD application and select the current GDB for the site layout plan they are working on to check for potential conflicts, as shown in Figure 5.35. Also, users can modify the safety distance parameters related to the IFC building components from the IFC safety distance dialogue as shown in Figure 5.35. In addition, users will select a name and location to save the conflict report, which is generated by the DCD tool. Afterwards, users will click on the “Detect conflicts” button to start the dynamic conflict detection process for the site layout plan, then the DCD module will run and notify users if any conflicts are detected with a short message, in case conflicts are detected, it will ask users to check the generated conflict report generated. The site objects in conflict will be highlighted on both the screen and their attribute tables. Some TFs may have more than one conflict and probably with different levels of risk. In this case, all the different conflicts will be included in the conflict report as shown in Figure 5.36, however only the attributes associated with the highest level of risk between the detected conflicts for that TF will be visualized on the map and included in the attribute table for that TF. Figure 5.36 provides explanations for the conflict report that is generated by the module. The DCD module assists users to detect conflicts in 2D and 3D during the whole project’s duration by using a rule-based dynamic conflict detection (DCD) tool. Parts of the development code for the DCD tool are presented in this paragraph to show how the constraints and restrictions rules between the site objects are incorporated in the DCD module however, the complete coding for the developed tool for the DCD module and the TFL module is provided in appendix I of this thesis. Part of the code that describes how the module identifies time-space overlap between two site objects for all the different cases of time overlap is shown in Figure 5.37.

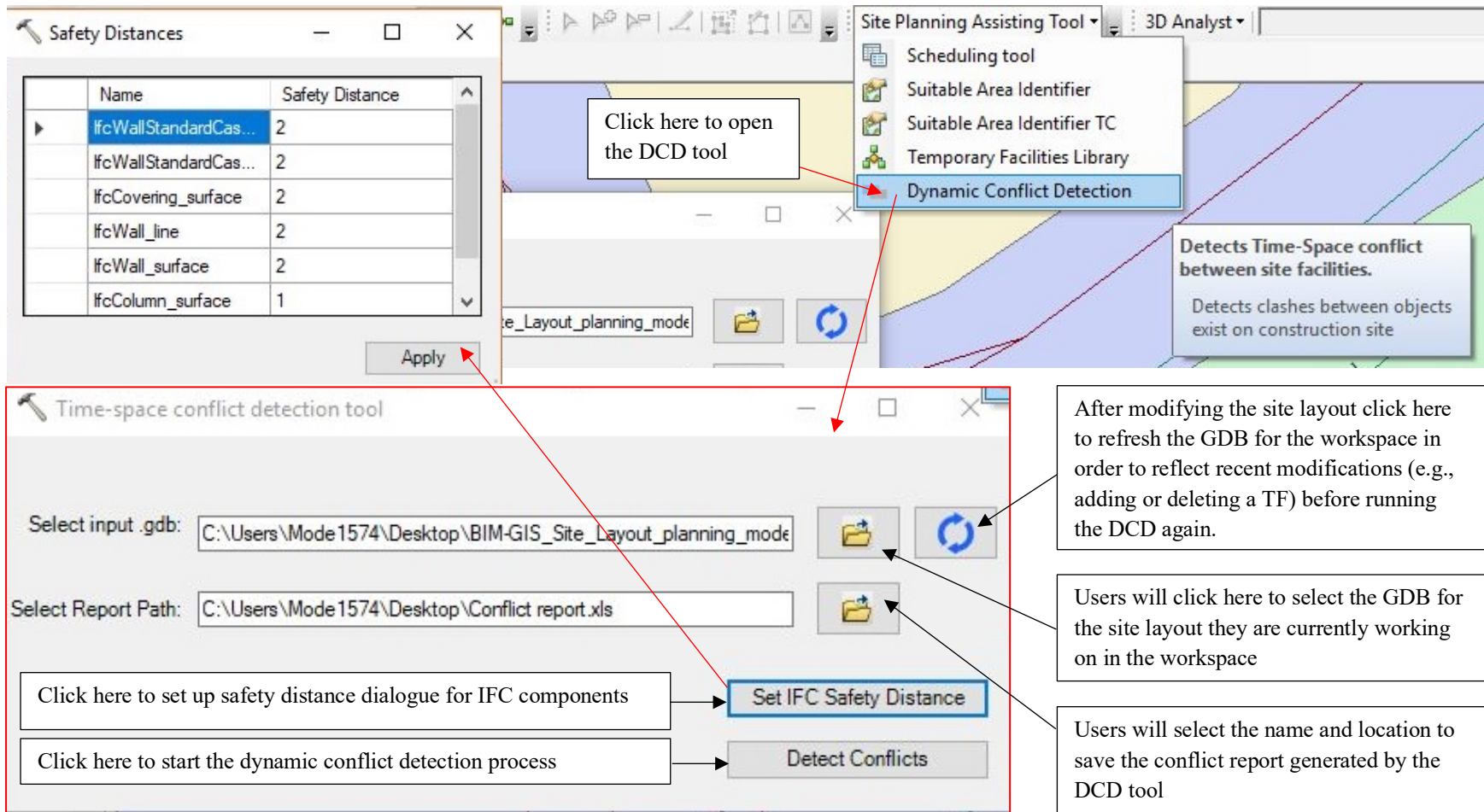


Figure 5.35: The developed UI for the implemented DCD tool

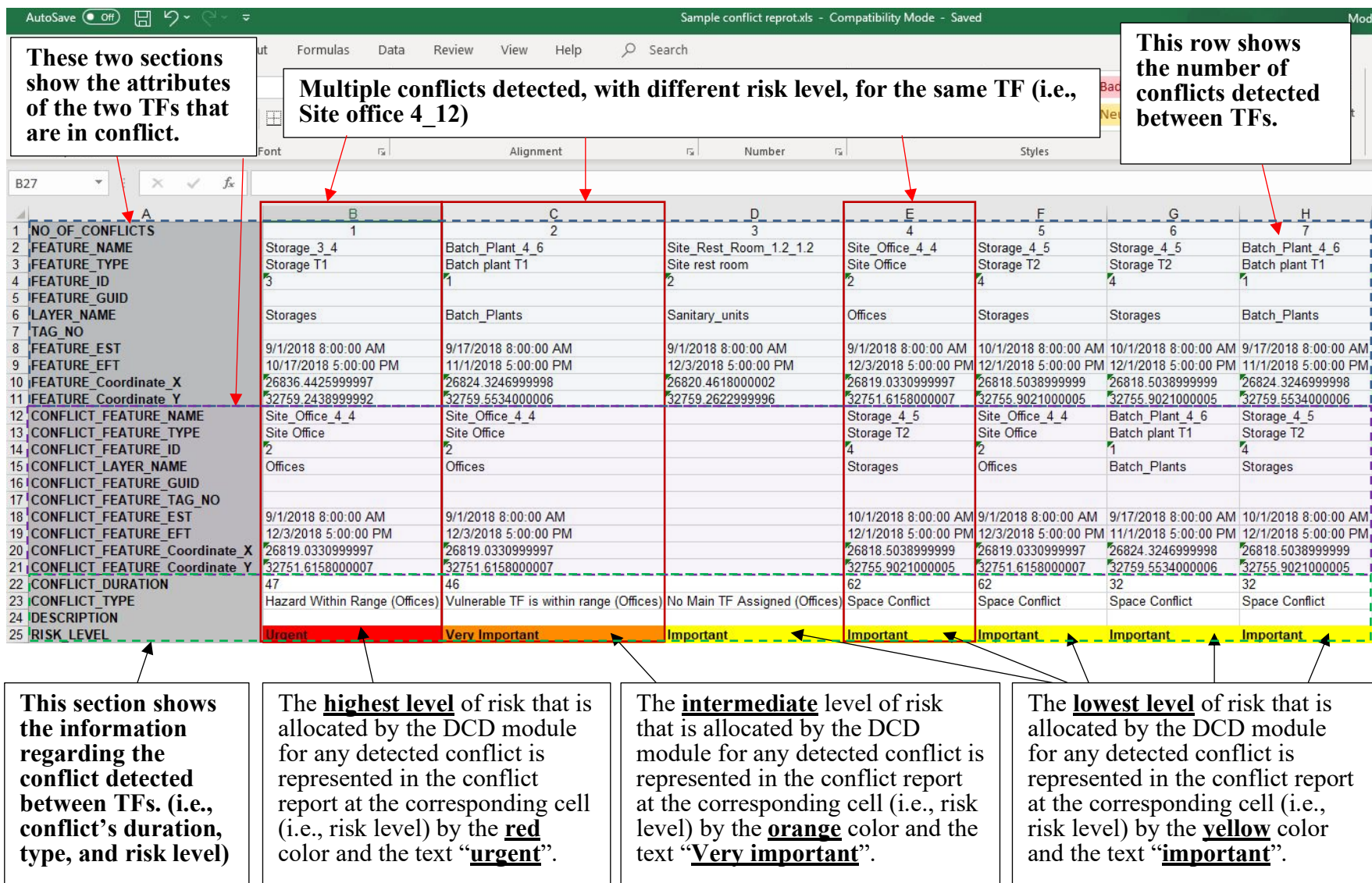


Figure 5.36: Conflict report showing information about the site objects in conflict

```

string feature_startDateFieldName = pInnerFClass.Fields.Field[inner_startDateFieldIndex].Name;
string feature_endDateFieldName = pInnerFClass.Fields.Field[inner_endDateFieldIndex].Name;

using (ComReleaser comReleaser = new ComReleaser())
{
    comReleaser.ManageLifetime(pOuterFCursor);

    while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
    {
        pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;

        double operationalDistance = 0.0;

        if (IsBuildingFeature(((IDataset)pOuterFeatureClass).Name))
        {
            operationalDistance = CommonClass.SafetyDistanceDict[(((IDataset)pOuterFeatureClass).Name)];
        }
        else
        {
            if (!double.TryParse(pOuterFeature.Value[operationalDistanceFieldIndex].ToString(), out operationalDistance))
            {
                continue;
            }
        }

        pOuterBufferGeometry = pTopoOperator.Buffer(operationalDistance);
        object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
        object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);

        if (sdate is DBNull)
            continue;

        DateTime outer_StartDate = Convert.ToDateTime(sdate);
        DateTime outer_EndDate = Convert.ToDateTime(edate);

        pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
        pSpatialFilter.Geometry = pOuterBufferGeometry;
        pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;

        IFeatureCursor pInnerFCursor = pInnerFClass.Search(pSpatialFilter, true);
        comReleaser.ManageLifetime(pInnerFCursor);

        IFeature pInnerFeature = null;

        while ((pInnerFeature = pInnerFCursor.NextFeature()) != null)
        {
            AddRecordToReportTable(pOuterFeature, pInnerFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Space_Conflict), RISK_LEVEL.YELLOW);
            conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = inputLayerClass.LayerName });
            conflictFeatures.Add(new ConflictFeature() { Geometry = pInnerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pInnerFeature.OID, LayerName = queryFClass.LayerName });
            bufferedFeatures.Add(pOuterBufferGeometry);
        }
    }
}

```

This part is for buffering the IFC building components based on the values of the safety distance identified for each component.

This part is for buffering TFs based on the operational distance which is stored in their attribute table

This part includes the expression used by the DCD to detect time overlap between site objects

This part adds the detected conflicts to the conflict report including the type of the conflict detected and the risk level associated with it

Figure 5.37: Part of the coding for the DCD module to detect conflicts between site objects.

Figure 5.38 shows part of the development code for applying the “minimum distance” constraint between storage for combustible materials and site offices while Figure 5.39 shows part of the development code for the same constraint between batch plants and both offices and roads.

```

1139 private void CalculateCombustiveStorageVsOffice()
1140 {
1141     ITopologicalOperator pTopoOperator = null;
1142     IFeature pOuterFeature = null;
1143     IGeometry pOuterBufferGeometry = null;
1144     ISpatialFilter pSpatialFilter = new SpatialFilter();
1145     IQueryFilter pQueryFilter = new QueryFilter();
1146
1147     try
1148     {
1149         List<LayerClass> tempFacilities = m_BIM_ObjectDic[BIM_Objects.TEMPORARY_FACILITIES];
1150
1151         LayerClass offices = (from item in tempFacilities
1152                               where item.LayerName.ToUpper() == "OFFICES"
1153                               select item).FirstOrDefault();
1154         LayerClass storages = (from item in tempFacilities
1155                               where item.LayerName.ToUpper() == "STORAGES"
1156                               select item).FirstOrDefault();
1157
1158         //Exit if any of the feature classes do not exists
1159         if (offices == null || storages == null)
1160             return;
1161
1162         //Storages
1163         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(storages.LayerName);
1164         pQueryFilter.WhereClause = "UPPER(Material_Status) = 'COMBUSTIVE MATERIALS'";
1165         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(pQueryFilter, true);
1166
1167         int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
1168         int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
1169
1170         //Select right safety distance
1171         int withinDistanceFieldIndex = -1;
1172
1173         withinDistanceFieldIndex = pOuterFeatureClass.FindField("Safety_Distance_from_Offices");
1174
1175         if (withinDistanceFieldIndex == -1)
1176         {
1177             MessageBox.Show(new WindowWrapperClass(this.Handle), "Safety_Distance_from_Offices Field does not exists in Storages", "Alert!", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
1178             return;
1179         }
1180     }
1181 }

```

This part is for checking the material status (combustive materials or otherwise) to determine which distance requirement to be selected and implemented in the checking for time-space conflict.

This part is for selecting the right field of distance requirement based on the identified material status.

This part is for generating an alert message if the “safety_Distance_from_Offices” field is not found.

Figure 5.38: Part of the coding for the DCD module to detect minimum distance conflicts

```
1266 private void CalculateBatchPlant_vs_Roads_Offices()
1267 {
1268     ITopologicalOperator pTopoOperator = null;
1269     IFeature pOuterFeature = null;
1270     IGeometry pOuterBufferGeometry = null;
1271     ISpatialFilter pSpatialFilter = new SpatialFilter();
1272     IQueryFilter pQueryFilter = new QueryFilter();
1273
1274     try
1275     {
1276         List<LayerClass> tempFacilities = m_BIM_ObjectDic[BIM_Objects.TEMPORARY_FACILITIES];
1277
1278         LayerClass batchPlants = (from item in tempFacilities
1279                                 where item.LayerName.ToUpper() == "BATCH_PLANTS"
1280                                 select item).FirstOrDefault();
1281         List<LayerClass> dependants = (from item in tempFacilities
1282                                     where item.LayerName.ToUpper() == "OFFICES" || item.LayerName.ToUpper() == "ROADS"
1283                                     select item).ToList();
1284
1285         //Exit if any of the feature classes do not exists
1286         if (batchPlants == null || dependants.Count == 0)
1287             return;
1288
1289         //Storage
1290         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(batchPlants.LayerName);
1291         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(null, true);
1292
1293         using (ComReleaser comReleaser = new ComReleaser())
1294         {
1295             comReleaser.ManageLifetime(pOuterFCursor);
1296             int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
1297             int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
1298
1299             //Select right safety distance
1300             int safteyDistanceFieldIndex = -1;
1301
1302             safteyDistanceFieldIndex = pOuterFeatureClass.FindField("Safety_Distance");
1303
1304             if (safteyDistanceFieldIndex == -1)
```

This part of the code is for checking the batch plants against the different vulnerable site objects (roads and offices) to apply the minimum distance constraint

```
LayerClass batchPlants = (from item in tempFacilities
                           where item.LayerName.ToUpper() == "BATCH_PLANTS"
                           select item).FirstOrDefault();
List<LayerClass> dependants = (from item in tempFacilities
                               where item.LayerName.ToUpper() == "OFFICES" || item.LayerName.ToUpper() == "ROADS"
                               select item).ToList();
```

This part of the code is for selecting the right spatial requirement field (safety distance field) to check if any vulnerable site objects violates the minimum distance constraint

```
//Select right safety distance
int safteyDistanceFieldIndex = -1;

safteyDistanceFieldIndex = pOuterFeatureClass.FindField("Safety_Distance");

if (safteyDistanceFieldIndex == -1)
```

Figure 5.39: Part of the coding for the DCD module to detect minimum distance conflicts

Figure 5.40 shows part of the development code for the DCD module to apply the “minimum distance” constraint to detect both categories of (TC-TC) conflicts (i.e., between tower cranes or TCs of the same height and between TCs with different height).

```

392 //check if crane heights is the same
393 if (resultCraneHeight == craneHeight_QueryCrane)
394 {
395
396
397
398
399
400
401
402
403 bufferedGeo1 = (GetCentroid(pCraneWithL_JSD as ITopologicalOperator).Buffer(rsJibLength + rsJSD);
404 bufferedGeo2 = (GetCentroid(pCraneWithS_JSD as ITopologicalOperator).Buffer(jibLength_QueryCrane);
405
406
407 }
408 else
409 {
410 pCraneWithL_JSD = QueryCrane.ShapeCopy;
411 pCraneWithS_JSD = resultFeature.ShapeCopy;
412
413 bufferedGeo1 = (GetCentroid(pCraneWithL_JSD as ITopologicalOperator).Buffer(jibLength_QueryCrane + jibSafetyDistance_QueryCrane);
414 bufferedGeo2 = (GetCentroid(pCraneWithS_JSD as ITopologicalOperator).Buffer(rsJibLength);
415
416
417 }
418 //Conflict occurs
419 if (((IRelationalOperator)bufferedGeo1).Overlaps(bufferedGeo2))
420 {
421 bufferedFeatures.Add(bufferedGeo1);
422 bufferedFeatures.Add(bufferedGeo2);
423 conflictFeatures.Add(new ConflictFeature() { Geometry = QueryCrane.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = QueryCrane.OID, LayerName = "Cranes" });
424 AddRecordToReportTable(resultFeature, QueryCrane, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " of TC (Same Level), space conflict with jibs of TCs", RISK_LEVEL.RED);
425 }
426
427 }
428 else
429 {
430 bool isNotJib_MastCase = false;
431 bool isJibsInConflict = false;
432 bool isJibsDisjoint = false;
433
434 if (usedIDList.Contains(subOID))
435     continue;
436
437 //Find taller crane and check if the shorter crane intersects with the mast of the taller crane
438 if (resultCraneHeight < craneHeight_QueryCrane)
439 {
440 //Taller crane (mast)
441 bufferedGeo1 = ((ITopologicalOperator)QueryCrane.ShapeCopy).Buffer(towerSafetyDistance_QueryCrane);
442
443 //Shorter crane buffer(jib)
444 bufferedGeo2 = ((ITopologicalOperator)GetCentroid(resultFeature.Shape)).Buffer(rsJibLength);
445
446 //Taller crane buffer (jib)
447 bufferedGeo3 = ((ITopologicalOperator)GetCentroid(QueryCrane.ShapeCopy)).Buffer(jibLength_QueryCrane);

```

This part of the code is for checking if the TCs in conflict have the same height

This part of the code is for selecting the largest jib safety distance (LJSD) in case two TCs in conflict and have the same height

This part of the code is for buffering the two TCs in conflict based on the largest jib safety distance (LJSD) in case they have the same height

This part of the code is for buffering the two TCs in conflict, in case they have the same JSD and the same height, based on that JSD

This part of the code is including the detected TC-TC conflicts and the risk level associated with it in the report

This part of the code is for the two TCs in conflict in case they have the different height. The shorter TC will be buffered based on the jib length as well as the taller TC. Also, the mast of the taller TC will be buffered based on the “towerSafetyDistance”

Figure 5.40: Part of the coding to detect both categories of (TC-TC) conflicts

Part of the development code to detect the conflicts of the TC-B category is shown in Figure 5.41.

```
1 reference
270 private bool isBuildingCraneConflict(double buidlingHeight, double craneHeight, double heightSafetyDistance)
271 {
272
273     int heightDifference = Math.Abs((int)(craneHeight - buidlingHeight));
274
275
276     if (buidlingHeight > craneHeight)
277         return true;
278     else
279     {
280         if (heightDifference > heightSafetyDistance)
281             return false;
282         else
283             return true;
284     }
285 }
286
```

This part of the code is for the rules of the category of TC-B of TC conflicts. The constraint is that the height of the building components should be less than the crane height and the difference should be larger than the “heightSafetyDistance” as explained in chapter 4

Figure 5.41: Part of the coding to detect minimum distance constraint for TC-B conflicts

For the “within distance” constraints, Figure 5.42 shows part of the development code to apply this constraint between site office and site washrooms/restrooms. Figure 5.43 shows part of the development code for the DCD module to apply the “operational distance” constraints between site objects.

```

//If a washroom has no intersection with any office
if (washroomCount == 0)
{
    AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
    conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
    bufferedFeatures.Add(pOuterBufferGeometry);
}
}
//else
if (washroomCount > 0)
{
    IFeature pWashroomFeature = null;

    //If it intersects with multiple washrooms process further
    if (washroomCount == 1)
    {
        pWashroomFeature = innerFeatureCursor.NextFeature();
        int oid = pWashroomFeature.OID;
        if (!assignedOIDs.Contains(oid))
            assignedOIDs.Add(oid);
    }
    else
    {
        AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
        conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
        bufferedFeatures.Add(pOuterBufferGeometry);
    }
}
else
{
    List<WashroomClass> conflictWashrooms = new List<WashroomClass>();

    while ((pWashroomFeature = innerFeatureCursor.NextFeature()) != null)
    {
        IGeometry officeGeo = pOuterFeature.ShapeCopy;
        IGeometry washroomGeo = pWashroomFeature.ShapeCopy;

        double distance = ((IPximityOperator)officeGeo).ReturnDistance(washroomGeo);
        if (!assignedOIDs.Contains(pWashroomFeature.OID))
            conflictWashrooms.Add(new WashroomClass() { DistanceFromOffice = distance, WashroomFeature = pWashroomFeature });
    }

    if (conflictWashrooms.Count == 0)
    {
        AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
        conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
        bufferedFeatures.Add(pOuterBufferGeometry);
        continue;
    }

    //Find the minimum distance from the site washroom
    double minDistance = (from x in conflictWashrooms select x.DistanceFromOffice).Min();
}
}

```

This part of the code is for reporting a conflict when no site washrooms (DSO) exist within the specified “within distance” of any site office (MSO). This will include the conflict and the risk level associated with it.

This part of the code is for checking if one site washroom (DSO) exist completely within the specified “within distance” in the attribute table of site offices (MSO).

This part of the code is for reporting detected conflicts and include the risk level associated with it.

This part of the code is for creating a list in case multiple site washrooms (DSO) exist within the specified “within distance” of a site office (MSO)

This part of the code is for assigning the closest site washroom (DSO) to the site office,

This part of the code is for reporting detected conflicts and include the risk level associated with it.

This part of the code is for finding the closest site washroom (DSO) when multiple site washrooms exist within the specified “within distance” from a site office.

Figure 5.42: Part of the coding for the module to apply the “within distance” constraints

```

//Get the featureClass
IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(inputLayerClass.LayerName);
IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(null, true);

int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);

//Select right safety distance
int operationalDistanceFieldIndex = -1;
operationalDistanceFieldIndex = pOuterFeatureClass.FindField("Operational_Distance");
if (operationalDistanceFieldIndex == -1 && !IsBuildingFeature(pOuterFeatureClass.AliasName))
{
    MessageBox.Show(new WindowWrapperClass(this.Handle), "Operational Distance field missing in " + inputLayerClass.LayerName, "Space conflict", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
    return;
}

if (outer_startDateFieldIndex < 0 || outer_endDateFieldIndex < 0)
{
    return;
}

//Inner FeatureClass
IFeatureClass pInnerFClass = m_pFeatureWorkspace.OpenFeatureClass(queryFClass.LayerName);
DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFClass.AliasName);

int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFClass.Fields);
int inner_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pInnerFClass.Fields);

if (inner_startDateFieldIndex < 0)
    return;

```

This part of the code is for selecting the appropriate field for spatial requirement (i.e., Operational distance) to check for time-space conflicts between site objects

Figure 5.43: Part of the coding for the module to apply the operational distance constraints

In the development code there is a part, included in the developed rules for every type of constraint, that makes the module in case a conflict or rule violation is detected to include that instance (detected conflict) in the conflict report that is generated by it after finishing the rule checking process. Figure 5.44 illustrates an example (for tower cranes) on how the detected conflicts are reported and also how risk level is being assessed and reported as well. Figure 5.45 shows the different fields (rows) included in the conflict report including layers name, type of conflict, risk level etc. It also, shows how the risk level color codes (e.g., red) will be included in the conflict report with their corresponding text (e.g., urgent).

```

//Conflict occurs
if (((IRelationalOperator)bufferedGeo1).Overlaps(bufferedGeo2))
{
    bufferedFeatures.Add(bufferedGeo1);
    bufferedFeatures.Add(bufferedGeo2);
    conflictFeatures.Add(new ConflictFeature() { Geometry = QueryCrane.ShapeCopy, ConflictColor = RISK_LEVEL.RED,
    AddRecordToReportTable(resultFeature, QueryCrane, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " of TC (Same Level), space conflict with jibs of TCs", RISK_LEVEL.RED);
}
}

```

This part of the code is for displaying the detected conflict with the color associated with the risk level

This part of the code is for including the layer's name, type of conflict, risk level and associated color and text in the conflict report

Figure 5.44: Part of the coding that shows risk assessment for detected conflicts (for TCs)

This part of the code is for including the required fields in the conflict report as explained in chapter 4

This part of the code is for giving a meaning to the color code when including the risk level in the attribute table of site objects and the conflict report (e.g., “Red” means “urgent”).

```

//The field indexes of the layers present in the report table
int layerName_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_NAME);
int featureName_FieldIndex = _ReportTable.FindField(CommonClass.FEATURE_NAME);
int id_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_ID);
int layer_type_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_TYPE);
int layerGUID_FieldIndex = _ReportTable.FindField(CommonClass.GUID);
int layer_Tag_No_FieldIndex = _ReportTable.FindField(CommonClass.TAG_NO);
int layer_startDate_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_EST);
int layer_endDate_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_EFT);
int layer_x_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_X);
int layer_y_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_Y);
int description_FieldIndex = _ReportTable.FindField(CommonClass.DESCRPTION);
int riskLevel_FieldIndex = _ReportTable.FindField(CommonClass.RISK_LEVEL);
int conflict_type_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_TYPE);

if (riskLevel_FieldIndex != -1)
{
    string riskLev = riskLevel.ToString();
    string value = "";
    switch (riskLev)
    {
        case "RED":
            value = "Urgent";
            break;
        case "ORANGE":
            value = "Very Important";
            break;
        case "YELLOW":
            value = "Important";
            break;
    }
}

```

Figure 5.45: Part of the coding for the fields included in the conflict report

5.8 Summary

This chapter focused on the development of the integrated BIM-GIS model for site layout planning. Two methods were followed while developing the model: 1) using the built-in functions that already exist in both tools for BIM (i.e., Autodesk Revit) and GIS (i.e., ArcGIS desktop); 2) new functions were created either as an application/extension with a user interface (within the BIM or GIS tool), or as plugins and linked to the associated tool (BIM or GIS). The developed model was implemented in a modular format consisting of six modules 1) a 3D modelling module; 2) a route planning and hauling (RPH) module; 3) an execution schedule time entry (ESTE) module; 4) a 4D visualization module; 5) a temporary facilities library module; 6) and a dynamic conflict detection (DCD) module. The methodology used in the development makes the integrated BIM-GIS model flexible to accept modifications, to be expanded to include more functions, and to tackle a variety of tasks related to site layout planning (SLP). The processes for developing the six modules were explained in a step by step manner using illustrative Figures and explanations. The developed SLP model provides users with various functions to assist them apply their knowledge and bring their expertise in planning the layout for a construction site that is efficient and safe in an intuitive and timely manner. Also, it provides users with an information-rich environment with a wide range of spatiotemporal analysis capabilities and a variety of feedback and outputs including textual, graphical, and tabular, which supports and facilitates the decision-making process for practitioners during the SLP process. Finally, the functionalities and capabilities of the presented SLP model will be tested and verified in chapter 6.

CHAPTER 6

Model testing and verification

6.1 Introduction

This chapter provides the testing verification of the developed integrated BIM-GIS model for site layout planning. Each module will be presented in a way that provides a clear idea on the capability of it, its functions, and its outcomes. A hypothetical case project will be used to test and verify the workability, functions, and performance of the different modules included in the developed BIM-GIS integrated model for SLP. A 3D BIM model was created by the author for three different buildings, including the building under construction, which is a six-storey residential apartment building, and two other two-story buildings surrounding it. The total gross area of the case project is 16,190 ft². The case project was selected to be in the city of Ottawa, Canada. All the information (provided by the City of Ottawa) regarding the transportation network, land distribution, and land use for the selected project area was obtained from Carleton University in the form of a shape file (.shp format). A total number of 21 temporary facilities will be used in the case project, which are 2 batch plants, 3 storage units, 3 storage areas (i.e., laydown area, brick depot, gravel depot), 3 site offices, 3 site washrooms, 1 geotechnical lab, 3 workshops (i.e., carpentry, rebar workshop and landscape workshop), and 3 tower cranes. Also, additional site objects, categorized as permanent facilities, such as trees, are included as well. The developed model will be used to plan the site layout of the case project and check the site layout plan for any potential clashes or issues. The BIM tool used in this study is Autodesk Revit while ESRI ArcMap is used as the GIS tool.

6.2 Testing and verification of the developed 3D modelling module

Once the BIM 3D model was created as shown in Figure 6.1, it was exported using the IFC export dialogue from the main menu in Revit as an IFC 2x3 file as shown in Figures 6.2 and 6.3. The option to split the walls and columns by level was checked as shown in Figure 6.3. to ensure that the building components will be divided by floor level in the exported 3D model and that the level information will be stored in their attribute table. This will enable the 4D simulation for the exported 3D model to be executed properly, which allows to display the different building components individually and independently.

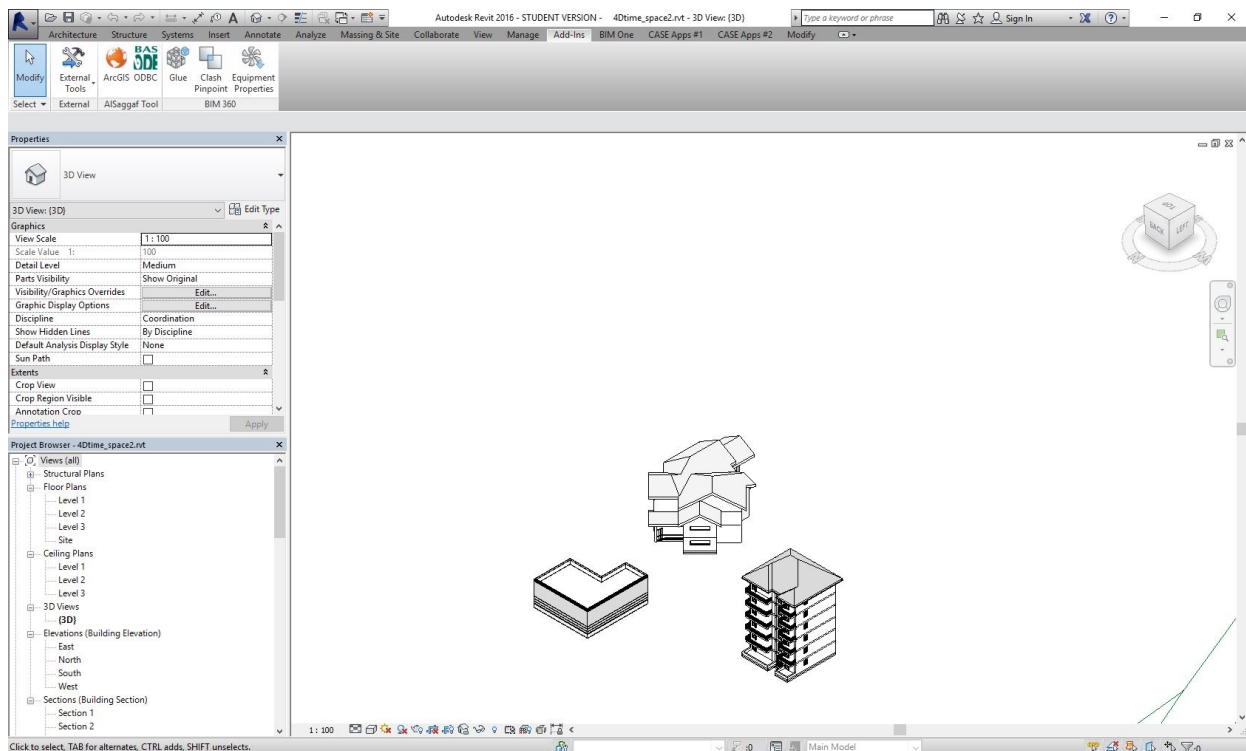


Figure 6.1: Created BIM 3D model in Revit

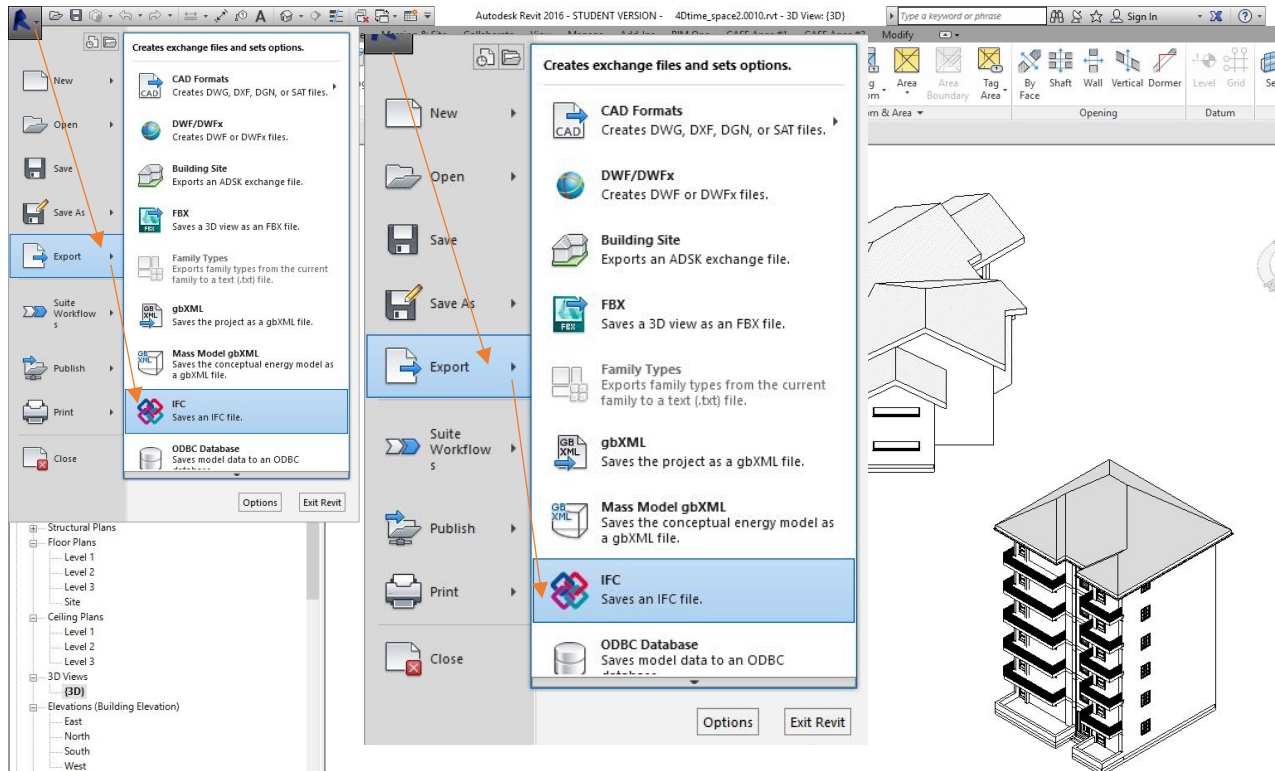


Figure 6.2: Selecting the IFC export option from main menu

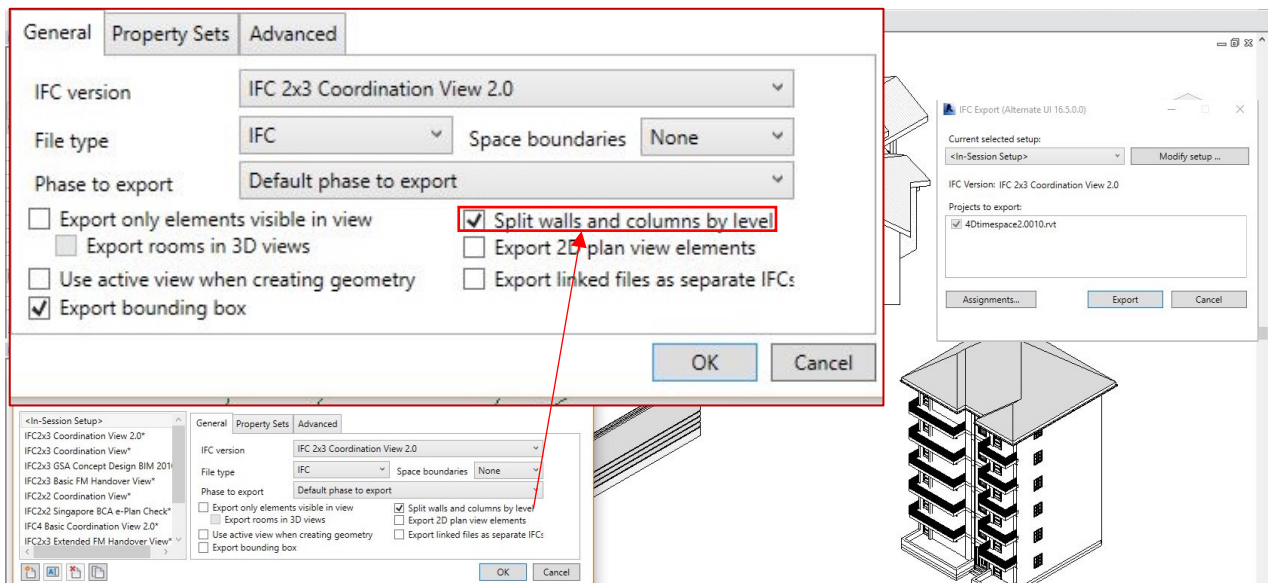


Figure 6.3: Configuring the IFC export menu

Figure 6.4. shows how the material quantity take off (QTO) is made by using Revit before exporting the BIM 3D model as an IFC file. This step is done when information needs to be associated with the 3D model in the GIS tool. Figures 6.5 and 6.6 show the developed plugin and how it is managed by clicking on it to open GIS tool from within BIM tool. This will to facilitate the data transition from one working schedule environment to another.

The screenshot displays the Revit 'Schedule/Quantities' window. The ribbon includes 'Analyze', 'Massing & Site', 'Collaborate', 'View', 'Manage', 'Add-Ins', 'BIM One', and 'CASE Apps #1'. The 'Properties' panel shows the schedule name '4Dtime_space2.0010.rvt - Schedule: Multi-Category Material Takeoff'. The main area contains a table with the following data:

| Material Name | Count | Material Area | Material Volume | Level | Material Description |
|---------------|------------------------|----------------------------------|-----------------|----------|----------------------|
| Basic Wall | Exterior - kama-EEBS o | Wood - Sheathing - Plywoo | 67.859 m² | 1.29 m³ | Plywood |
| Basic Wall | Exterior - kama-EEBS o | Structure - kama-EEBS | 67.859 m² | 10.34 m³ | kama-EEBS™ Panels |
| Basic Wall | Exterior - kama-EEBS o | Finishes - Interior - Gypsum | 67.859 m² | 0.34 m³ | GWB |
| Basic Wall | Exterior - kama-EEBS o | Air Barrier - Air Infiltration B | 6.056 m² | 0.00 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Misc. Air Layers - Air Spac | 6.056 m² | 0.46 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Vapor / Moisture Barriers - | 6.056 m² | 0.00 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Paint | 6.056 m² | 0.03 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Wood - Sheathing - Plywoo | 6.056 m² | 0.12 m³ | Plywood |
| Basic Wall | Exterior - kama-EEBS o | Structure - kama-EEBS | 6.056 m² | 0.92 m³ | kama-EEBS™ Panels |
| Basic Wall | Exterior - kama-EEBS o | Finishes - Interior - Gypsum | 6.056 m² | 0.03 m³ | GWB |
| Basic Wall | Exterior - kama-EEBS o | Vapor / Moisture Barriers - | 6.056 m² | 0.00 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Paint | 6.056 m² | 0.03 m³ | |
| Basic Wall | Exterior - kama-EEBS o | Wood - Sheathing - Plywoo | 6.056 m² | 0.12 m³ | Plywood |
| Basic Wall | Exterior - kama-EEBS o | Structure - kama-EEBS | 6.056 m² | 0.92 m³ | kama-EEBS™ Panels |
| Basic Wall | Exterior - kama-EEBS o | Finishes - Interior - Gypsum | 6.056 m² | 0.03 m³ | GWB |

The 'Schedules/Quantities' legend on the left shows 'Multi-Category Material Takeoff' selected. A red box highlights this entry and the corresponding rows in the table.

Figure 6.4: Using Revit (BIM tool) to prepare Material QTO

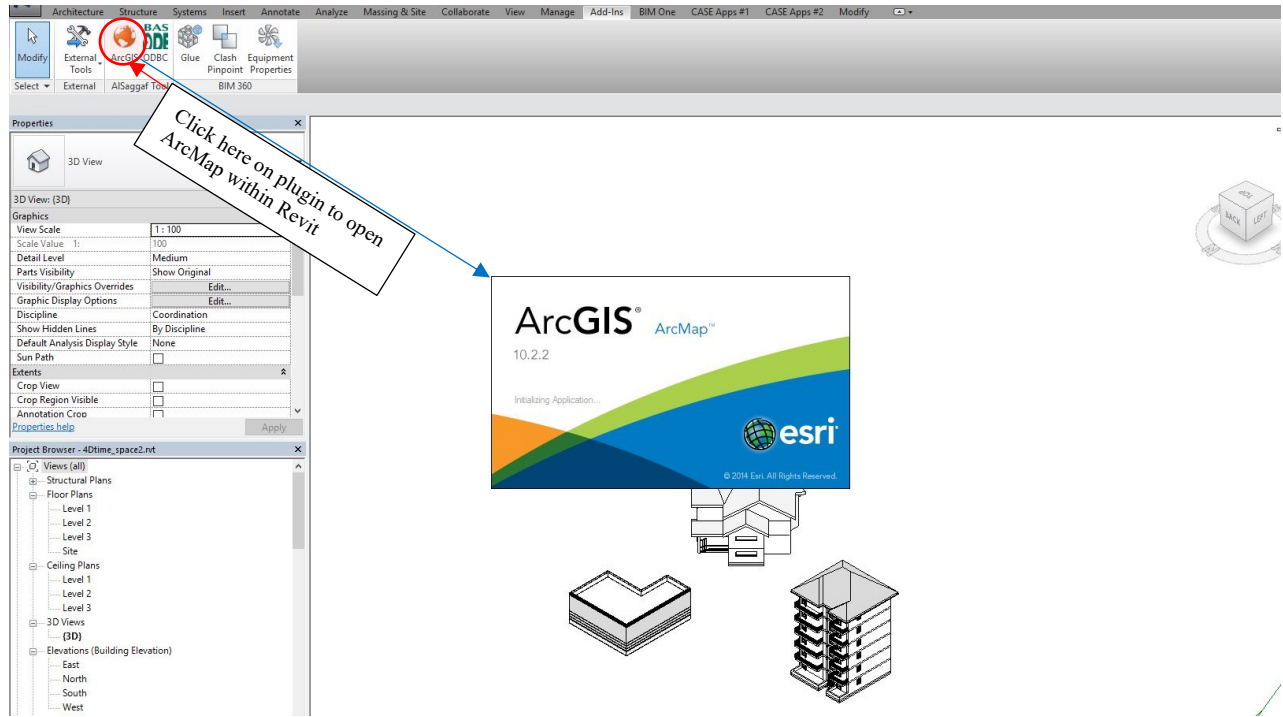


Figure 6.5: A plug-in to open GIS (ArcMap) within BIM (Revit) environment

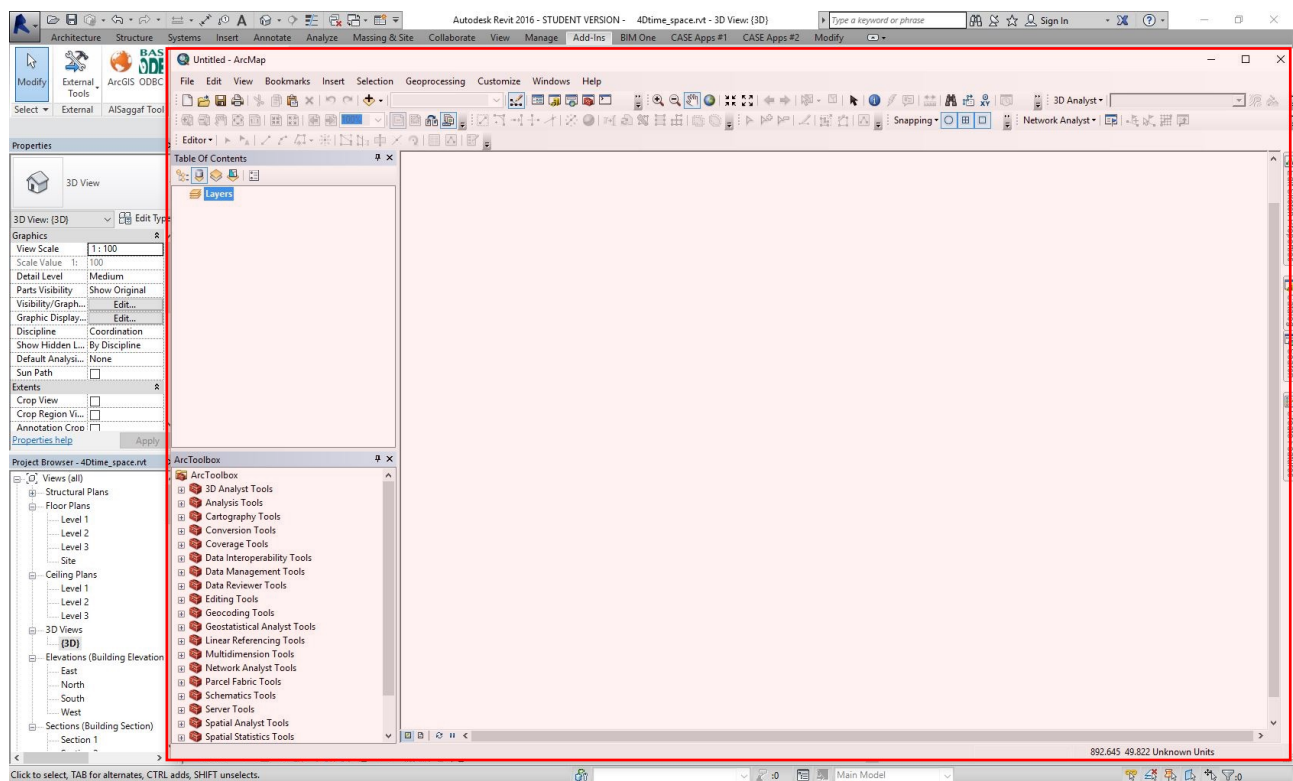


Figure 6.6: ArcMap is opened using the plug-in created in Revit

Figure 6.7 shows how the Data Interoperability extension was used in ArcMap to transform the IFC file exported from Revit into a Personal File Geodatabase (GDB) format. After this, the GDB was imported into ArcMap including the 3D model for the facility with its associated attributes.

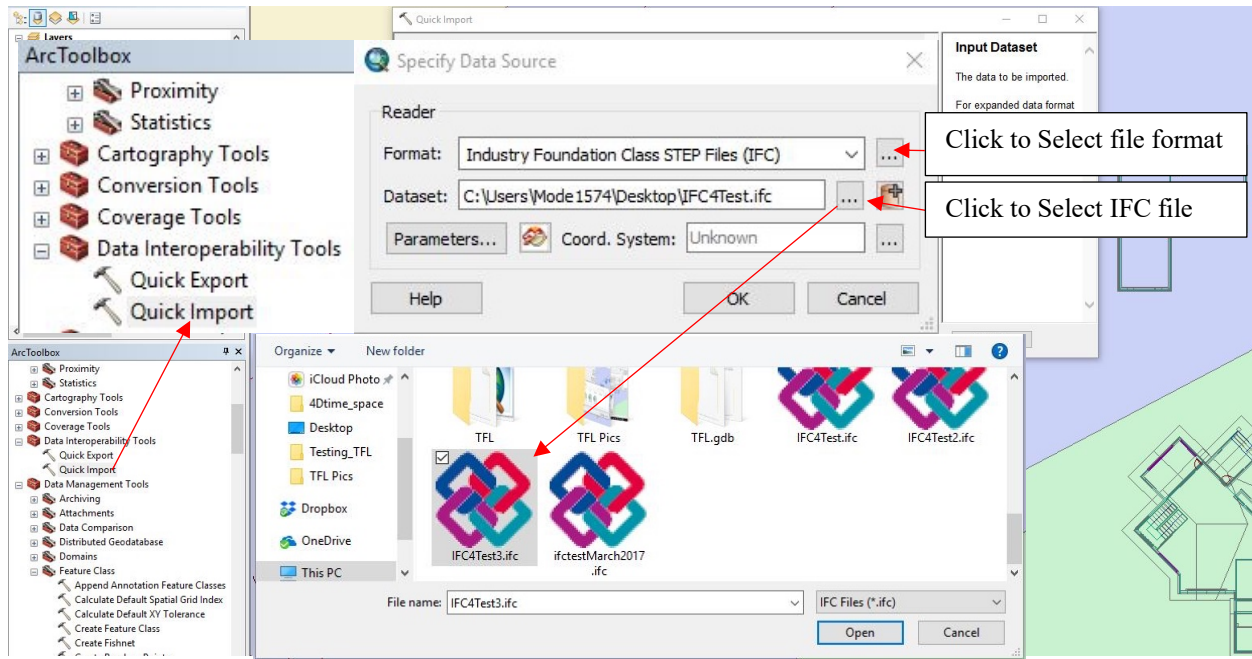


Figure 6.7: Importing IFC file with data interoperability tools

The 3D model is imported into ArcMap as different layers (feature classes) that represent the different building components (e.g., floor, slabs, windows, doors, etc.) in accordance with the IFC schema as shown in Figure 6.8. Each feature class will contain the geometrical and functional information for the building components it represents, and depending on the building component, the shape and functional information included in its attribute table will vary. If more information is needed than what is automatically transformed with the imported IFC 3D model, we can associate the information QTO, which was prepared or we create a new one, which is exported as a spreadsheet with the imported IFC building components, as shown in Figure 6.9. This will enrich the feature classes (layers) of the imported 3D model with the required information, as illustrated in Figure 6.10.

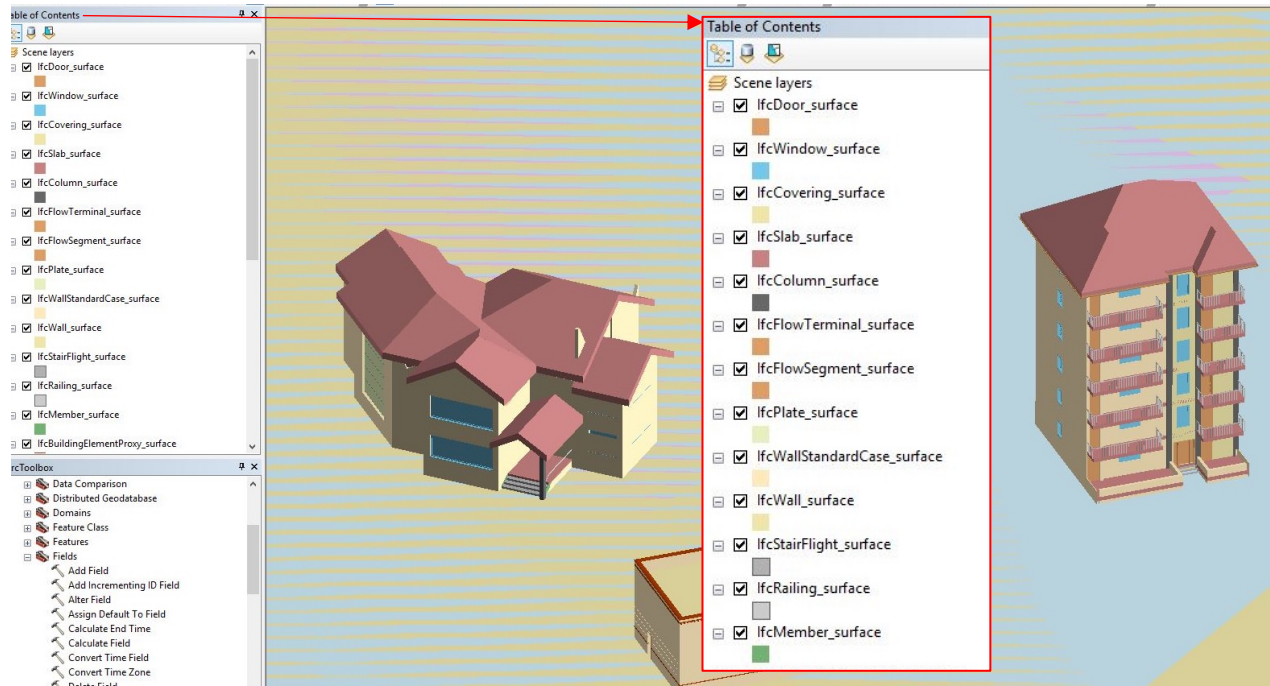


Figure 6.8: IFC 3D model after being imported into ArcMap

Table

Multi_Category_Material_Takeoff

| OBJECTID * | IfcGUID * | Type_IfcGUID | Family_and_Type | Family | Volume | Level |
|------------|-----------------------|------------------------|--|--|-----------|----------------|
| 1 | <Null> | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 37.392367 | <Null> |
| 2 | <Null> | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 23.753947 | <Null> |
| 3 | <Null> | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 20.38161 | <Null> |
| 4 | <Null> | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 17.048475 | <Null> |
| | | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 13.22809 | <Null> |
| | | 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 40.564691 | <Null> |
| | vOFVbuWqQD97 | <Null> | Single-Cold Room: 32' x 84" | Single-Cold Room: 32' x 84" | 0.189566 | Level: Level 1 |
| | vOFVbuWqQDAS | 2JFSJxaxWHau3u0C1FZlqm | Basic Wall: Interior - 3 1/8" Partition (1-hr) | Basic Wall: Interior - 3 1/8" Partition (1-hr) | 1.628947 | <Null> |
| | vOFVbuWqQDI | 2JFSJxaxWHau3u0C1FZlqm | Basic Wall: Interior - 3 1/8" Partition (1-hr) | Basic Wall: Interior - 3 1/8" Partition (1-hr) | 1.483992 | <Null> |
| | vOFVbuWqQDCN | 2JFSJxaxWHau3u0C1FZlqm | Basic Wall: Interior - 3 1/8" Partition (1-hr) | Basic Wall: Interior - 3 1/8" Partition (1-hr) | 1.446064 | <Null> |
| | vOFVbuWqQDCr | 2JFSJxaxWHau3u0C1FZlqm | Basic Wall: Interior - 3 1/8" Partition (1-hr) | Basic Wall: Interior - 3 1/8" Partition (1-hr) | 0.951547 | <Null> |
| | oemL8JnnFCds | <Null> | Single-Flush: 30' x 80" | Single-Flush: 30' x 80" | 0.097929 | Level: Level 1 |
| | oemL8JnnFCWn | <Null> | Single-Flush: 30' x 80" | Single-Flush: 30' x 80" | 0.097929 | Level: Level 1 |
| | oemL8JnnFBFx | <Null> | Casement 3x3 with Trim: 36' x 48" | Casement 3x3 with Trim: 36' x 48" | 0.075744 | Level: Level 1 |
| | oemL8JnnFB8J | <Null> | Casement 3x3 with Trim: 36' x 48" | Casement 3x3 with Trim: 36' x 48" | 0.075744 | Level: Level 1 |
| | oemL8JnnFB9C | <Null> | Casement 3x3 with Trim: 36' x 48" | Casement 3x3 with Trim: 36' x 48" | 0.075744 | Level: Level 2 |
| | 23u08RRCvFoemL8JnnB4w | <Null> | Casement 3x3 with Trim: 36' x 48" | Casement 3x3 with Trim: 36' x 48" | 0.075744 | Level: Level 2 |
| | 0LZmqwRH7FxXV3Jo_3EB | <Null> | Single-Flush: 32' x 84" | Single-Flush: 32' x 84" | 1.108351 | Level: Level 1 |
| | 1rA7QWkT6xf6SUU_OVRPH | <Null> | Casement DbI with Trim: 32' x 48" | Casement DbI with Trim: 32' x 48" | 0.074349 | Level: Level 1 |
| | 1rA7QWkT6xf6SUU_OVRPH | <Null> | Casement DbI with Trim: 32' x 48" | Casement DbI with Trim: 32' x 48" | 0.074349 | Level: Level 1 |

| Type_IfcGUID | Family_and_Type | Family | Volume | Level |
|------------------------|--|--|-----------|--------|
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 37.392367 | <Null> |
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 23.753947 | <Null> |
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 20.38161 | <Null> |
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 17.048475 | <Null> |
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 13.22809 | <Null> |
| 0YG8rYvETBTPkBeg5NeNew | Basic Wall: Exterior - Brick and CMU on MTL Stud | Basic Wall: Exterior - Brick and CMU on MTL Stud | 40.564691 | <Null> |

Figure 6.9: Spreadsheet for material QTO after being imported into ArcMap

Asterisk indicates that field is being used for associating information between spreadsheet and corresponding components in

| ObjectTyp | Tag | OverallHeight | OverallWidth | OBJECTID * | IfcGUID * | Type_IfcGUID | Family_and_Type | Family | Volume | Level |
|-----------|--------|---------------|--------------|------------|-------------------------|--------------|-----------------------------------|-----------------------------------|----------|----------------|
| 36" x 48" | 312517 | 1.2192 | 0.9144 | 14 | 2\$u8cRHCvFoemL8JnnfBFx | <Null> | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 312621 | 1.2192 | 0.9144 | 15 | 2\$u8cRHCvFoemL8JnnfB8J | <Null> | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 312690 | 1.2192 | 0.9144 | 16 | 2\$u8cRHCvFoemL8JnnfB9C | <Null> | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 36" x 48" | 312836 | 1.2192 | 0.9144 | 17 | 2\$u8cRHCvFoemL8JnnfB4w | <Null> | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 32" x 48" | 314550 | 1.2192 | 0.8128 | 19 | 1rA7QfwKT6xfe9UW_OWRPH | <Null> | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 314628 | 1.2192 | 0 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 314731 | 1.2192 | 0 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 32" x 48" | 314732 | 1.2192 | 0 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 36" x 48" | 318182 | 1.2192 | 0 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318183 | 1.2192 | 0 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318184 | 1.2192 | 0 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 36" x 48" | 318185 | 1.2192 | 0 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 32" x 48" | 318188 | 1.2192 | 0 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318189 | 1.2192 | 0.6128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318190 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 32" x 48" | 318191 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 36" x 48" | 318556 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318557 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318558 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 36" x 48" | 318559 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 32" x 48" | 318561 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318562 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318563 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 32" x 48" | 318564 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |
| 36" x 48" | 318942 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318943 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 1 |
| 36" x 48" | 318944 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 36" x 48" | 318945 | 1.2192 | 0.9144 | | | | Casement 3x3 with Trim: 36" x 48" | Casement 3x3 with Trim: 36" x 48" | 0.075744 | Level: Level 2 |
| 32" x 48" | 318947 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318948 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 1 |
| 32" x 48" | 318949 | 1.2192 | 0.8128 | | | | Casement Dbl with Trim: 32" x 48" | Casement Dbl with Trim: 32" x 48" | 0.074349 | Level: Level 2 |

(1 out of 96 Selected)

Multi_Category_Material_Takeoff | Multi_Category_Material_Takeoff_2 | BaseQuantities | IfcGroup | IfcDoor_surface | IfcStairFlight_surface | IfcBuildingElementProxy_surface | IfcWindow_surface

Figure 6.10: Information in QTO spreadsheet associated with its corresponding components

6.3 Testing and verification of the developed route planning and hauling (RPH) module

The RPH module was used to identify the task points (supply point and demand point) for the materials/waste and then to calculate the most efficient route by using the Network Analyst as shown in Figure 6.11. Knowing the average speed of the truck and the distance of the trip, the trip time can be calculated as shown Figure 6.11. Also, by knowing the quantities of materials to be transported, truck capacity, average speed of the truck, and the distance of the trip, the total trip time, the number of trucks required for hauling and moving operations can be estimated. Figures 6.12 and 5.13 show how the model is used to implement the common methodology used in the literature (number of loads/ trips) to estimate the required number of trucks.

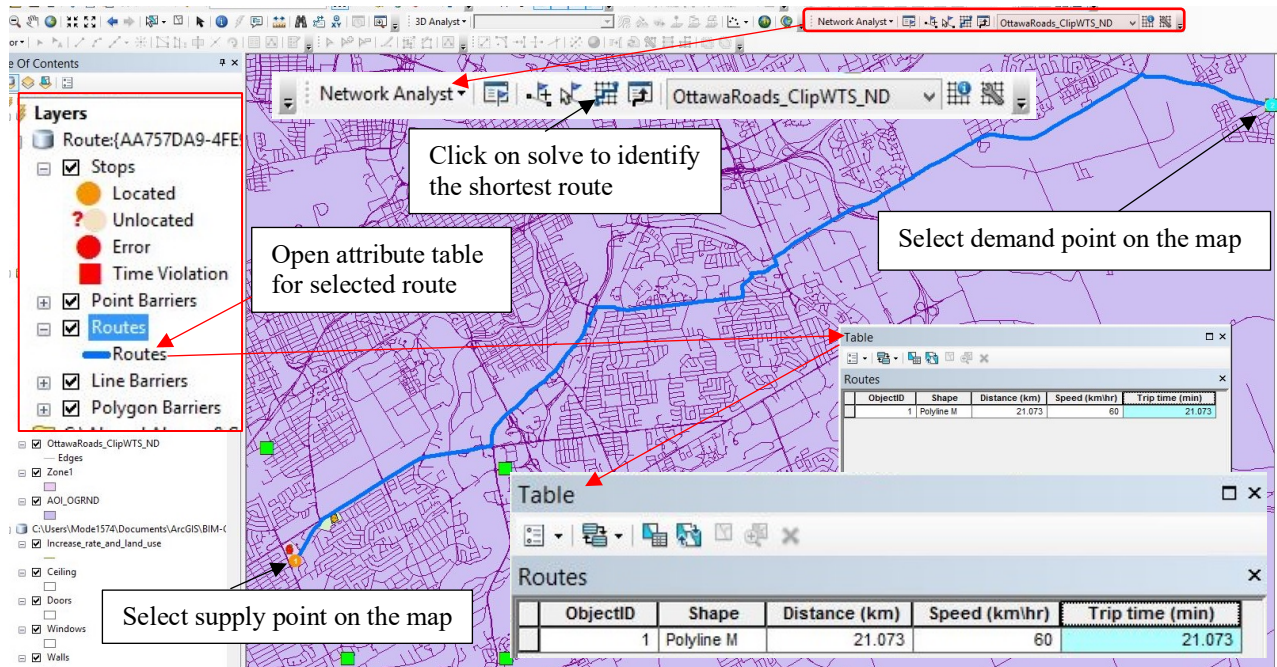


Figure 6.11: Selecting the fastest route between two, supply and demand, points

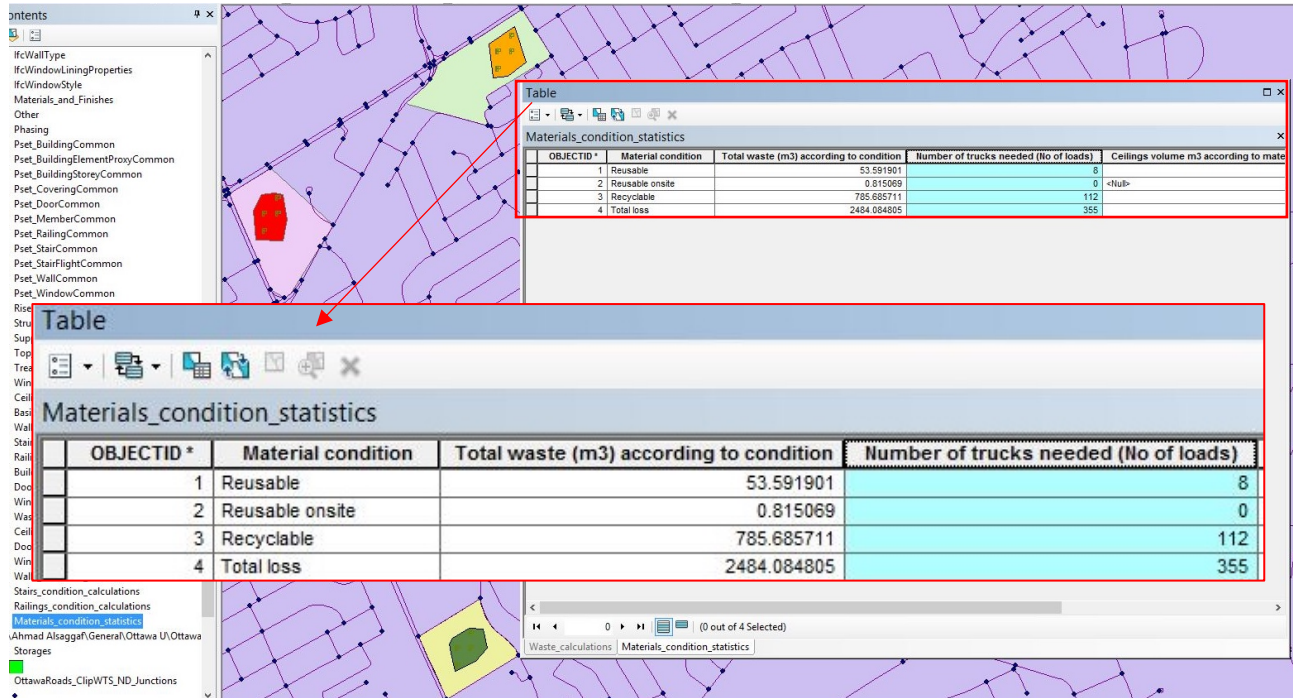


Figure 6.12: Common methodology for estimating the number of trucks (number of loads)

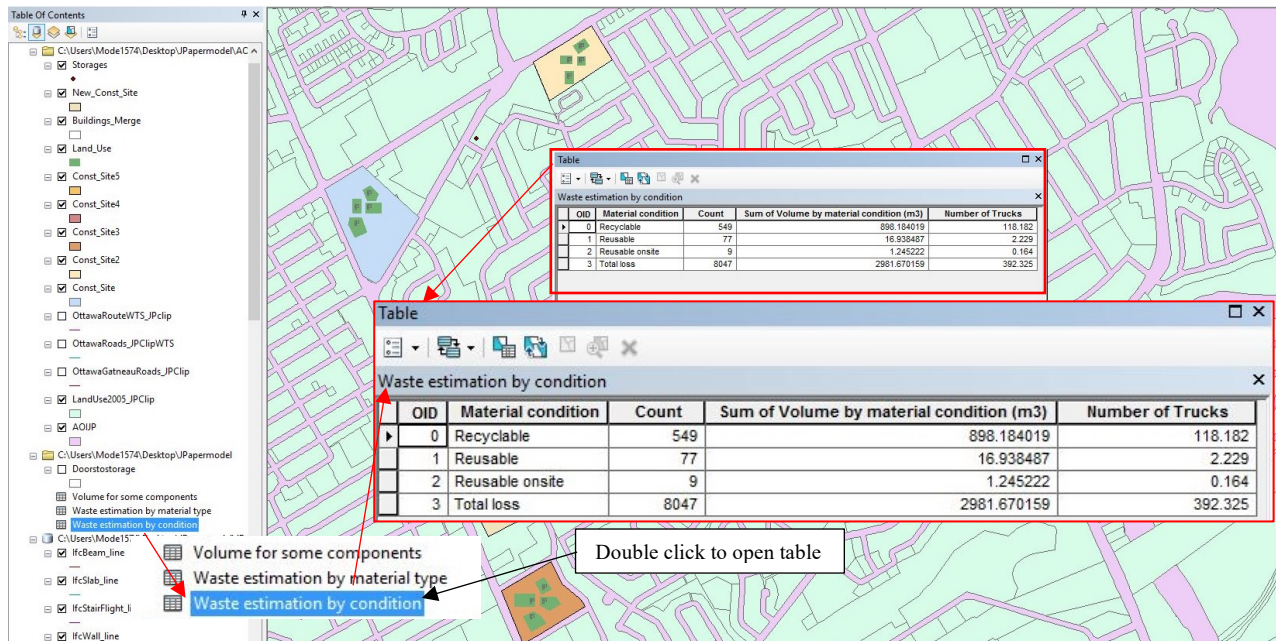


Figure 6.13: Common methodology for estimating the number of trucks (number of loads)

In addition, the integrated BIM-GIS model assists users in choosing a suitable location for the supply or demand points by estimating and categorizing the volumes of building components or potential waste generated onsite based on the three waste categorization approaches as seen in Figures 6.14, 6.15 and 6.16. Furthermore, the model is used to identify the quantities of building components or waste based on functional and locational attributes, as shown in Figure 6.17. This is possible because of the spatial analysis capabilities of the integrated model.

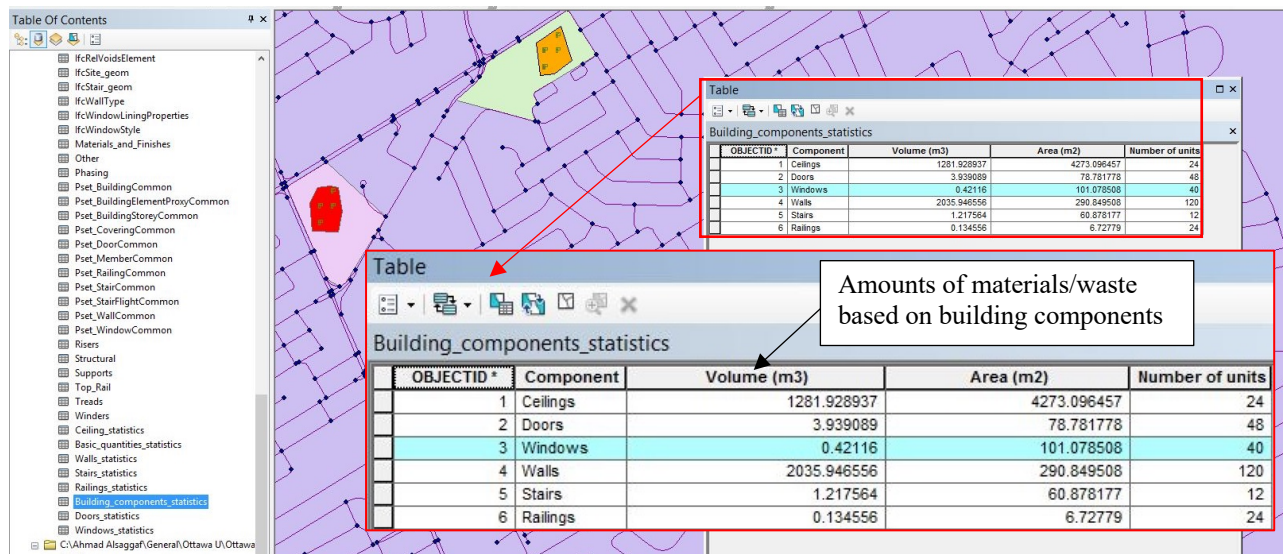


Figure 6.14: Estimating the amounts of materials/waste based on building components

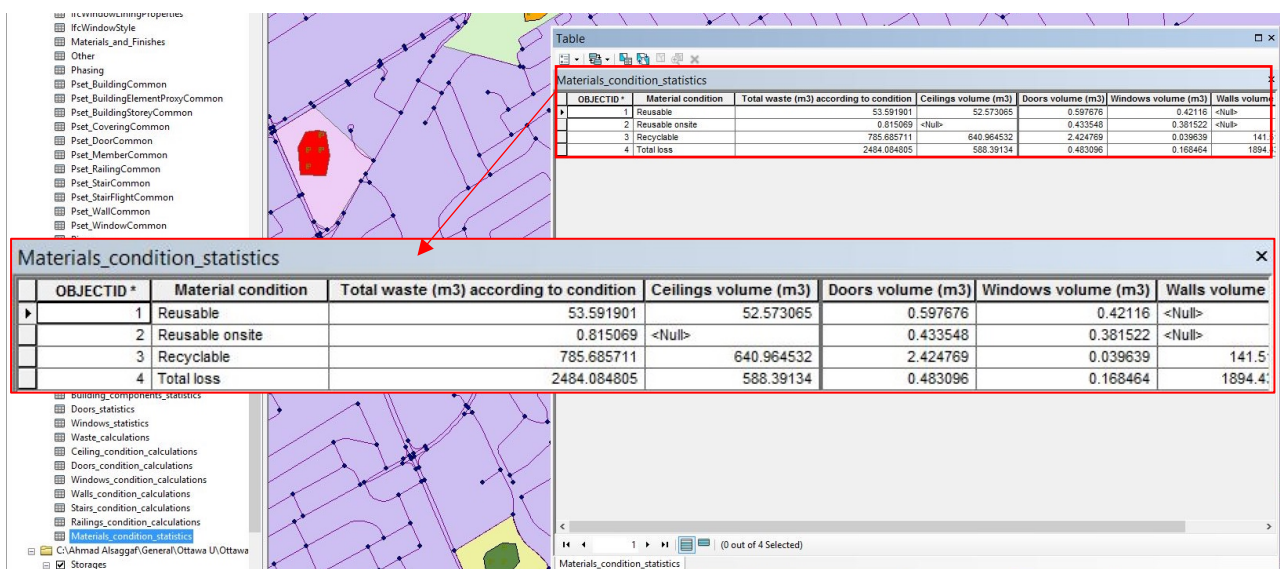


Figure 6.15: Estimating the amounts of waste based on material's condition

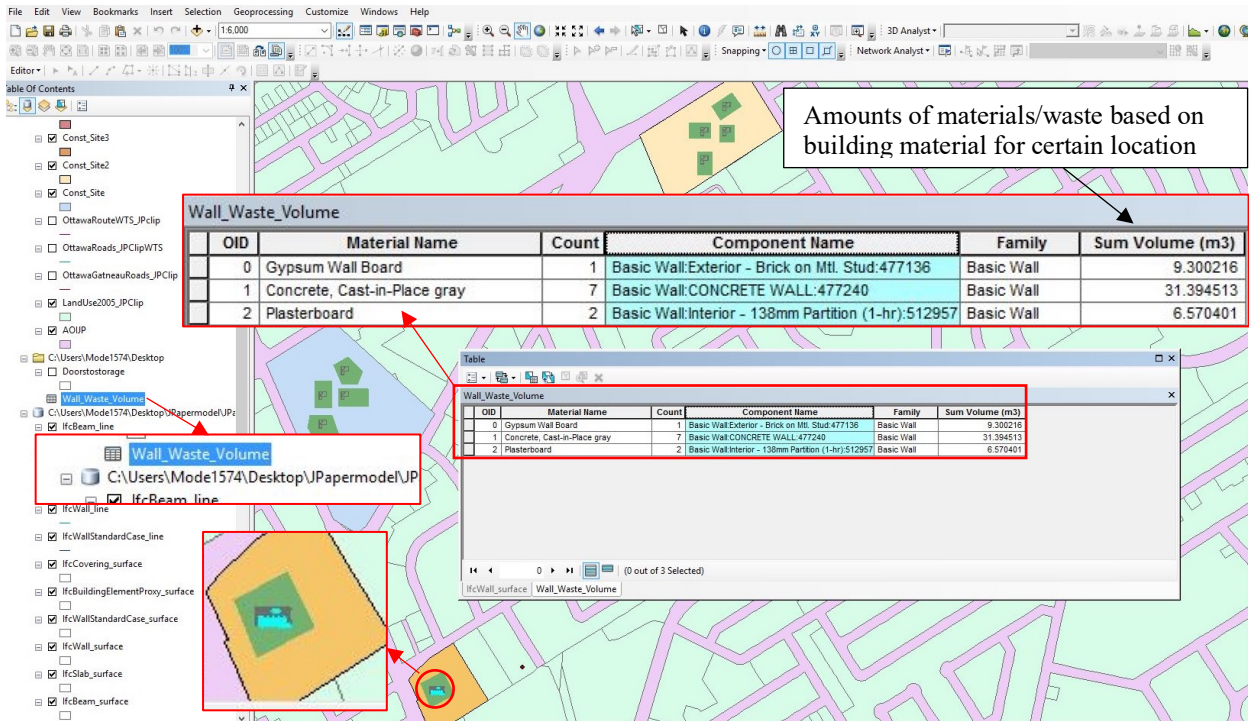


Figure 6.16: Estimating material/waste based on building material for certain location

In addition, the model is used to can identify all doors that exist on a certain site, as shown in Figure 6.17, as well as doors within a specific volume range (e.g., $\geq 0.2476 \text{ m}^3$) that are built from or containing certain material (e.g., glass) on a certain floor, as shown in Figure 6.18. Those type of analytical capabilities that the model offers are valuable as they help in selecting a suitable place for task points (e.g., point of material demand). A report containing information on the volumes and conditions of specific building components (i.e., ceiling) is produced by the model, as in shown Figure 6.19.

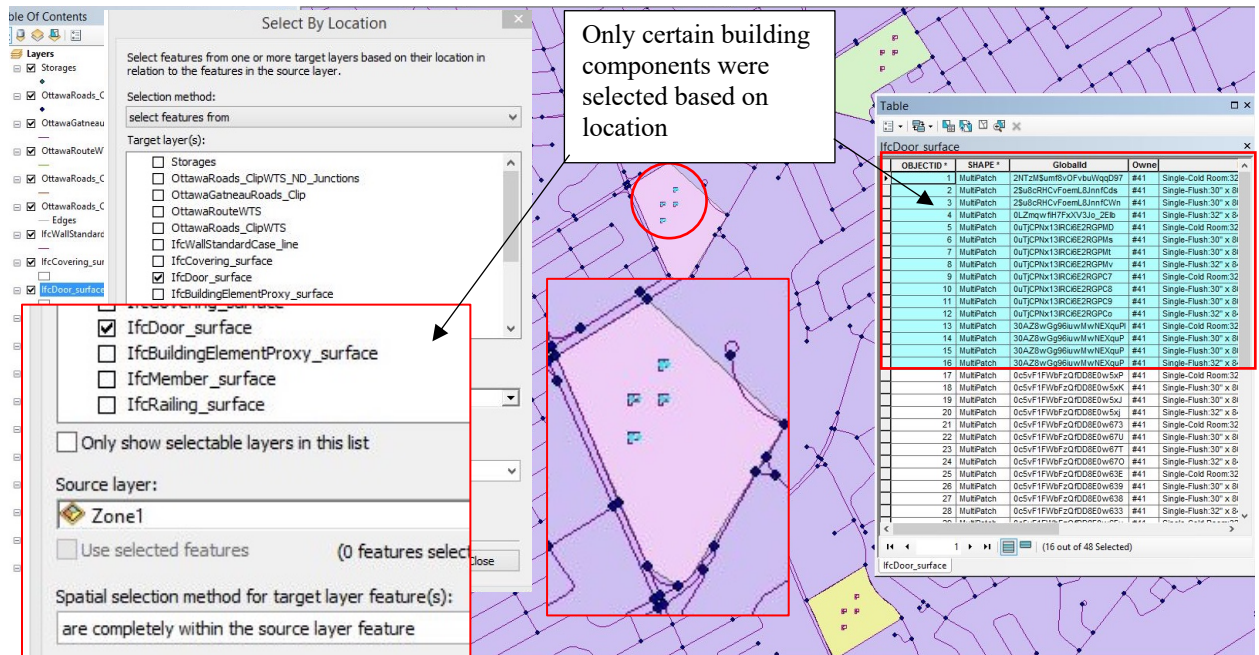


Figure 6.17: Identifying the amounts of building components/waste based on location.

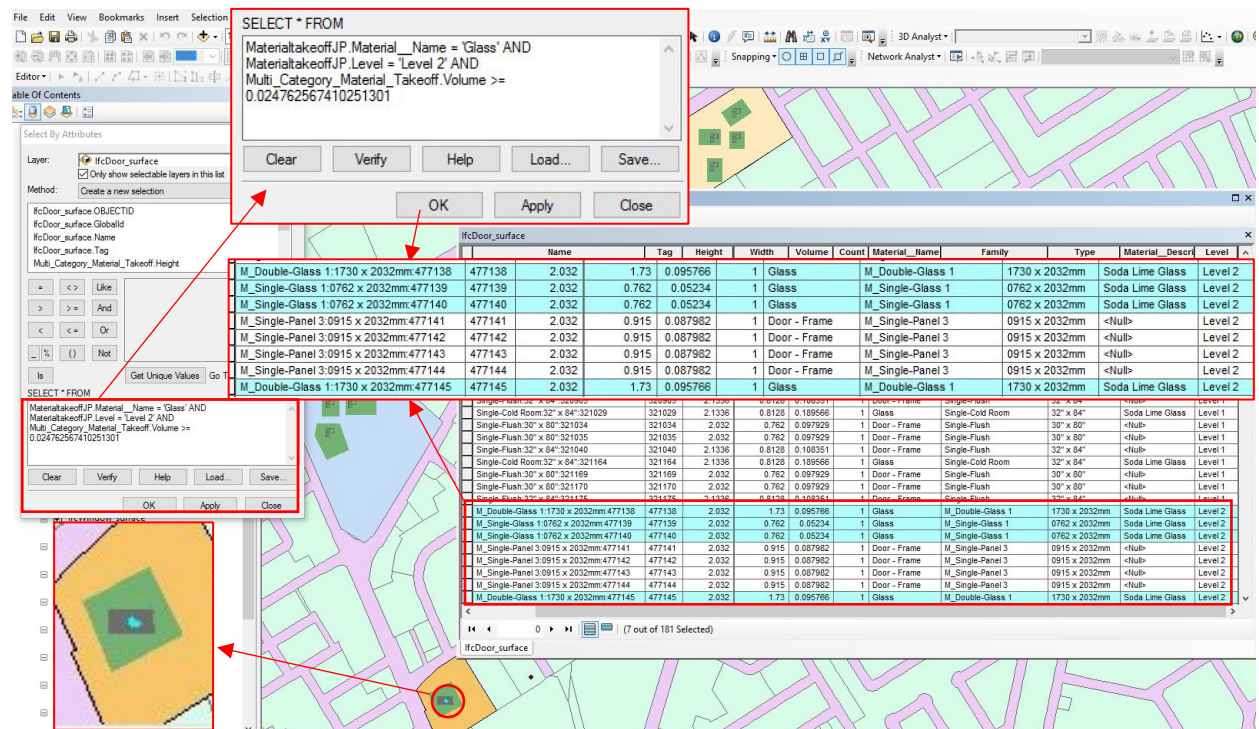


Figure 6.18: Identifying the amounts of waste based on thematic locational attributes

Ceiling

| Material condition | Ceiling volume |
|-------------------------|----------------|
| Recyclable | |
| | 52.573065 |
| | 52.573065 |
| | 52.573114 |
| | 52.573114 |
| | 52.573114 |
| | 52.573114 |
| | 54.254324 |
| | 54.254324 |
| | 54.254324 |
| | 54.254324 |
| | 54.254324 |
| | 54.254324 |
| Sum Ceiling volume (m3) | 640.964532 |
| Reusable | |
| | 52.573065 |
| Sum Ceiling volume (m3) | 52.573065 |
| Total loss | |
| | 52.573046 |
| | 52.573046 |
| | 52.573046 |
| | 52.573046 |
| | 52.573065 |
| | 54.254324 |
| | 54.254324 |
| | 54.254361 |
| | 54.254361 |
| | 54.254361 |
| | 54.254361 |
| Sum Ceiling volume (m3) | 588.39134 |
| Sum Ceiling volume (m3) | 1281.928957 |
| Sum Ceiling volume (m3) | 1281.928957 |

Figure 6.19: Sample report generated showing materials/waste quantities

6.4 Testing and verification of the developed Execution Schedule Time Entry (ESTE) module

We can enter the information for EST, EFT, AST, and AFT individually or simultaneously for a single or for multiple building components by using the user interface (UI) that was developed for that module as shown in Figure 6.20.

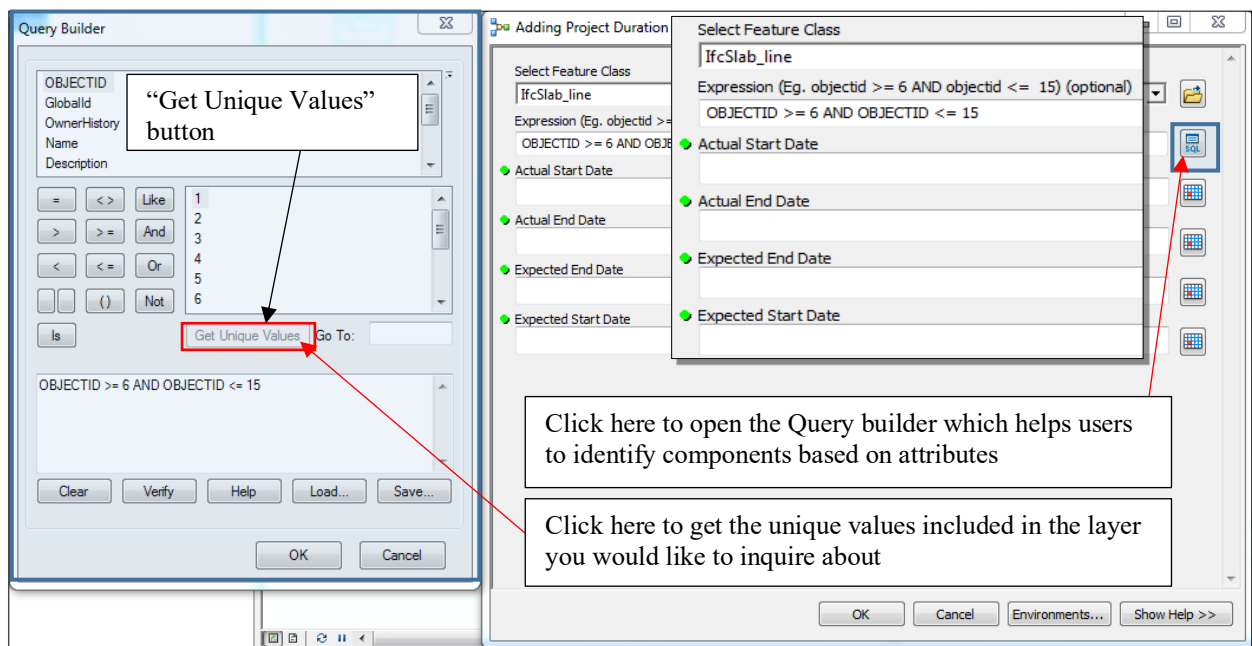


Figure 6.20: UI of the ESTE extension and layer selection via query builder

Figure 6.21 illustrates how we select from the date menu the date and time information to be allocated to the selected building components (activities). The module is used to identify the activities (building components) based on locational and thematic attributes. Using the query builder, as shown in Figure 6.20, the module is used to select based on thematic attributes a certain column, as seen in Figure 6.22, and a certain slab on a specific level or floor, as shown in Figure 6.23. While allocating time information to activities, we can quickly review the values for a certain field in the attribute table for a layer, we can do that using the “Get Unique Values” option

highlighted in Figure 6.20. This helps us to check for a certain value (e.g., a certain floor level) we want to include in the query process, as illustrated in Figure 6.23. Figures 6.24 and 6.25 show the processing of adding temporal data into the selected layers and also the selected multiple components after the time information is allocated to them by the ESTE module.

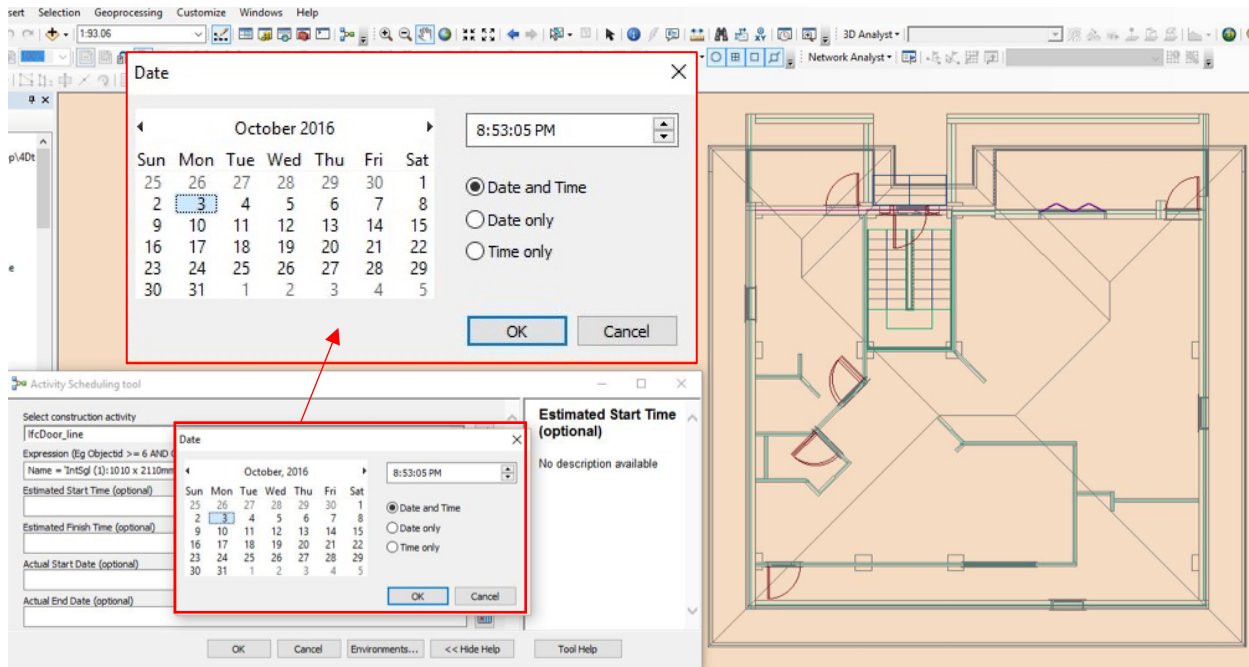


Figure 6.21: Using ESTE extension to select the time from date menu to be allocated to layers

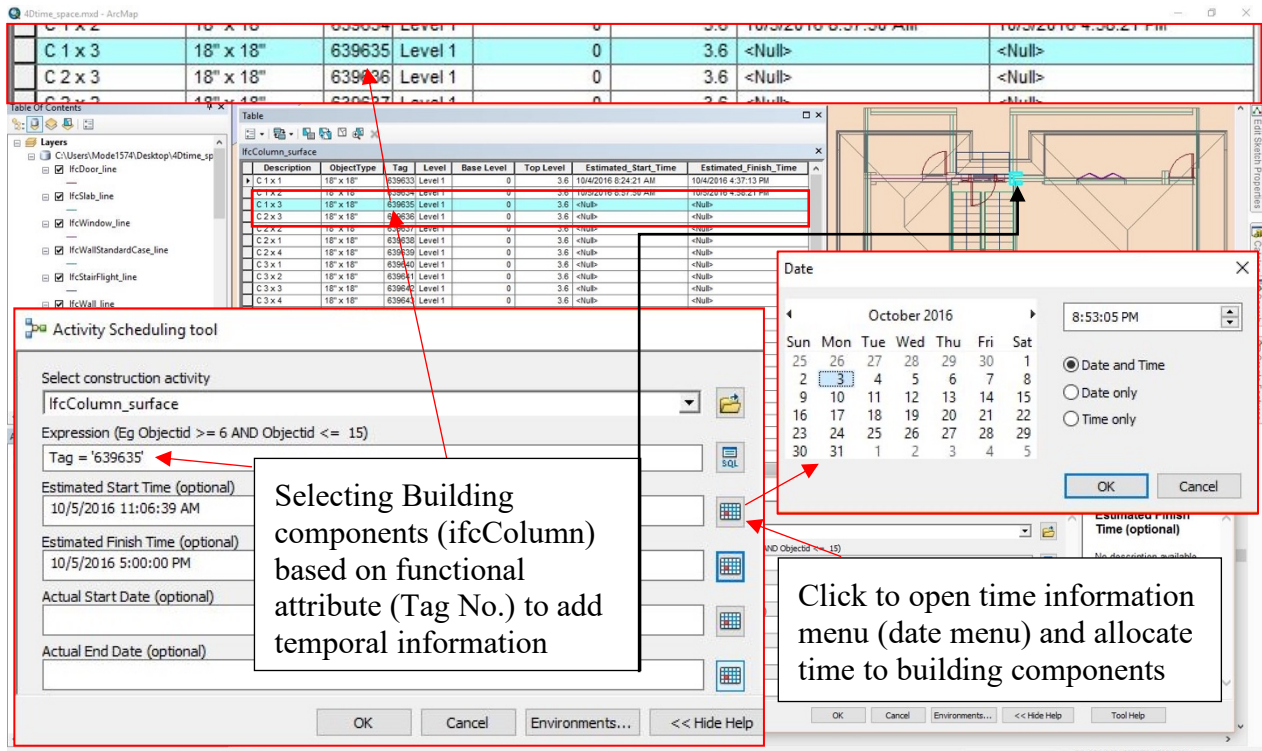


Figure 6.22: Selecting building components based on attributes using the ESTE.

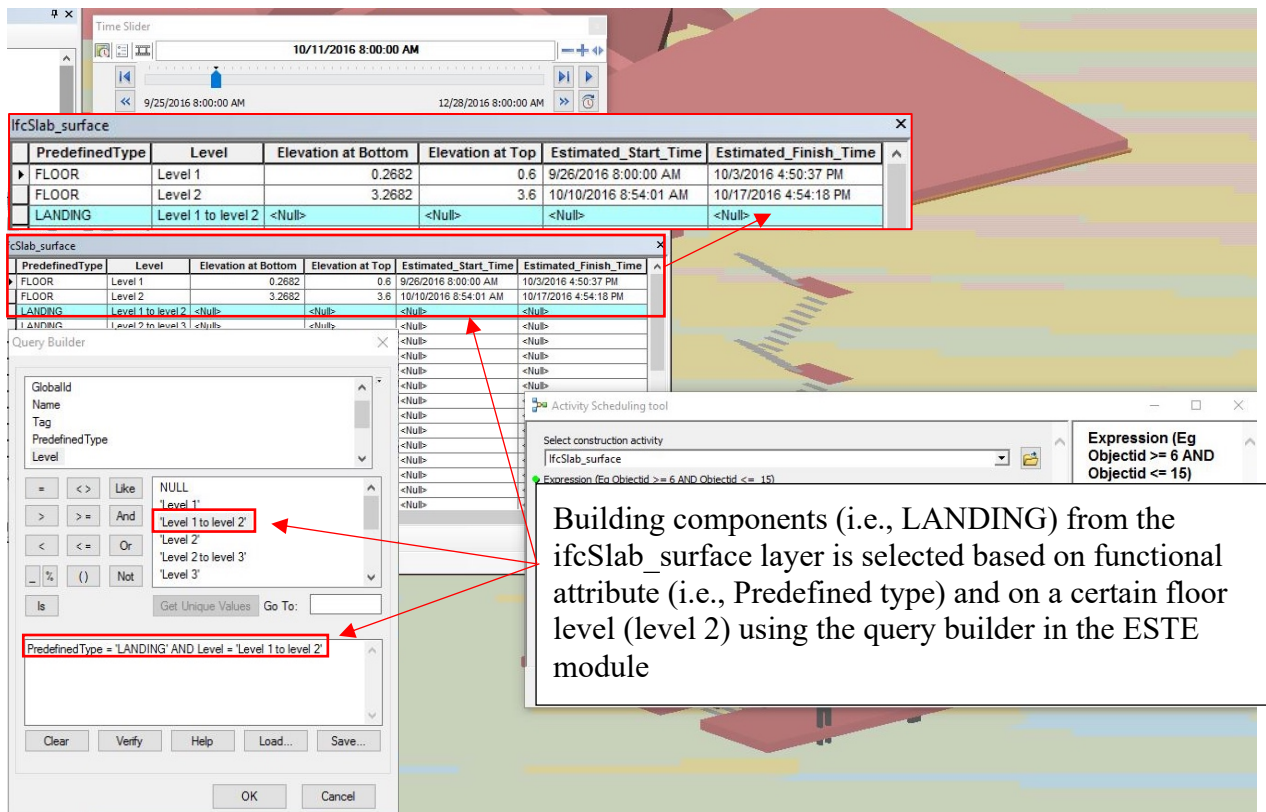


Figure 6.23: Selecting building components based on attributes by getting unique values.

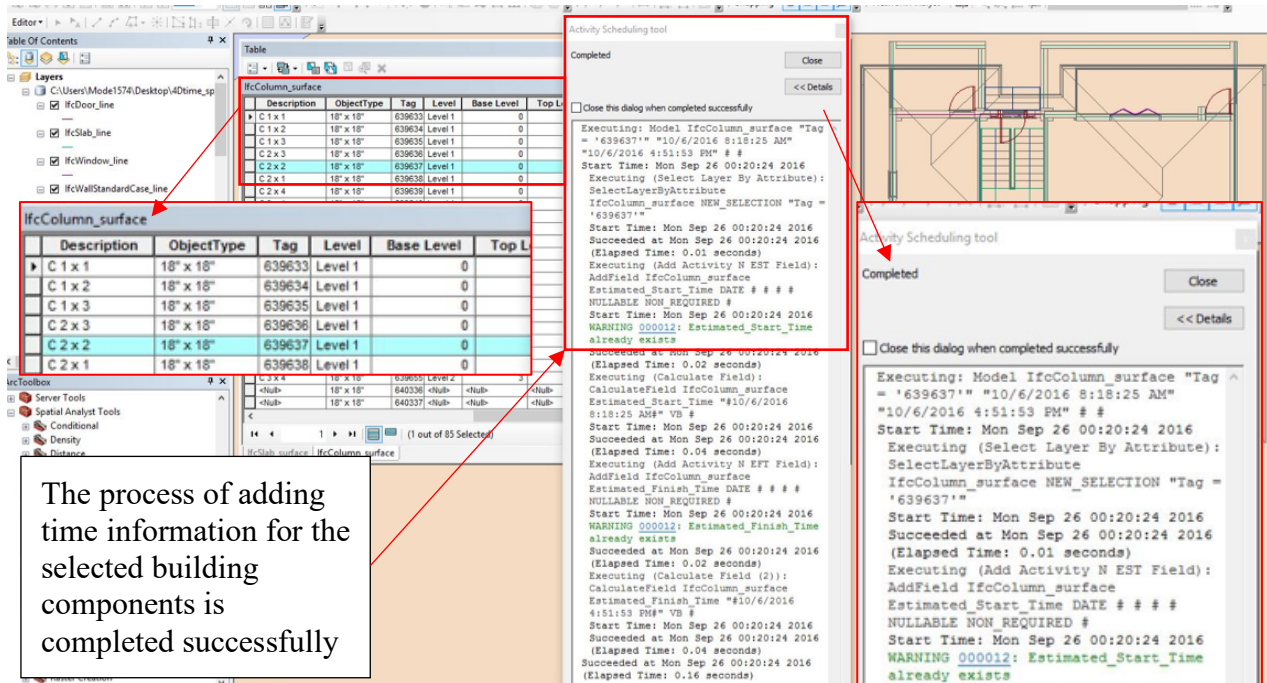


Figure 6.24: Processing and adding temporal data into selected layers.

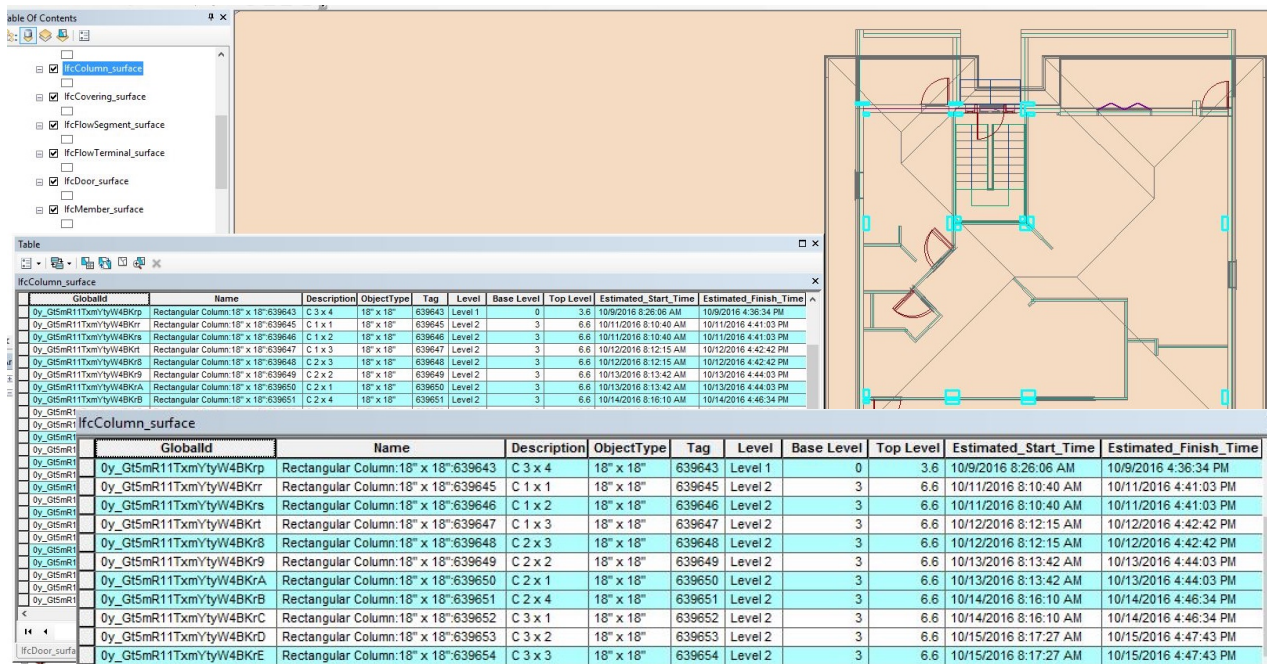


Figure 6.25: The selected multiple components after time allocation process.

6.5 Testing and verification of the developed 4D Visualization module

By using the 4D module, the construction project's progress is simulated in 4D, as shown in Figure 6.26 and the schedule and construction process flow were revised to confirm and to make modifications to the construction's execution plan. This module helps in identifying potential clashes in the construction sequence by visualizing the construction process that are hard to identify by only looking at the execution schedule. Time information is displayed on screen along with the corresponding layers. Based on that, it is possible to identify the required temporary facilities to support the construction process. Figures 6.26, 6.27 and 6.28 show the capabilities of the 4D module. This module we can export videos for the 4D models that can be used for documentation purposes. This module is also used to simulate the process flow for temporary facilities and assign and modify the number of TFs required for the construction process.

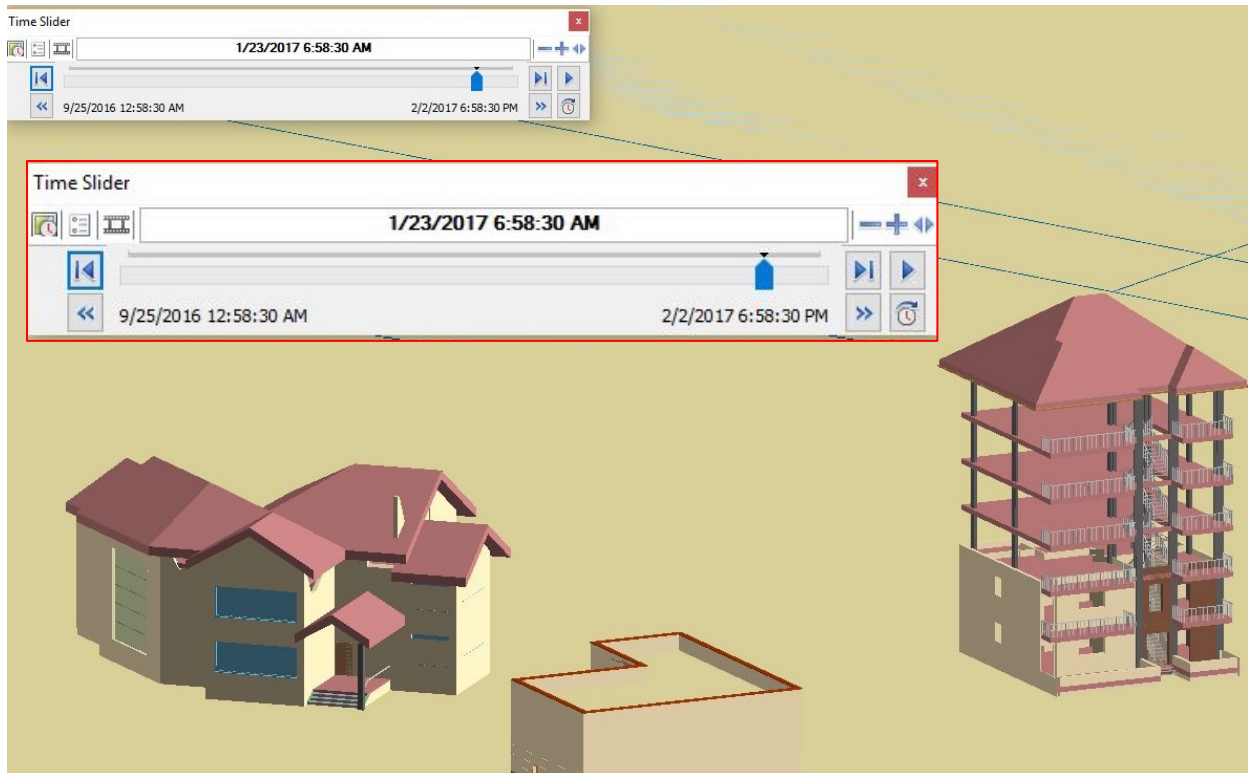


Figure 6.26: Illustration for the 4D capabilities of ArcMap (Time Slider tool)

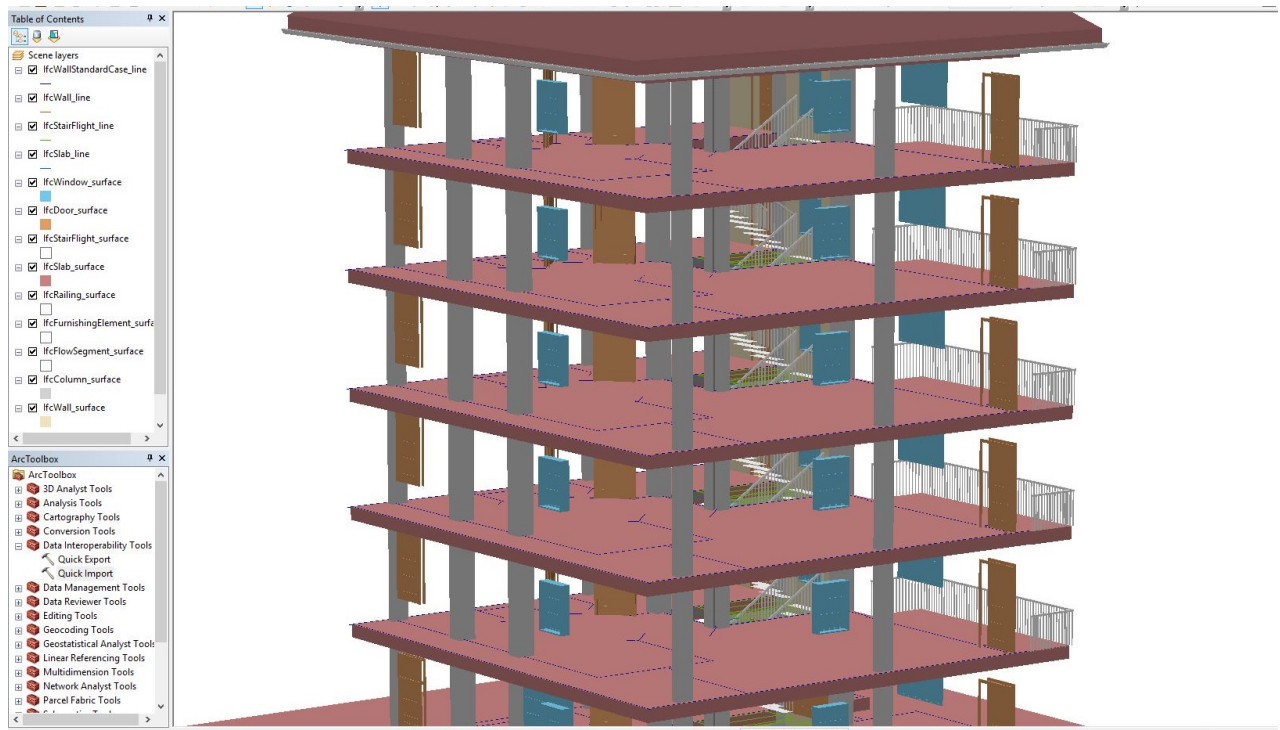


Figure 6.27: Interior view showing details of the 3D model's components

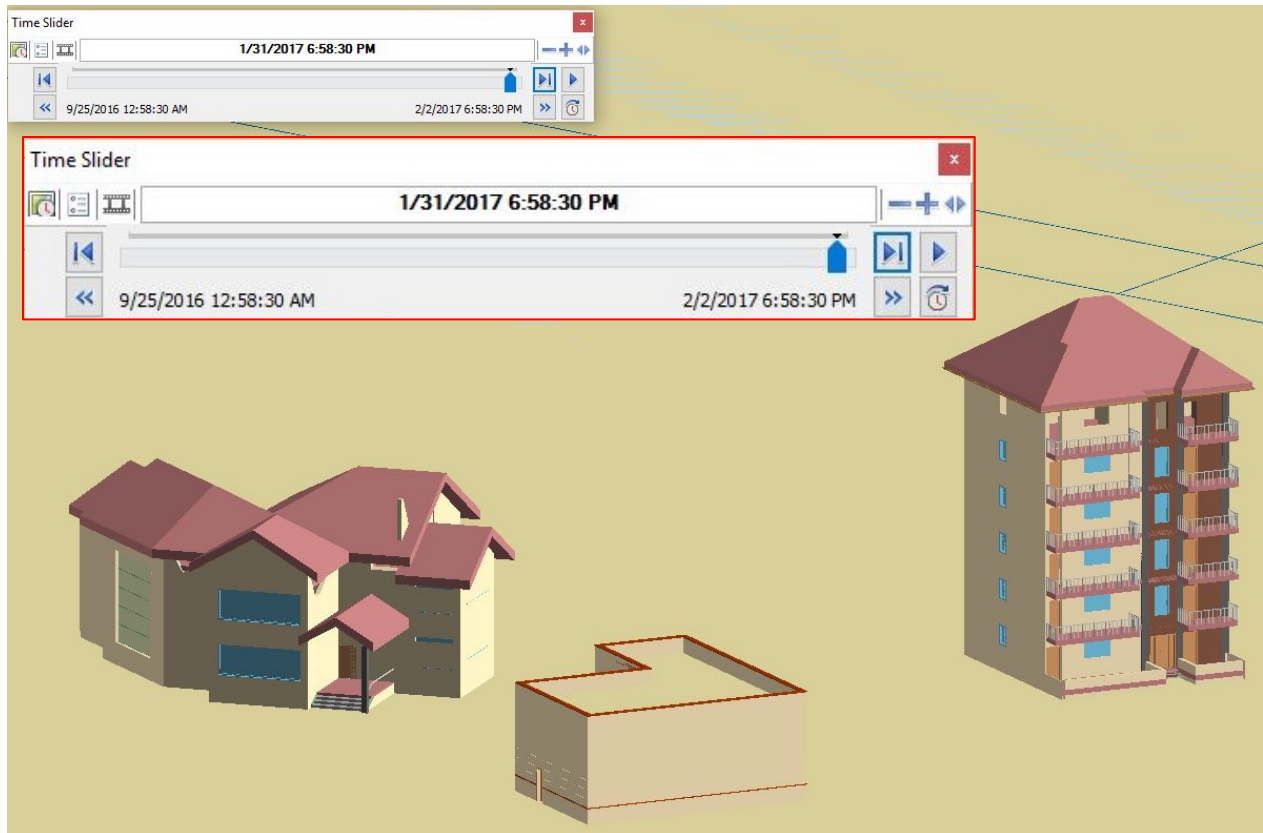


Figure 6.28: Virtual review for the construction sequence

6.6 Testing and verification of the developed Temporary facilities library (TFL) module

The developed suitable area identifier (SAI) is used to identify the available area on the construction site. First, the two points (supply and demand) are identified on the map, each in a separate layer. Then, as shown in Figure 6.29, the developed user interface (UI) for the SAI automatically identifies the layers required for this process. Then, the values assigned for the safety distance required for the different layers (i.e., roads, building, and site objects) are checked before clicking “ok” to generate the available and suitable area onsite. As shown in Figure 6.30, the module subtracts the areas for the different layers of roads, building, and site objects (while considering the spatial requirements for each layer) from the total area of the construction site and generates the suitable area on site.

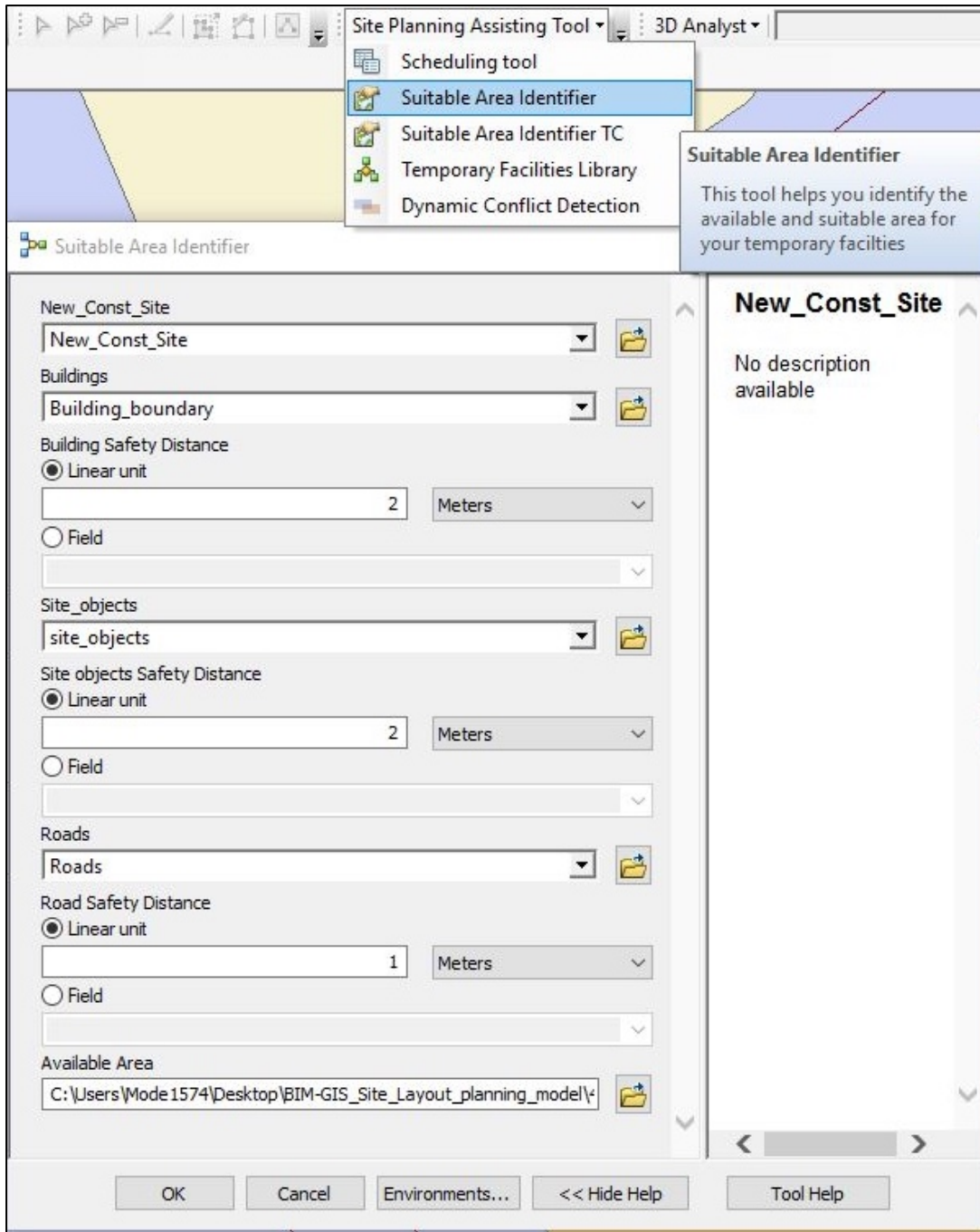


Figure 6.29: User interface for the suitable area identifier.

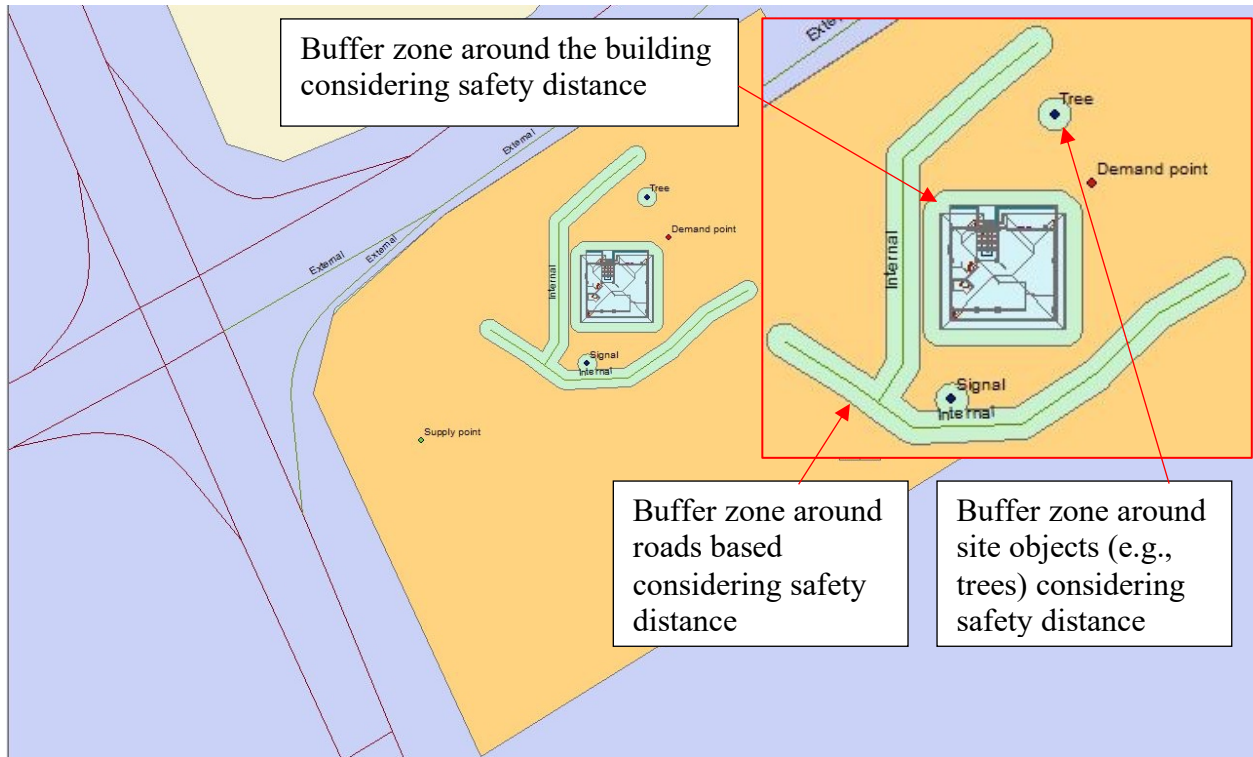


Figure 6.30: Suitable area identified by the SAI.

Also, the suitable area identifier for tower cranes (SAITC) is used to identify the suitable area for tower cranes (TCs). Figure 6.31 shows the created UI for the SAITC, which also automatically identifies the layers required for this process (i.e., suitable area and the supply and demand points). Afterwards, the jib length of the selected TC for the project is entered before clicking on “ok” to identify the suitable area for that tower crane as shown in Figure 6.32. The generated suitable area for TC can be large depending on the length of the jib for the selected TC as shown in Figure 6.32 (the beige area). This gives an indication that the selected TC for the project is larger than what might actually be needed for the construction process and, in this case, we can select a smaller TC and use the module again to identify the new suitable area for the smaller TC as shown in Figure 6.32 (the green area). Also, the lifting capacity for a TC changes based on the length of the jib as it increases as the jib length gets shorter and vice versa. Thus, we can identify the suitable area for a TC not only based on the maximum jib length but also based on any length we find appropriate,

such as the minimum jib length, for finishing the task for which we need the TC and generate the suitable area based on that length as shown in Figure 6.32 (the red area). In addition, it is possible that the module does not generate a suitable area for the selected TC based on the maximum jib length, this gives an indication that one TC is not enough to cover the target tasks and accordingly a bigger TC or more than one TC may be required to cover those tasks. This shows that the module can also help in deciding and selecting the number and type or size of some of the TFs that are required to support the construction process such as tower cranes.

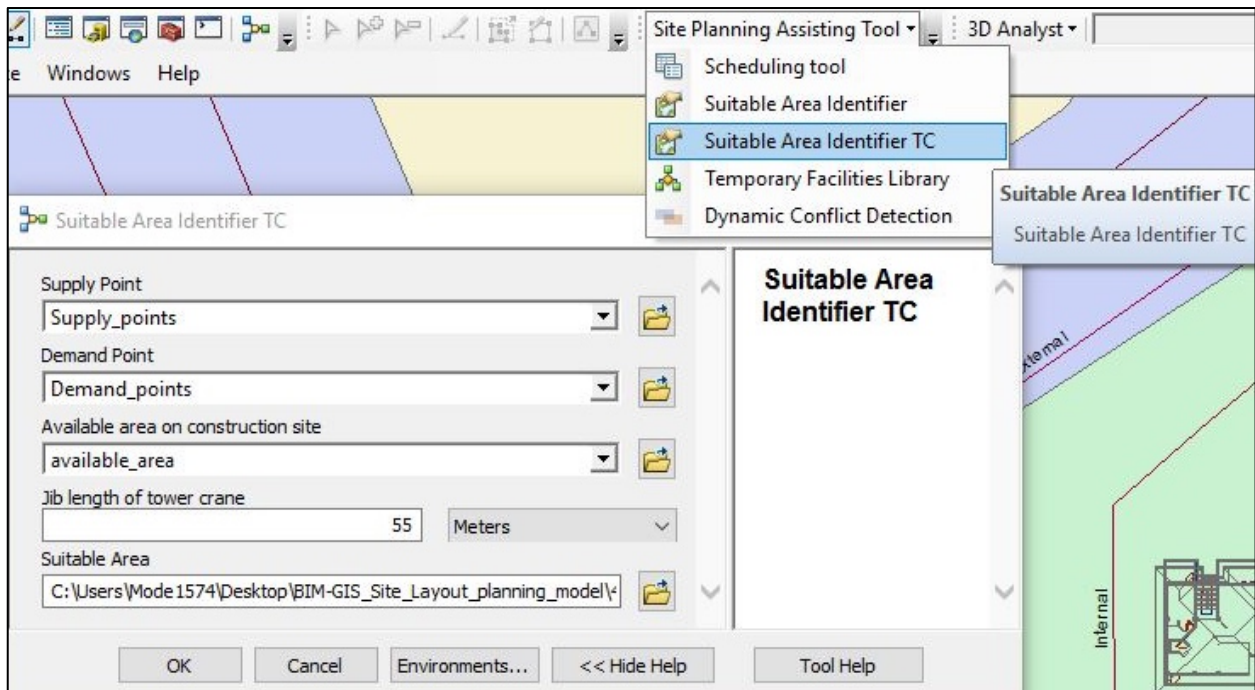


Figure 6.31: UI for the suitable area identifier for tower cranes (SAITC).

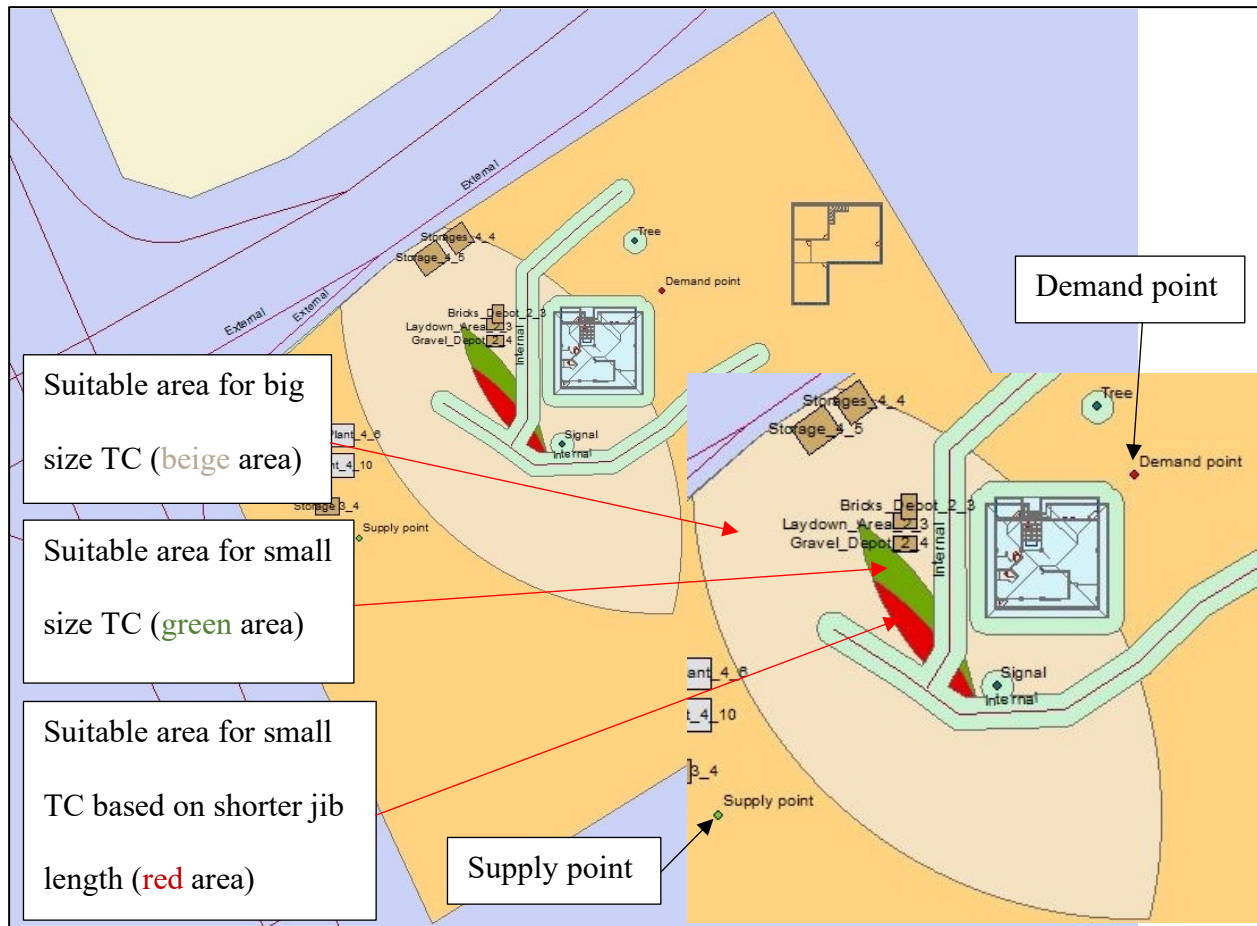


Figure 6.32: Suitable area for tower cranes identified by the module

Furthermore, the BIM-GIS SLP model provides various information such as topographical and soil information, which will help in making better judgments on locating the supply and demand points as well as some of the TFs (e.g., storage areas, laydown areas, etc.) on the construction site. Figure 6.33 shows some of the soil information for the Ottawa-Gatineau area (in Canada) from a detailed soil survey (DSS) (Agriculture and Agri-Food Canada, 2013) that is used to make good choices on the aforementioned task. This includes information about the surface slope degree, water table, drainage, types and names of the existing soil, etc. In addition, Figures 6.34 and 6.35 show more soil information gathered from boreholes found in (Agriculture and Agri-Food Canada 2019) that are close to the construction site of the case project. Figure 6.36 shows the TIN layer, which visualizes the topographical information for the construction site to show the difference in

terrain and elevation. We can use topographical and soil data gathered from authorized and specialized sources such as the sources used for the case project (i.e., Agriculture and Agri-Food Canada, 2013; Ontario Ministry of Energy, 2017; and Agriculture and Agri-Food Canada, 2019) or we can add our own soil data to the map of the construction site they working on. The integrated model is used to export the required soil information in multiple output types including report (textual), MS access database (tabular), and graphical (graphs), as shown in Figure 6.37. These multiple types of output produced by the model are shown in Figure 6.38, Figure 6.39, and Figure 6.40 and Figure 6.41 for textual, tabular, and graphical respectively. This shows the capability of the integrated model by providing us with a data-rich environment that includes information about the building, transportation network, and topographical and soil information that will support our decision making while planning the site layout and selecting the appropriate temporary facility for supporting the construction of the case project.

Table

dss_v3_on_Ottawa_Gatineau

| SURVEY | SOILNAME | PROFILE | SLOPE_P | SLOPE_LEN | STONINESS | WATERTBL | DRAINAGE | CLI | CLI_1 | CLI_2 | HYDRO | ATEXTURE |
|----------------|-----------------|---------|---------|-----------|-----------|----------|----------|-----|-------|-------|-------|----------|
| OTTAWA CARLETO | GRENVILLE | A | 1.2 | -9 1 | NO | NO | W | 3 | R | | B | L |
| OTTAWA CARLETO | REEVECRAIG | A | 1.2 | -9 0 | YU | YU | P | 3 | F | W | C | LVFS |
| OTTAWA CARLETO | MOUNTAIN | A | 1.2 | -9 0 | YU | YU | I | 3 | F | | C | FSL |
| OTTAWA CARLETO | UNCLASSIFIED | N | 1.2 | -9 0 | YU | YU | P | 2 | W | | D | SIL |
| OTTAWA CARLETO | HERBERTS CORNER | A | 1.2 | -9 0 | YU | YU | I | 4 | F | | B | LS |
| OTTAWA CARLETO | VAUDREUIL | N | 1.2 | -9 0 | YU | YU | P | 3 | F | W | C | LFS |
| OTTAWA CARLETO | REEVECRAIG | A | 1.2 | -9 0 | YU | YU | P | 3 | F | W | C | LVFS |
| OTTAWA CARLETO | JOCKVALE | A | 1.2 | -9 0 | NO | NO | W | 3 | F | | A | LFS |
| OTTAWA CARLETO | VAUDREUIL | N | 1.2 | -9 0 | YU | YU | P | 3 | F | W | C | LFS |
| OTTAWA CARLETO | MATILDA | A | 1.2 | -9 1 | YN | YN | I | 4 | F | | A | GSL |
| OTTAWA CARLETO | UNCLASSIFIED | N | 7 | -9 3 | YU | YU | W | 6 | R | | B | LS |

Figure 6.33: Some of the soil information included in the DSS

Soil_info_Ottawa_Gatineau_AOI

| PM1_MD_DEP | DRAINAGE | PM1_PHYS | PM1_LIT_MD | PM1_CHEM | PM1_WEATHR | STONINESS | ROCKINES | SURF_EXP_1 | SLP_TYPE | SLP_POS | SLP_A |
|------------|----------------|----------------------------|--------------------------------------|------------------------------|---------------|-----------|----------|------------|----------|---------|-------|
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |
| Marine | Poorly drained | Fine loamy, and fine silty | Sedimentary - siltstone and mudstone | Moderately acidic to neutral | Weak chemical | Nonstony | Nonrocky | Undulating | Simple | Middle | West |

Figure 6.34: Some of the soil information included in the boreholes

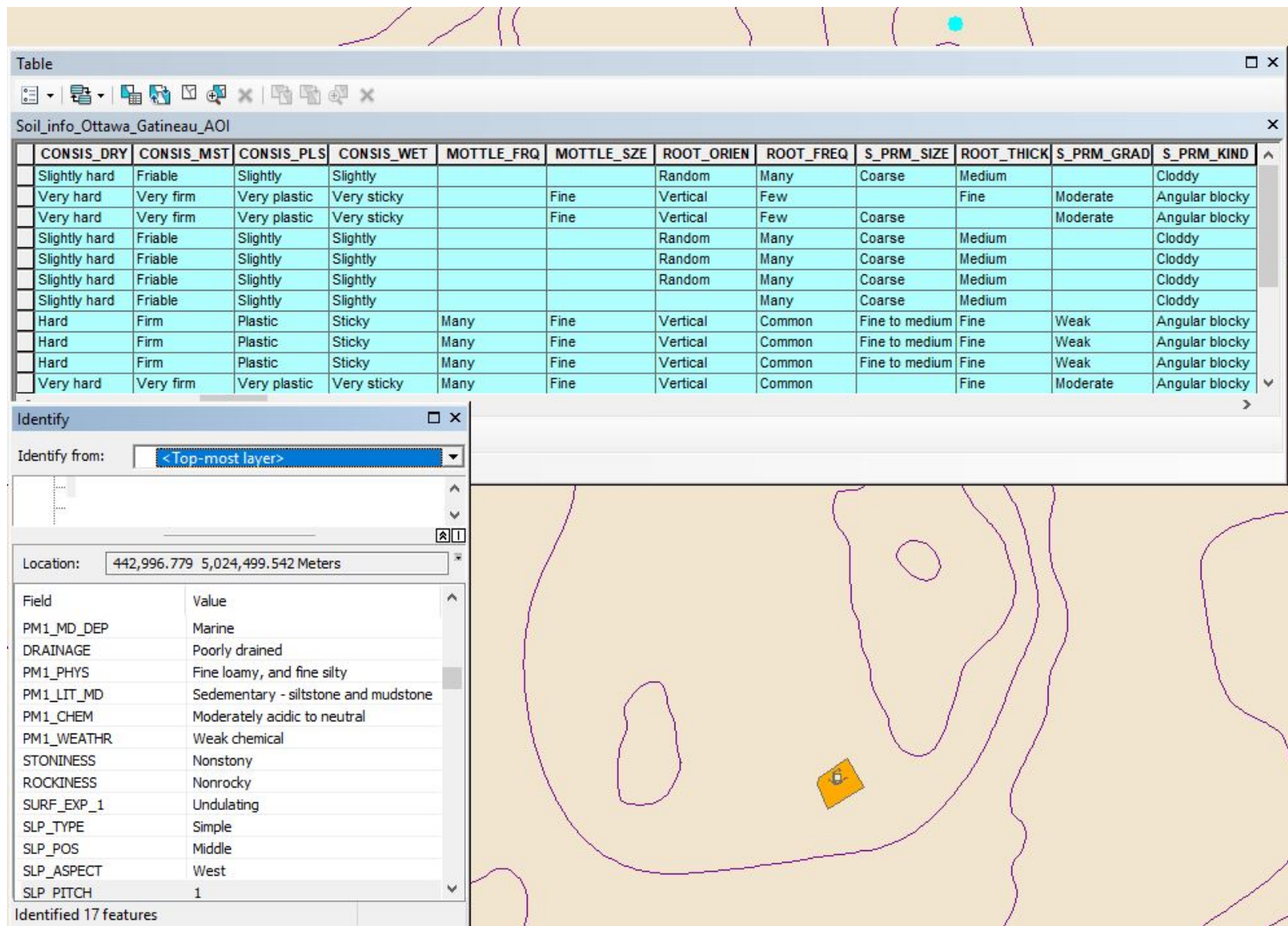


Figure 6.35: Some of the soil information included in the boreholes

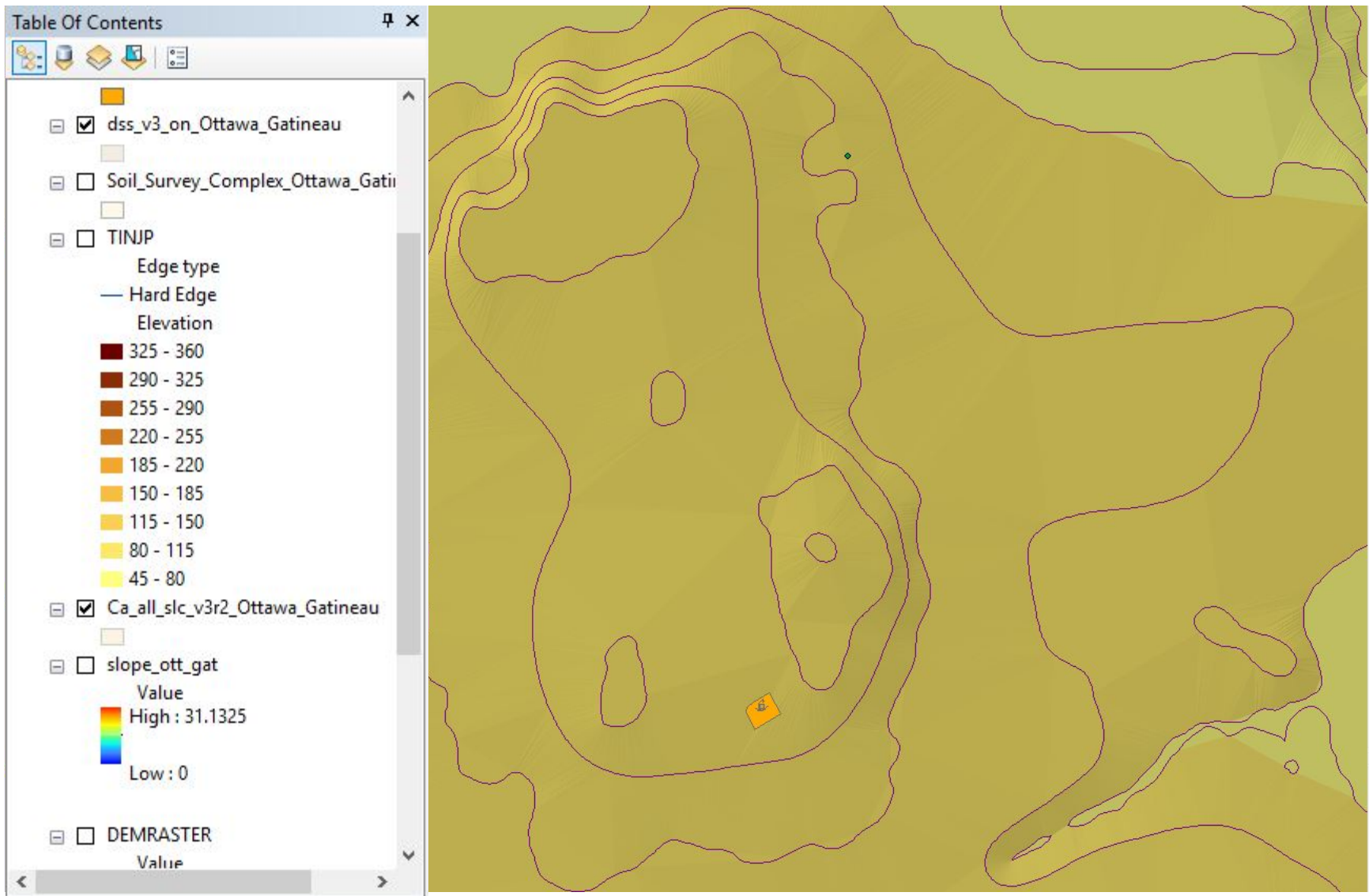


Figure 6.36: TIN layer for the construction site shows the difference in terrain and elevation

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Table

| PROVINCE | CAL_YEAR | PURPOSE | CON SIS_DRY | CON SIS_MST | CON SIS_PL S | CON SIS_WET | MOTTLE_FRQ | MOTTLE_SIZE | ROOT_FREQ | ROOT_LOCTN | ROOT_ORIEN | ROOT_THICK | S_PR M_GRAD | S_PR M_KIND | S_PR M_MOD | S_PR M_SIZE | DRAINAI |
|----------|----------|---------------|-------------|-------------|--------------|-------------|------------|-------------|-----------|------------|------------|------------|-------------|----------------|------------|----------------|--------------|
| ario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| ario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| ario | 1975 | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Angular blocky | | Fine to medium | Poorly drain |
| ario | 1975 | | Very hard | Very firm | Very plastic | Very sticky | Many | Fine | Common | Exped | Vertical | Fine | Moderate | Angular blocky | | Fine to medium | Poorly drain |
| ario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Common | Exped | Vertical | Fine | None | | | | Moderately |
| ario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Few | Exped | Vertical | Fine | None | | | | Moderately |
| ario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| ario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| ario | 1976 | Research Site | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | | | Moderately |
| ario | 1976 | Research Site | Very hard | Firm | Plastic | Sticky | | | | | | | | Angular blocky | Pseudo | Fine to medium | Moderately |

Find and Replace...

Select By Attributes...

Clear Selection

Switch Selection

Select All

Add Field...

Turn All Fields On

Show Field Aliases

Arrange Tables

Restore Default Column Widths

Restore Default Field Order

Joins and Relates

Related Tables

Create Graph...

Add Table to Layout

Reload Cache

Print...

Reports

Export...

App Export

ArcToolbox

Distributed Geodatabase

Domains

Feature Class

Append Annotation Feature

Calculate Default Spatial Grid

Calculate Default XY Tolerance

Create Feature Class

Create Unregistered Feature Class

Integrate

Recalculate Feature Class Extent

Update Annotation Feature Class

Features

Create Graph

Creates a graph from the table.

Reload Cache

Print...

Reports

Export...

App Export

ArcToolbox

Exports the table to a new table.

Create Report...

Load Report...

Run Report...

Create a report, load an existing report from a file, or regenerate a report so it reflects the latest data.

Create Report...

Creates a graph from the table.

Create Report...

Load Report...

Run Report...

Create a report, load an existing report from a file, or regenerate a report so it reflects the latest data.

Figure 6.37: Different outputs can be generated by the presented model

| Soil information from local boreholes_Location: McCooley Ln, City: Ottawa, Province: ON, Country: Canada | | | | | | | | | | | | | | | | | | | | | |
|--|----------|---------|---------------|---------|----------------|------------|----------------|------------|--------------|-------------|------------|-------------|----------------|------------|----------------|------------|------------|----------------|-------------------------|----------|-----------|
| OID | CAL_YEAR | PROV/IN | PURPOSE | CSSC_CO | N_CHEMICAL | N_PHYSICAL | CONSIDRY | CONSID_MST | CONSID_PLS | CONSID_WET | MOTTLE_FRQ | MOTTLE_SIZE | ROOT_FREQ | ROOT_LOCIN | ROOT_ORIEN | ROOT_THICK | S_PRM_GRAD | S_PRM_SIZE | DRAINAGE | STONINES | ROCKINESS |
| 1 | 1975 | Ontario | | BIV | 99 | 48 | Slightly hard | Friable | Slightly | Slightly | | | Many | | Random | Medium | | Coarse | Poorly drained | Nonstony | Nonrocky |
| 2 | 1975 | Ontario | | BIV | 99 | 48 | Very hard | Very firm | Very plastic | Very sticky | | Fine | Few | Exped | Vertical | Fine | Moderate | | Poorly drained | Nonstony | Nonrocky |
| 3 | 1975 | Ontario | | BIV | 99 | 48 | Very hard | Very firm | Very plastic | Very sticky | | Fine | Few | Exped | Vertical | | Moderate | Coarse | Poorly drained | Nonstony | Nonrocky |
| 4 | 1975 | Ontario | | BIV | 99 | 48 | Slightly hard | Friable | Slightly | Slightly | | | Many | | Random | Medium | | Coarse | Poorly drained | Nonstony | Nonrocky |
| 5 | 1975 | Ontario | | BIV | 99 | 48 | Slightly hard | Friable | Slightly | Slightly | | | Many | | Random | Medium | | Coarse | Poorly drained | Nonstony | Nonrocky |
| 6 | 1975 | Ontario | | BIV | 99 | 48 | Slightly hard | Friable | Slightly | Slightly | | | Many | | Random | Medium | | Coarse | Poorly drained | Nonstony | Nonrocky |
| 7 | 1975 | Ontario | | BIV | 99 | 48 | Slightly hard | Friable | Slightly | Slightly | | | Many | | | Medium | | Coarse | Poorly drained | Nonstony | Nonrocky |
| 8 | 1975 | Ontario | | BIV | 99 | 48 | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Fine to medium | Poorly drained | Nonstony | Nonrocky |
| 9 | 1975 | Ontario | | BIV | 99 | 48 | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Fine to medium | Poorly drained | Nonstony | Nonrocky |
| 10 | 1975 | Ontario | | BIV | 99 | 48 | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Exped | Vertical | Fine | Weak | Fine to medium | Poorly drained | Nonstony | Nonrocky |
| 11 | 1975 | Ontario | | BIV | 99 | 48 | Very hard | Very firm | Very plastic | Very sticky | Many | Fine | Common | Exped | Vertical | Fine | Moderate | | Poorly drained | Nonstony | Nonrocky |
| 12 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Loose | Loose | Nonplastic | Nonsticky | | | Common | Exped | Vertical | Fine | None | | Moderately well drained | | |
| 13 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Loose | Loose | Nonplastic | Nonsticky | | | Few | Exped | Vertical | Fine | None | | Moderately well drained | | |
| 14 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | Moderately well drained | | |
| 15 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | Moderately well drained | | |
| 16 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Loose | Loose | Nonplastic | Nonsticky | Common | Fine | Few | Exped | Vertical | Fine | None | | Moderately well drained | | |
| 17 | 1976 | Ontario | Research Site | MOK | 50 | 67 | Very hard | Firm | Plastic | Sticky | | | | | | | None | Fine to medium | Moderately well drained | | |
| Average | 82 | | Count | 17 | Max N_CHEMICAL | 99 | Min N_CHEMICAL | 50 | Average | 55 | Count | 17 | Max N_PHYSICAL | 67 | Min N_PHYSICAL | 48 | | | | | |
| N_CHEMICAL | 24 | | Sum | 1389 | | | | | Standard | 9 | Sum | 930 | | | | | | | | | |
| Deviation | | | N_CHEMICAL | | | | | | N_PHYSICAL | | Deviation | | | | | | | | | | |
| N_CHEMICAL | | | | | | | | | N_PHYSICAL | | | | | | | | | | | | |

Figure 6.38: A report generated by the presented model including soil information for the case project

| CAL_YEAR | PROVINCE | CSSC_CODE | PURPOSE | CONSID_DRY | CONSID_MS | CONSID_PLS | CONSID_WE | MOTTLE_FRQ | MOTTLE_SIZE | ROOT_FREQ | PM1_PHYS | PM1_LIT_MI | PM1_CHEM | PM1_WEATF | DRAINAGE | |
|----------|----------|-----------|---------------|---------------|-----------|--------------|-------------|------------|-------------|-----------|----------------|---------------|----------------|----------------|----------------|---------------|
| 1975 | Ontario | BIV | | Slightly hard | Friable | Slightly | Slightly | | | Many | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Very hard | Very firm | Very plastic | Very sticky | | Fine | Few | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Very hard | Very firm | Very plastic | Very sticky | | Fine | Few | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Slightly hard | Friable | Slightly | Slightly | | | Many | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Slightly hard | Friable | Slightly | Slightly | | | Many | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Slightly hard | Friable | Slightly | Slightly | | | Many | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Slightly hard | Friable | Slightly | Slightly | | | Many | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Hard | Firm | Plastic | Sticky | Many | Fine | Common | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1975 | Ontario | BIV | | Very hard | Very firm | Very plastic | Very sticky | Many | Fine | Common | Fine loamy, an | Sedimentary - | Moderately aci | Weak chemical | Poorly drained | |
| 1976 | Ontario | MOK | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Common | | | Igneous - unsp | Moderately aci | Weak chemical | Moderately we |
| 1976 | Ontario | MOK | Research Site | Loose | Loose | Nonplastic | Nonsticky | | | Few | | | Igneous - unsp | Moderately aci | Weak chemical | Moderately we |

Figure 6.39: A database table generated by the model including soil information for the case project

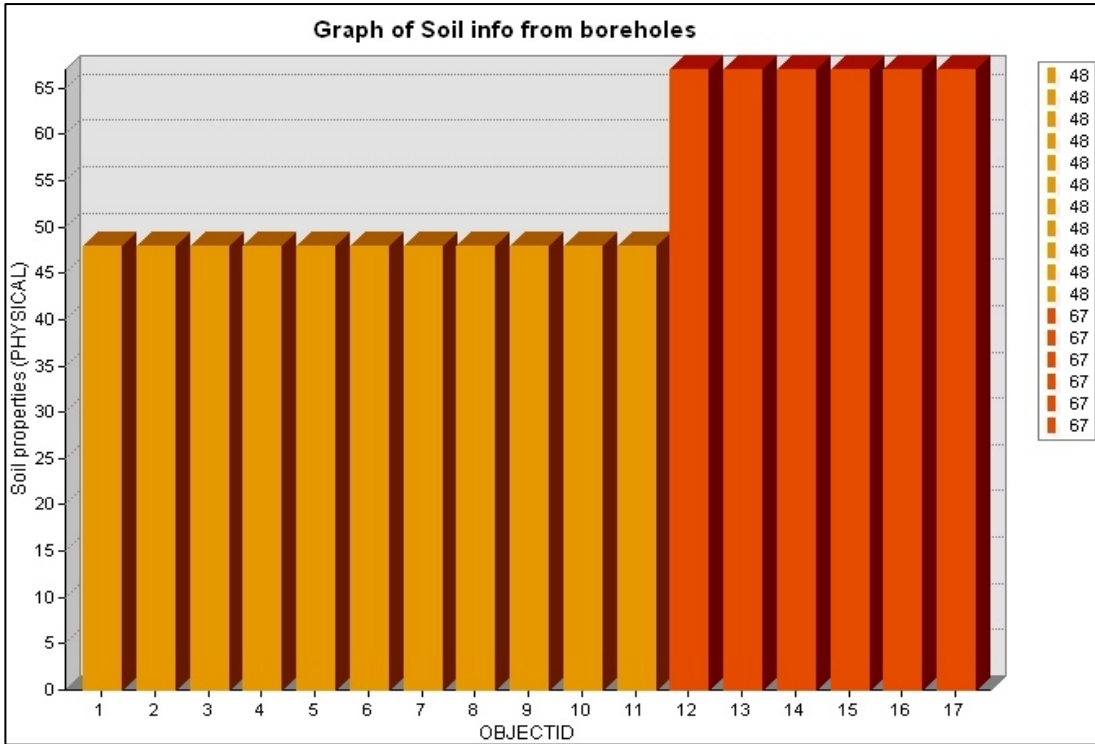


Figure 6.40: A graph generated by the model showing some properties of the soil (physical) for the case project

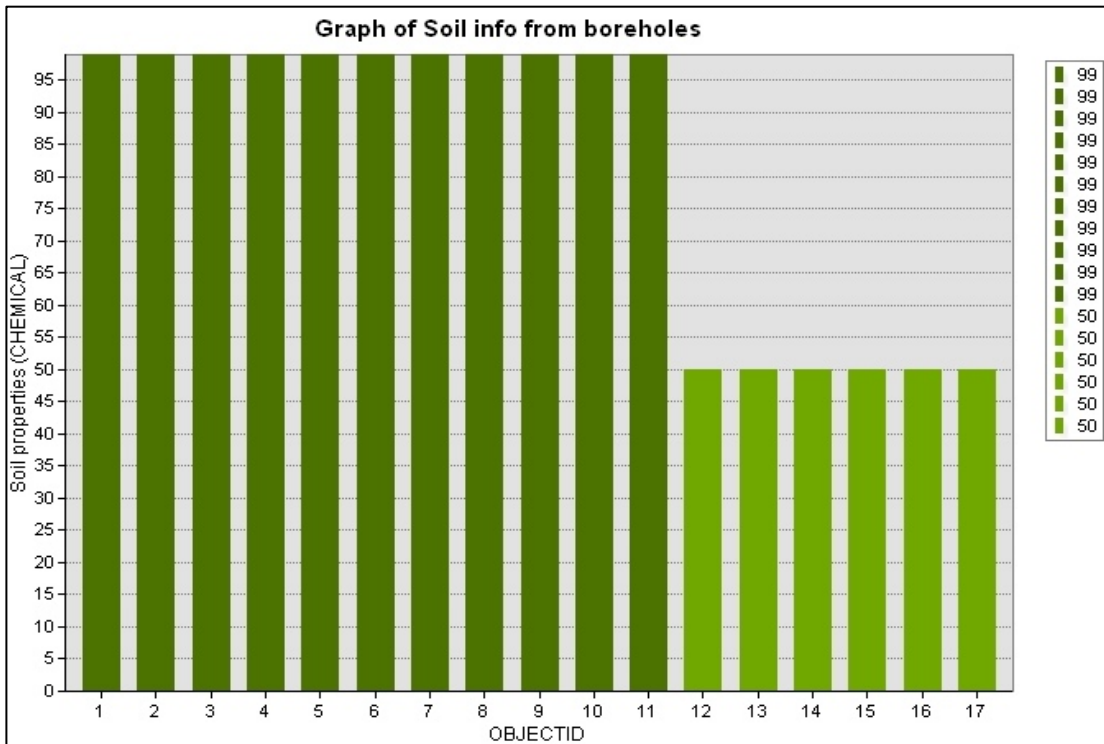


Figure 6.41: A graph generated by the model showing some properties of the soil (chemical) for the case project

After identifying the suitable areas for the construction site and for the tower cranes as shown in the previous sections, the developed temporary facilities library (TFL) is used to plan the layout for the construction site. Figure 6.42 shows how the TFL is opened by clicking on TFL button located in the created ArcSPAT tool extension. Then, the TFs required for the construction process are selected from the TFL's UI and successfully created after clicking on the chosen place on the map for each of them as shown in Figure 6.43. Figure 6.44 show some of the created TFs by the TFL while Figure 6.45 shows the attribute tables for the different TFs created by the TFL for the case project.

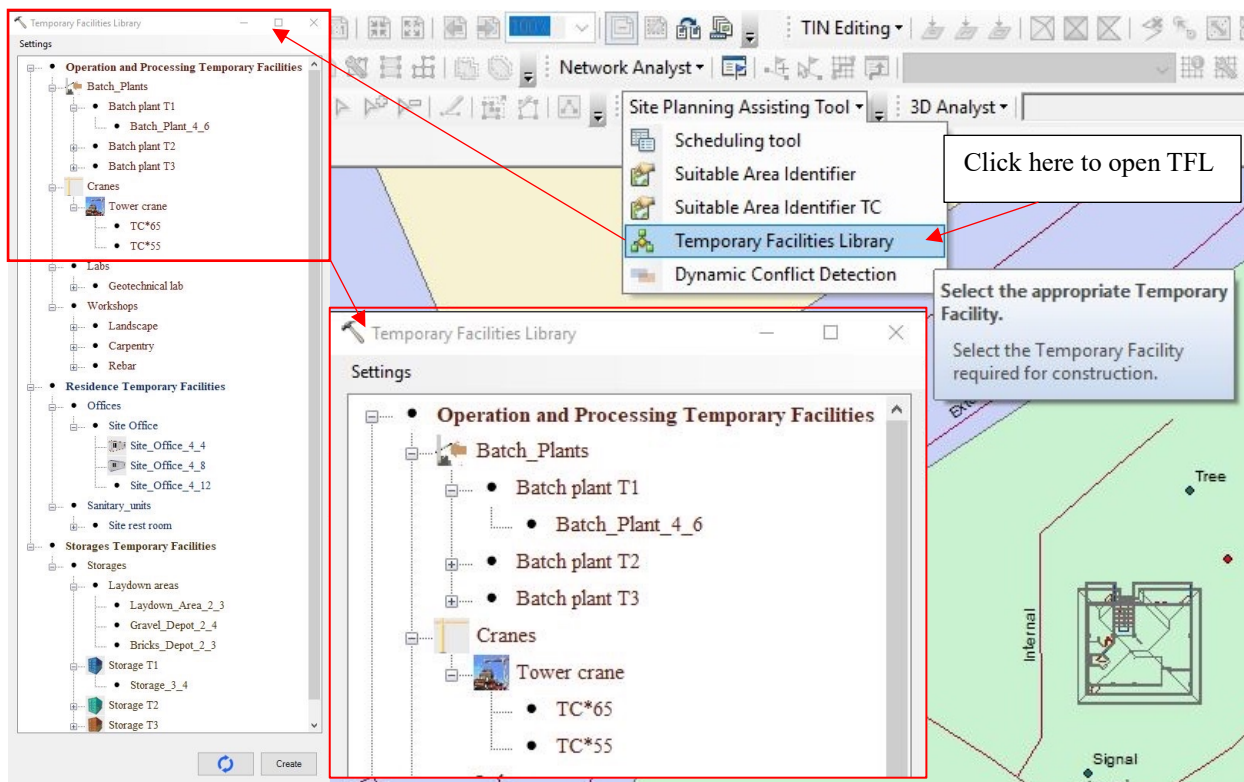


Figure 6.42: User interface (UI) for the TFL

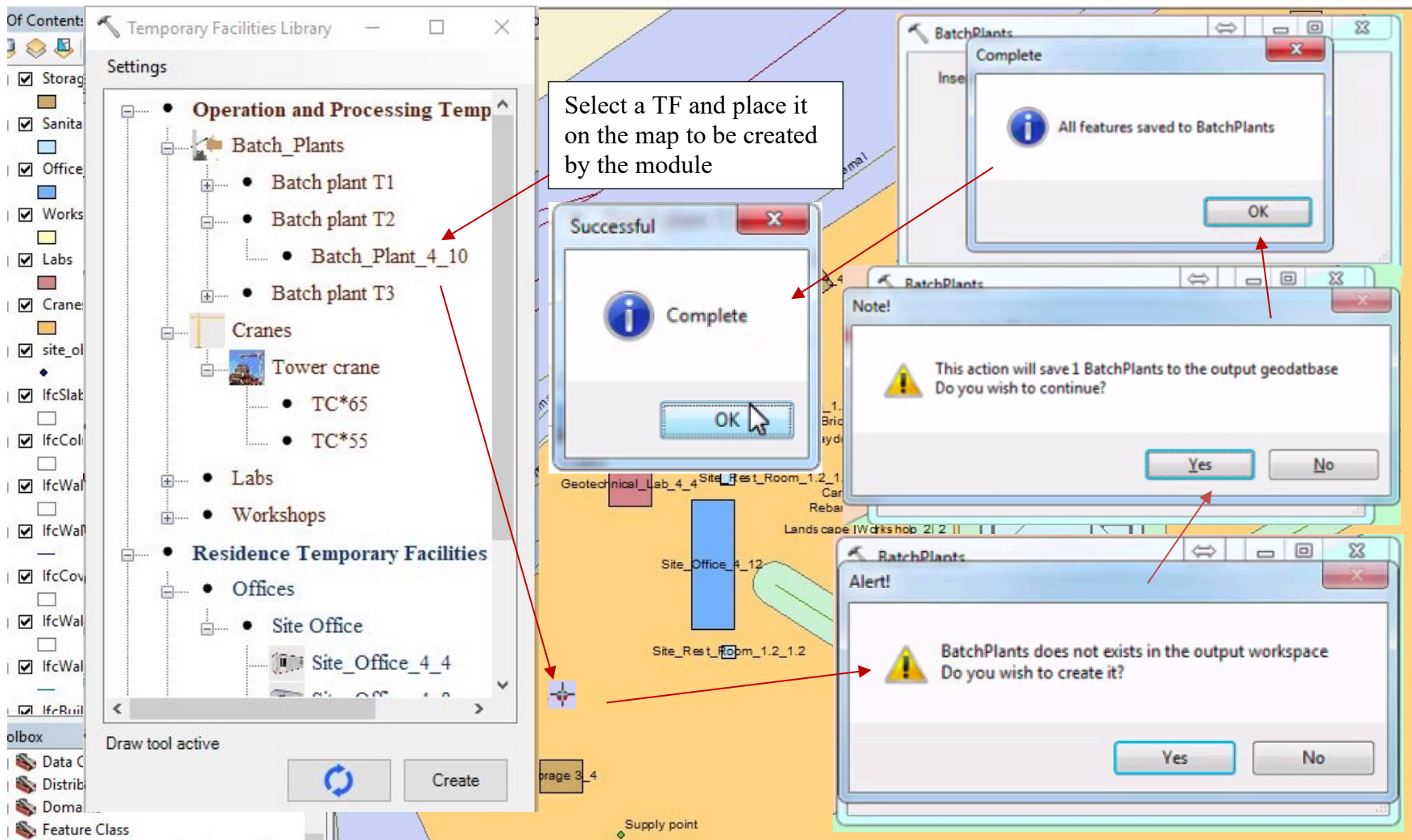


Figure 6.43: Creating temporary facilities using the TFL model

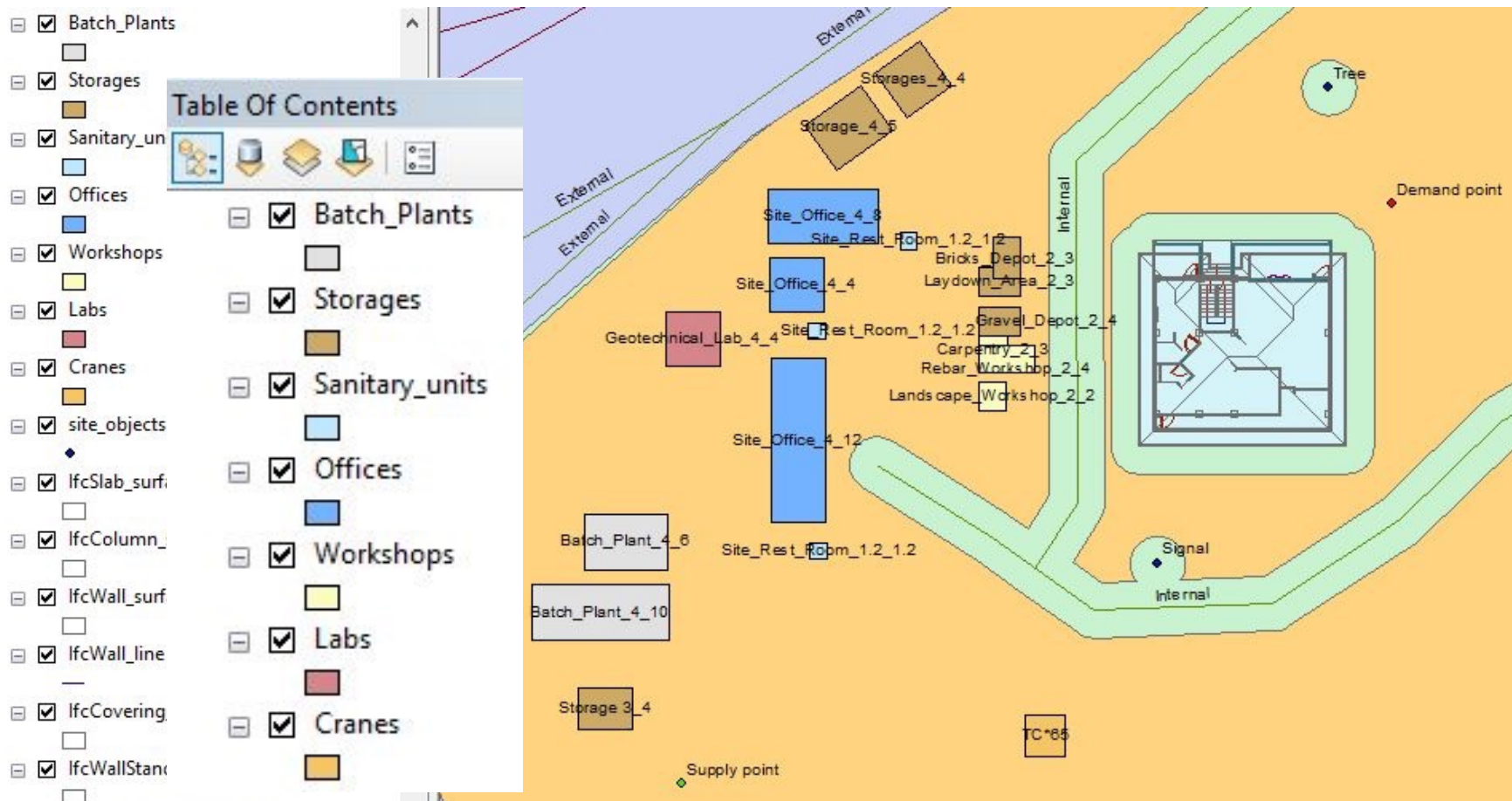


Figure 6.44: Created temporary facilities using the TFL model

| Table | | | | | | | | | | | | | | | | |
|------------|---------|-------------|-----------|---------------|------------------|--------|-------|--------|------------------|-----------------|-----------------|--------------------------|--------------|------------|--|--|
| Storages | | | | | | | | | | | | | | | | |
| OBJECTID * | Shape * | TF Category | TF Family | TF Type | TF NAME | Length | Width | Height | Operational dist | Safety distance | Sfty.D frm ofcs | M.sts | Shape_Length | Shape_Area | | |
| 1 | Polygon | STF | Storages | Laydown areas | Laydown_Area_2_3 | 3 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 | | |
| 2 | Polygon | STF | Storages | Laydown areas | Gravel_Depot_2_4 | 3 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 | | |
| 3 | Polygon | STF | Storages | Laydown areas | Bricks_Depot_2_3 | 4 | 2 | 0 | 0.7 | 0 | <Null> | <Null> | 10 | 6 | | |
| 4 | Polygon | STF | Storages | Storage T1 | Storage_3_4 | 4 | 3 | 3.6 | 0.7 | 15 | 15 | Combustive materials | 14 | 12 | | |
| 5 | Polygon | STF | Storages | Storage T2 | Storage_4_5 | 5 | 4 | 4 | 0.7 | 0 | <Null> | Non-combustive materials | 18.000121 | 20.000214 | | |
| 6 | Polygon | STF | Storages | Storage T3 | Storages_4_4 | 4 | 4 | 3.6 | 0.7 | 0 | <Null> | Non-combustive materials | 16.000172 | 16.000343 | | |

| Offices | | | | | | | | | | | | | | | | | |
|------------|---------|-------------|-----------|-------------|-----------------|--------|-------|--------|------------------|----------------|--|-----------------|--------------|------------|-----------|--|--|
| OBJECTID * | Shape * | TF Category | TF Family | TF Type | TF NAME | Length | Width | Height | Operational dist | WC within dist | Safety distance from combustive storages | Safety distance | Shape_Length | Shape_Area | | | |
| 1 | Polygon | RTF | Offices | Site Office | Site_Office_4_4 | 4 | 4 | 3.6 | 0.7 | 5 | | 10 | <Null> | 16 | 16 | | |
| 2 | Polygon | RTF | Offices | Site Office | Site_Office_4_8 | 8 | 4 | 3.6 | 0.7 | 8 | | 12 | <Null> | 24 | 32 | | |
| 3 | Polygon | RTF | Offices | Site Office | Site_Office_4_1 | 12 | 4 | 3.6 | 0.7 | 10 | | 15 | <Null> | 32.000011 | 48.000032 | | |

| Cranes | | | | | | | | | | | | | | | | | | |
|------------|---------|-------------|-------------|-----------|---------|------------------|-------|-------|----------------|----------|----------|----------|-----------------|--------|-------|--------|--------------|------------|
| OBJECTID * | Shape * | TF Category | TF Type | TF Family | TF NAME | Operational dist | Jib.L | Jib.H | Base cabinet.A | T.Sfty.D | J.Sfty.D | H.Sfty.D | Safety distance | Length | Width | Height | Shape_Length | Shape_Area |
| 1 | Polygon | OPTF | Tower crane | Cranes | TC*65 | 0.75 | 65 | 35 | 9 | 6 | 5 | 4 | 3 | 3 | 3 | 35 | 12 | 9 |
| 3 | Polygon | OPTF | Tower crane | Cranes | TC*55 | 0.75 | 55 | 30 | 4 | 5 | 5 | 5 | 0 | 2 | 2 | 30 | 8 | 4 |
| 5 | Polygon | OPTF | Tower crane | Cranes | TC*65 | <Null> | 65 | 35 | 9 | 6 | 5 | 7 | 0 | 3 | 3 | 35 | 12 | 9 |

| Batch_Plants | | | | | | | | | | | | | | |
|--------------|---------|-------------|--------------|----------------|------------------|--------|-------|--------|------------------|-----------------|--------------|------------|--|--|
| OBJECTID * | SHAPE * | TF Category | TF Family | TF Type | TF NAME | Length | Width | Height | Operational dist | Safety distance | Shape_Length | Shape_Area | | |
| 1 | Polygon | OPTF | Batch plants | Batch plant T1 | Batch_Plant_4_6 | 6 | 4 | 5 | 1 | 4 | 20 | 24 | | |
| 3 | Polygon | OPTF | Batch plants | Batch plant T2 | Batch_Plant_4_10 | 10 | 4 | 6 | 1 | 5 | 28 | 40 | | |

| Workshops | | | | | | | | | | | | | | |
|------------|---------|-------------|-----------|-----------|------------------------|--------|-------|--------|------------------|-----------------|--------------|------------|--|--|
| OBJECTID * | Shape * | TF Category | TF Family | TF Type | TF NAME | Length | Width | Height | Operational dist | Safety distance | Shape_Length | Shape_Area | | |
| 1 | Polygon | OPTF | Workshops | Landscape | Landscape_Workshop_2_2 | 2 | 2 | 1.8 | 0.7 | 0 | 8 | 4 | | |
| 2 | Polygon | OPTF | Workshops | Carpentry | Carpentry_2_3 | 3 | 2 | 1.8 | 0.7 | 0 | 10 | 6 | | |
| 3 | Polygon | OPTF | Workshops | Rebar | Rebar_Workshop_2_4 | 4 | 2 | 1.8 | 0.7 | 0 | 12.000015 | 8.00002 | | |

Figure 6.45: Attributes tables of different temporary facilities created by the TFL

Identify

Identify from: <Top-most layer>

Offices
Site_Office_4_12

Location: 364,914.629 5,023,727.165 Meters

| Field | Value |
|---------------------------|----------------------|
| OBJECTID | 3 |
| Shape | Polygon |
| Length | 12 |
| Width | 4 |
| Height | 3.6 |
| Opr dist | 0.7 |
| TF Category | RTF |
| TF Family | Offices |
| TF Type | Site Office |
| TF NAME | Site_Office_4_12 |
| Perimeter | 32.000011 |
| Area | 48.000032 |
| Sfty dist frm comb m strg | 15 |
| WC within dist | 10 |
| EST | 9/26/2018 8:00:26 AM |
| EFT | 2/4/2019 5:00:00 PM |
| Risk_Level | Urgent |

Time-space conflict detection tool

Select input .gdb: C:\Users\Mode1574\Des

Select Report Path: C:\Users\Mode1574\Des

Generating Report

Detect Conflicts

Preparing Layers

Processing IfcSlab_surface

Completed

23 conflicts detected please check Report!

| TF Category | TF Family | TF Type | TF NAME | Perimeter | Area | Sfty dist frm comb m strg | WC within dist | EST | EFT | Risk_Level |
|-------------|-----------|-------------|------------------|-----------|---------|---------------------------|----------------|----------------------|---------------------|----------------|
| RTF | Offices | Site Office | Site_Office_4_4 | 16 | 16 | 10 | 5 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Very Important |
| RTF | Offices | Site Office | Site_Office_4_8 | 24 | 32 | 8 | 8 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Important |
| RTF | Offices | Site Office | Site_Office_4_12 | 32.000011 | 48.0000 | 15 | 10 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Urgent |

| OBJECTID | Shape | Length | Width | Height | Opr dist | TF Category | TF Family | TF Type | TF NAME | Perimeter | Area | Sfty dist frm comb m strg | WC within dist | EST | EFT | Risk_Level |
|----------|---------|--------|-------|--------|----------|-------------|-----------|-------------|------------------|-----------|---------|---------------------------|----------------|----------------------|---------------------|----------------|
| 1 | Polygon | 4 | 4 | 3.6 | 0.7 | RTF | Offices | Site Office | Site_Office_4_4 | 16 | 16 | 10 | 5 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Very Important |
| 2 | Polygon | 8 | 4 | 3.6 | 0.7 | RTF | Offices | Site Office | Site_Office_4_8 | 24 | 32 | 12 | 8 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Important |
| 3 | Polygon | 12 | 4 | 3.6 | 0.7 | RTF | Offices | Site Office | Site_Office_4_12 | 32.000011 | 48.0000 | 15 | 10 | 9/26/2018 8:00:26 AM | 2/4/2019 5:00:00 PM | Urgent |

Figure 6.47: Selecting the Geodatabase for the site layout plan users working on

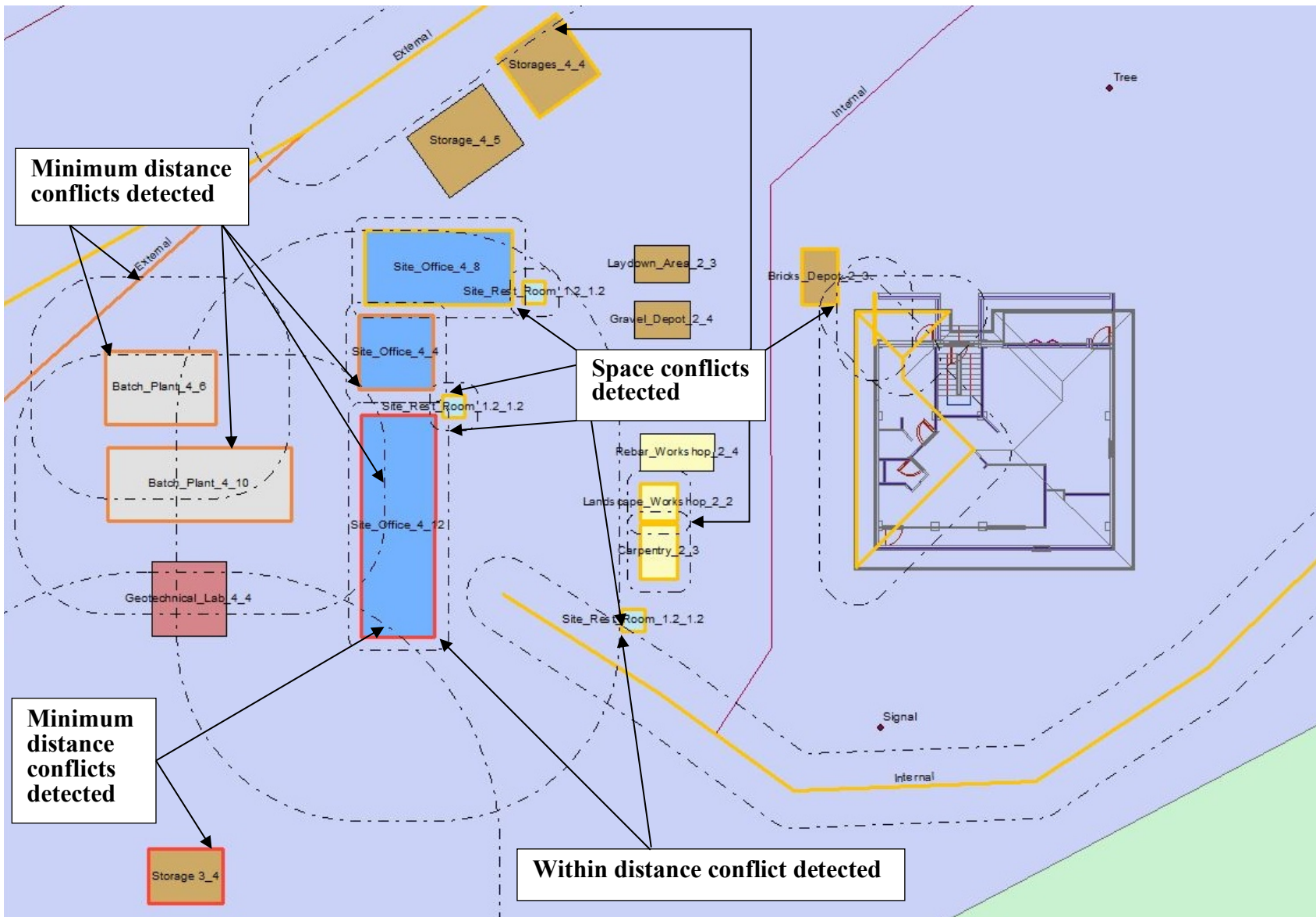


Figure 6.48: The detected conflicts are visualized on map by the DCD module

Blow up views for the detected conflicts in Figure 6.48 are shown in Figures 6.49 and 6.50.

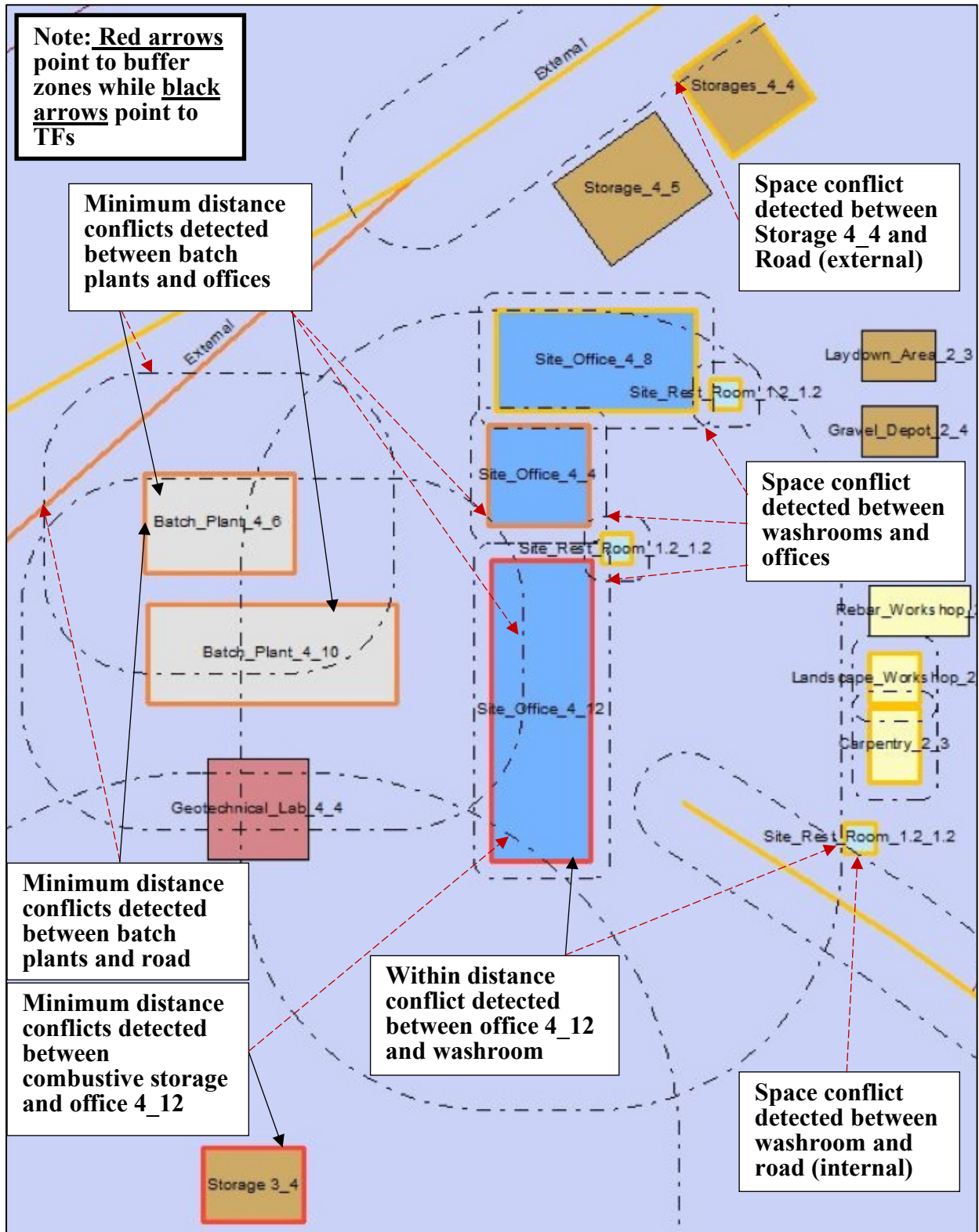


Figure 6.49: Blow-up view for the detected conflicts by the DCD (1 of 2)

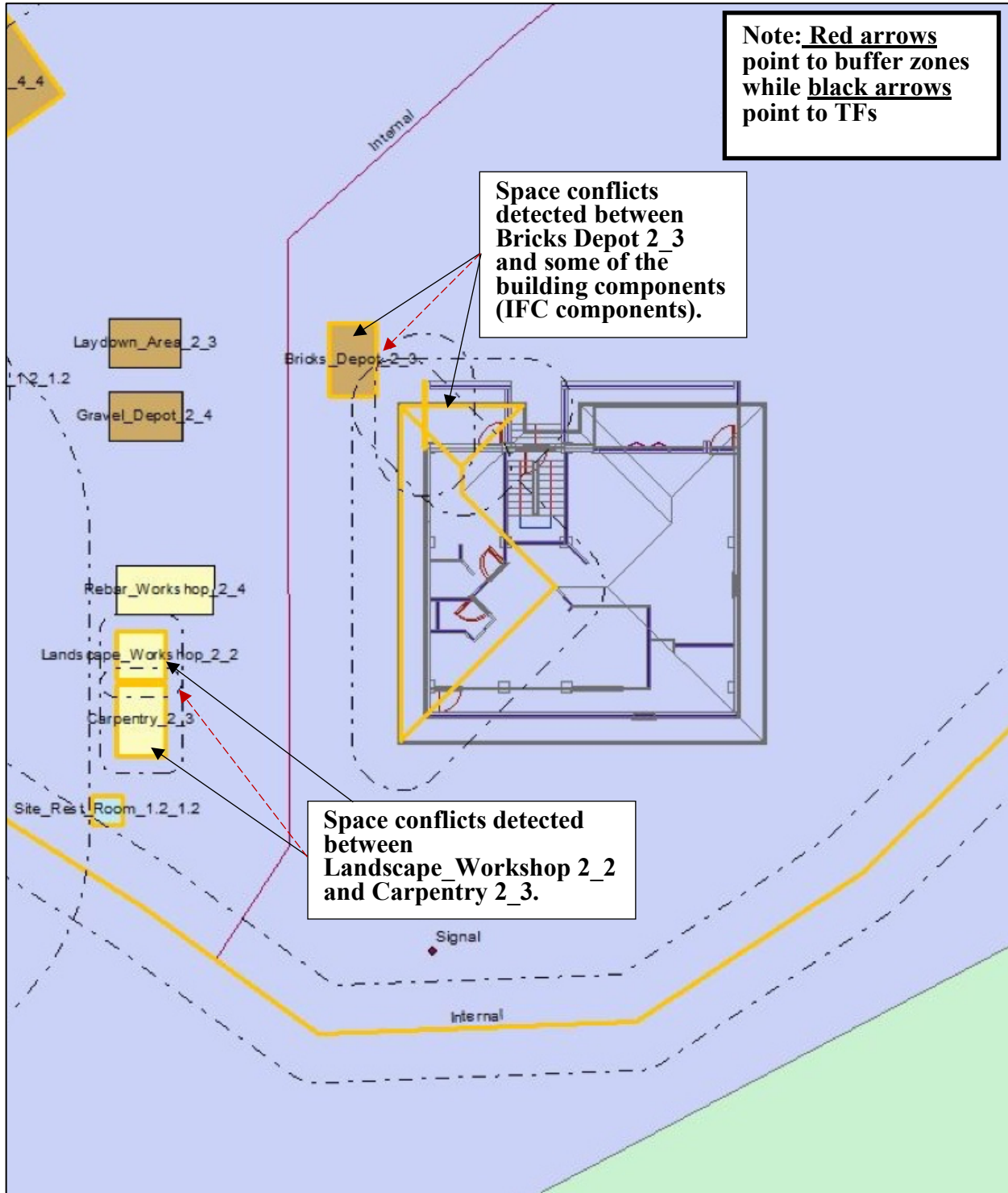


Figure 6.50: Blow up view for the detected conflicts by the DCD (2 of 2)

In addition, Figures 6.48, 6.49, and 6.50 show that even though there is no geometry overlap between Batch plant 4_6 and both the road close to it and the office 4_4 they got detected by the module as they (office 4_4 and the road) both intersected with the minimum distance required from the batch plant. Also, despite the fact that office 4_4 has a space conflict with one of the site washrooms and site office 4_8, which means it should have been highlighted on the map in yellow, since it is a geometry overlap (with an “important” risk level), it is highlighted in orange because it has another conflict (with the batch plant 4_6) that is categorized as a higher risk level (i.e., very important) and accordingly the module displays the higher risk attributes (i.e., orange color) on the map. Similar case is with the site office 4_12 that has four different conflicts; 1) A space conflict with one of the site washrooms, which is categorized as “important”; 2) it does not have a required facility (site washroom), which is categorized as “important”; 3) A hazard conflict with batch plant 4_10, which is categorized as “very important”; and 4) A hazard conflict with a combustive material storage, which is categorized as “urgent”. However, only the highest level of risk of the four detected conflicts is visualized on the map, the “urgent” level, which is presented in a red color. Nevertheless, all four conflicts are included, in detail, in the generated conflict report, as shown in Figure 6.51. All the detected conflicts between site objects that are shown in Figures 6.47, 6.48, 6.49 and 6.50 were reported by the module and included in the conflict report as shown in Figures 6.51, 6.52, 6.53

Conflict report for the site layout plan 6.xls - Compatibility Mode

Home Insert Draw Page Layout Formulas Data Review View

Multiple conflicts detected, with different risk level, for the same TF (i.e., Site office 4_12)

| | A | B | C | D | E | F | G | |
|----|-------------------------------|-------------------------------|---------------------------------------|---|---|--|-------------------------------|-------|
| 1 | NO_OF_CONFLICTS | 1 | 2 | 3 | 4 | 5 | 6 | |
| 2 | FEATURE_NAME | Storage 3_4 | Batch_Plant_4_6 | Batch_Plant_4_10 | Batch_Plant_4_10 | Site_Office_4_12 | Site_Rest_Room_1.2_1.2 | Bas |
| 3 | FEATURE_TYPE | Storage T1 | Batch plant T1 | Batch plant T2 | Batch plant T2 | Site Office | Site rest room | |
| 4 | FEATURE_ID | 4 | 1 | 3 | 3 | 3 | 1 | 104 |
| 5 | FEATURE_GUID | | | | | | | 0y_t |
| 6 | LAYER_NAME | Storages | Batch_Plants | Batch_Plants | Batch_Plants | Offices | Sanitary_units | IfcW |
| 7 | TAG_NO | | | | | | | 639 |
| 8 | FEATURE_EST | 11/15/2018 8:03:00 AM | 9/27/2018 8:08:15 AM | 9/27/2018 8:08:15 AM | 9/27/2018 8:08:15 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 1/4/ |
| 9 | FEATURE_EFT | 1/19/2019 5:00:00 PM | 1/1/2019 4:50:28 PM | 1/1/2019 4:50:28 PM | 1/1/2019 4:50:28 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 1/4/ |
| 10 | FEATURE_Coordinate_X | 364903.1258 | 364901.7489 | 364903.8741 | 364903.8741 | 364914.6293 | 364927.3623 | 364 |
| 11 | FEATURE_Coordinate_Y | 5023708.1879 | 5023734.6581 | 5023729.4256 | 5023729.4256 | 5023727.16455 | 5023722.0783 | 502 |
| 12 | CONFLICT_FEATURE_NAME | Site_Office_4_12 | External | Site_Office_4_4 | Site_Office_4_12 | | | Brict |
| 13 | CONFLICT_FEATURE_TYPE | Site Office | | Site Office | Site Office | | | Layc |
| 14 | CONFLICT_FEATURE_ID | 3 | 4 | 1 | 3 | | | 3 |
| 15 | CONFLICT_LAYER_NAME | Offices | Roads | Offices | Offices | | | Stor |
| 16 | CONFLICT_FEATURE_GUID | | | | | | | |
| 17 | CONFLICT_FEATURE_TAG_NO | | | | | | | |
| 18 | CONFLICT_FEATURE_EST | 9/26/2018 8:00:26 AM | 9/30/2018 2:38:49 PM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | | | 12/2 |
| 19 | CONFLICT_FEATURE_EFT | 2/4/2019 5:00:00 PM | 10/1/2019 2:40:44 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | | | 1/15 |
| 20 | CONFLICT_FEATURE_Coordinate_X | 364914.6293 | | 364914.5027 | 364914.6293 | | | 364 |
| 21 | CONFLICT_FEATURE_Coordinate_Y | 5023727.16455 | | 5023736.5771 | 5023727.16455 | | | 502 |
| 22 | CONFLICT_DURATION | 66 | 94 | 97 | 94 | | | 1 |
| 23 | CONFLICT_TYPE | Hazard Within Range (Offices) | Vulnerable TF is within range (Roads) | Vulnerable TF is within range (Offices) | Vulnerable TF is within range (Offices) | Required Facilites not within range (Sanitary units) | No Main TF Assigned (Offices) | Spa |
| 24 | DESCRIPTION | | | | | | | Tem |
| 25 | RISK_LEVEL | Urgent | Very Important | Very Important | Very Important | Important | Important | Imp |

Figure 6.51: Conflict report showing information about the site objects in conflict

| H | I | J | K | L | M |
|---|---|---|------------------------|------------------------|------------------------|
| 7 | 8 | 9 | 10 | 11 | 12 |
| Basic Wall:Exterior - kama-EEBS on Mtl. Stud:639671 | Basic Roof:Roof_GAF-Eik - Grand Slate over Wood Framed 1/2" CDX Deck:640549 | Basic Roof:Roof_GAF-Eik - Grand Slate over Wood Framed 1/2" CDX Deck:640549 | Site_Office_4_4 | Site_Office_4_8 | Site_Office_4_12 |
| 104 | 13 | 16 | 1 | 2 | 3 |
| 0y_Gt5mR11TxmYtyW4BKV | 0y_Gt5mR11TxmYtye4BKdD | 0y_Gt5mR11TxmYtyq4BKdD | Site Office | Site Office | Site Office |
| IfcWallStandardCase_surface | IfcSlab_surface | IfcSlab_surface | Offices | Offices | Offices |
| 639671 | 640549 | 640549 | | | |
| 1/4/2019 8:22:31 AM | 1/3/2019 8:41:28 AM | 1/3/2019 8:41:28 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM |
| 1/4/2019 4:22:44 PM | 1/13/2019 12:55:56 AM | 1/13/2019 12:55:56 AM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM |
| 364940.431121826 | 364941.530044205 | 364941.970357259 | 364914.5027 | 364916.7954 | 364914.6293 |
| 5023738.39608765 | 5023731.63949177 | 5023737.9124349 | 5023736.5771 | 5023741.1691 | 5023727.16455 |
| Bricks_Depot_2_3 | Bricks_Depot_2_3 | Bricks_Depot_2_3 | Site_Rest_Room_1.2_1.2 | Site_Rest_Room_1.2_1.2 | Site_Rest_Room_1.2_1.2 |
| Laydown areas | Laydown areas | Laydown areas | Site rest room | Site rest room | Site rest room |
| 3 | 3 | 3 | 2 | 3 | 2 |
| Storages | Storages | Storages | Sanitary_units | Sanitary_units | Sanitary_units |
| | | | | | |
| 12/20/2018 8:00:00 AM | 12/20/2018 8:00:00 AM | 12/20/2018 8:00:00 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM |
| 1/19/2019 5:00:00 PM | 1/19/2019 5:00:00 PM | 1/19/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM |
| 364937.4679 | 364937.4679 | 364937.4679 | 364917.6268 | 364922.0036 | 364917.6268 |
| 5023740.6518 | 5023740.6518 | 5023740.6518 | 5023733.6241 | 5023739.8236 | 5023733.6241 |
| 1 | 11 | 11 | 131 | 131 | 131 |
| Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict |
| Terrace | | | | | |
| Important | Important | Important | Important | Important | Important |

Figure 6.52: Conflict report showing information about space conflict between site objects

| N | O | P | Q | R | S | T | U | V |
|------------------------|------------------------|------------------------|------------------------|-----------------------|------------------------|------------------------|----------------------|----------------------|
| 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| Site_Rest_Room_1.2_1.2 | Site_Rest_Room_1.2_1.2 | Site_Rest_Room_1.2_1.2 | Internal | External | Carpentry_2_3 | Landscape_Workshop_2_2 | Site_Office_4_8 | Site_Office_4_4 |
| Site rest room | Site rest room | Site rest room | | | Carpentry | Landscape | Site Office | Site Office |
| 2 | 2 | 3 | 1 | 5 | 2 | 1 | 2 | 1 |
| Sanitary_units | Sanitary_units | Sanitary_units | Roads | Roads | Workshops | Workshops | Offices | Offices |
| | | | | | | | | |
| 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/30/2018 2:38:49 PM | 9/30/2018 2:38:49 PM | 12/29/2018 8:09:19 AM | 1/20/2019 8:00:00 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM |
| 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 1/3/2019 2:39:11 PM | 10/1/2019 2:40:44 PM | 2/2/2019 5:00:00 PM | 2/2/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM |
| 364917.6268 | 364917.6268 | 364922.0036 | | | 364928.742 | 364928.7366 | 364916.7954 | 364914.5027 |
| 5023733.6241 | 5023733.6241 | 5023739.8236 | | | 5023725.7731 | 5023728.4345 | 5023741.1691 | 5023736.5771 |
| Site_Office_4_4 | Site_Office_4_12 | Site_Office_4_8 | Site_Rest_Room_1.2_1.2 | Storages_4_4 | Landscape_Workshop_2_2 | Carpentry_2_3 | Site_Office_4_4 | Site_Office_4_8 |
| Site Office | Site Office | Site Office | Site rest room | Storage T3 | Landscape | Carpentry | Site Office | Site Office |
| 1 | 3 | 2 | 1 | 6 | 1 | 2 | 1 | 2 |
| Offices | Offices | Offices | Sanitary_units | Storages | Workshops | Workshops | Offices | Offices |
| | | | | | | | | |
| 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM | 11/15/2018 8:03:00 AM | 1/20/2019 8:00:00 AM | 12/29/2018 8:09:19 AM | 9/26/2018 8:00:26 AM | 9/26/2018 8:00:26 AM |
| 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 1/19/2019 5:00:00 PM | 2/2/2019 5:00:00 PM | 2/2/2019 5:00:00 PM | 2/4/2019 5:00:00 PM | 2/4/2019 5:00:00 PM |
| 364914.5027 | 364914.6293 | 364916.7954 | 364927.3623 | 364922.729564355 | 364928.7366 | 364928.742 | 364914.5027 | 364916.7954 |
| 5023736.5771 | 5023727.16455 | 5023741.1691 | 5023722.0783 | 5023752.10776994 | 5023728.4345 | 5023725.7731 | 5023736.5771 | 5023741.1691 |
| 131 | 131 | 131 | 96 | 66 | 14 | 14 | | 131 |
| Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict | Space Conflict |
| Important | Important | Important | Important | Important | Important | Important | Important | Important |

Figure 6.53: Conflict report showing information about space conflict between site objects

Moreover, the storage 4_4 and one of the site washrooms have space conflicts with one of the external roads and one of the internal roads respectively, since they interfered with the operational area of both roads. The level of risk for those conflicts is categorized as “important” by the DCD module and accordingly both are visualized by the corresponding yellow color. The brick depot 2_3 has space conflicts, which risk level is categorized as “important”, with the building (IFC) components, since it interferes with the area of safety distance for those components. Some of the IFC components (e.g., ifcSlab, ifcWall, etc.) may exist on different floors thus they may be on a higher level (floor) than the brick depot 2_3, which means they should not have a space conflict with it since they exist on different height levels, however the DCD module detected those conflicts, as there should be a safety distance from the building to avoid accidents due to fallen objects, which is a main cause for injuries and fatalities on construction sites. For the landscape workshop 2_2 and carpentry 2_3 the module detected a space conflict with the risk level categorized as “important”, as both have an overlap while they exist on the site during the same time period. This is not the case, as shown in Figure 6.54, for the Bricks depot 2_3 and the laydown area 2_3 and for the carpentry 2_3 and both the gravel depot 2_4 and rebar workshop since the DCD module did not detect any conflict between any of them, even though there is a clear space overlap in their geometry, because they do not have a time intersection during the period they exist on the site.

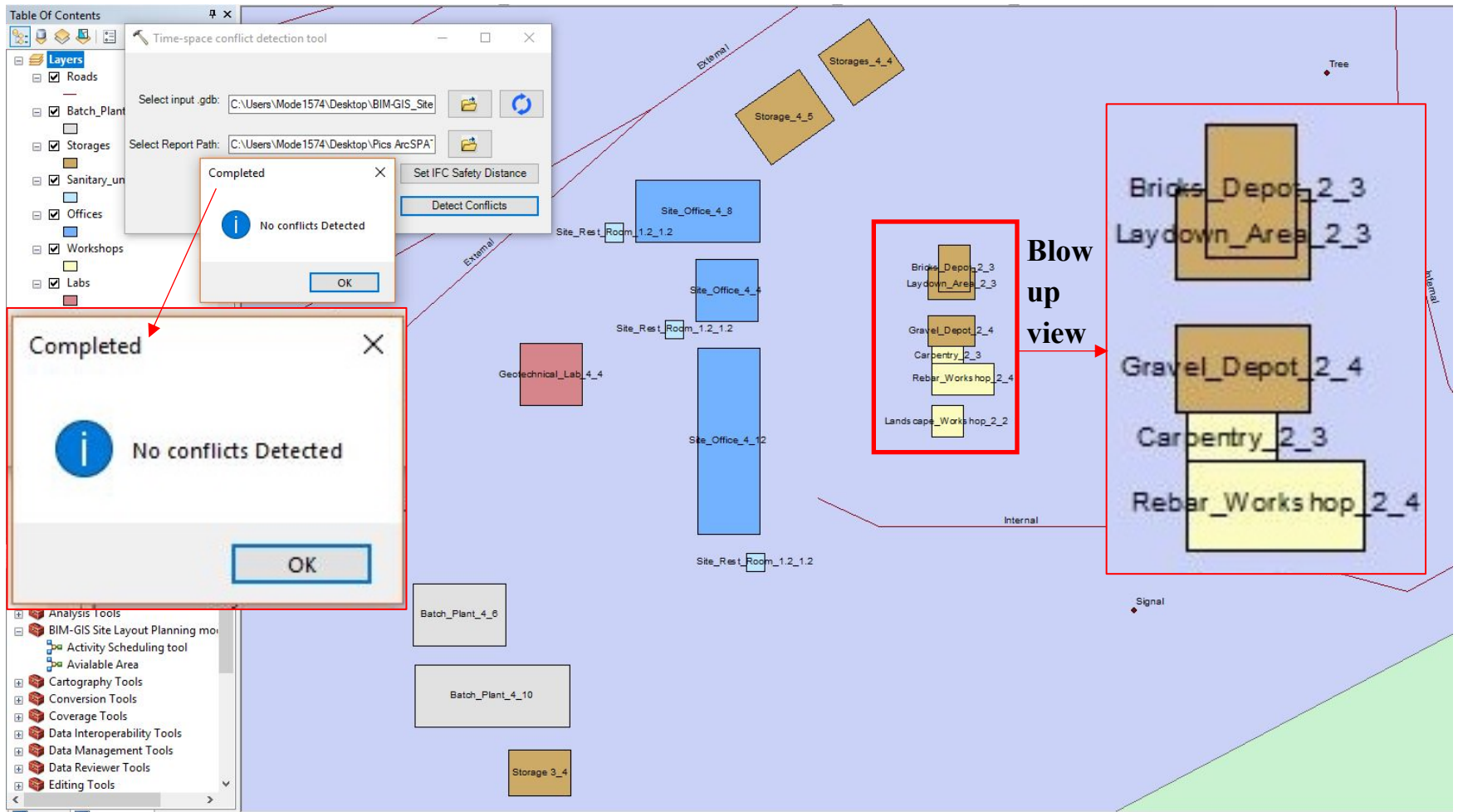


Figure 6.54: No conflicts were detected or visualized by the DCD module

Furthermore, Figure 6.55 shows how the DCD module detected TC-TC and TC-B conflicts between the 3 tower cranes (TC 1, TC 2, and TC 3) and between both tower crane 1 (TC1) and tower crane 2 (TC2) and some of the building components, respectively. The risk level for all TC conflicts is categorized as “urgent” since the DCD module considers any type of conflict that involves tower cranes as “urgent” and all conflicts accordingly are visualized on the map in red. TC 1 and TC 3 have the same height and accordingly a space conflict is detected, as shown Figure 6.55, since there should be a safety distance equivalent to or larger than H (as depicted in Equation 4.4 and Figure 4.28). The module draws two dotted lines for both TCs representing their jib length and the H safety distance for both instead of applying the larger one because the values of “ H ” for both TCs are equal in this case. Therefore, the module gives such a presentation to help users decide on the TC that should be relocated, replaced or removed. TC 1 and TC 3 have different heights than TC 2, where both TC 1 and TC 3 are higher than TC 2. The module detected a “jib-tower mast” conflict between TC 2 and TC 3 because the jib of TC 2 interfered with the Tower mast safety distance X (as shown in Figure 4.29). However, such a conflict was not detected between TC 2 and TC1 because the distance between the jib of TC 2 and the tower mast of TC 1 is larger than the value of the tower mast safety distance (X). Furthermore, the module detected a “jib-jib” conflict between TC 1 and TC 2 as the (Y) distance (as depicted in Equation 4.5 and Figure 4.29) between the jib of the taller TC (TC 1) and the jib of the shorter TC (TC 2) is less than the value of the safety distance ($H.Safety.D$) stored in the attribute table of the taller TC (TC 1).

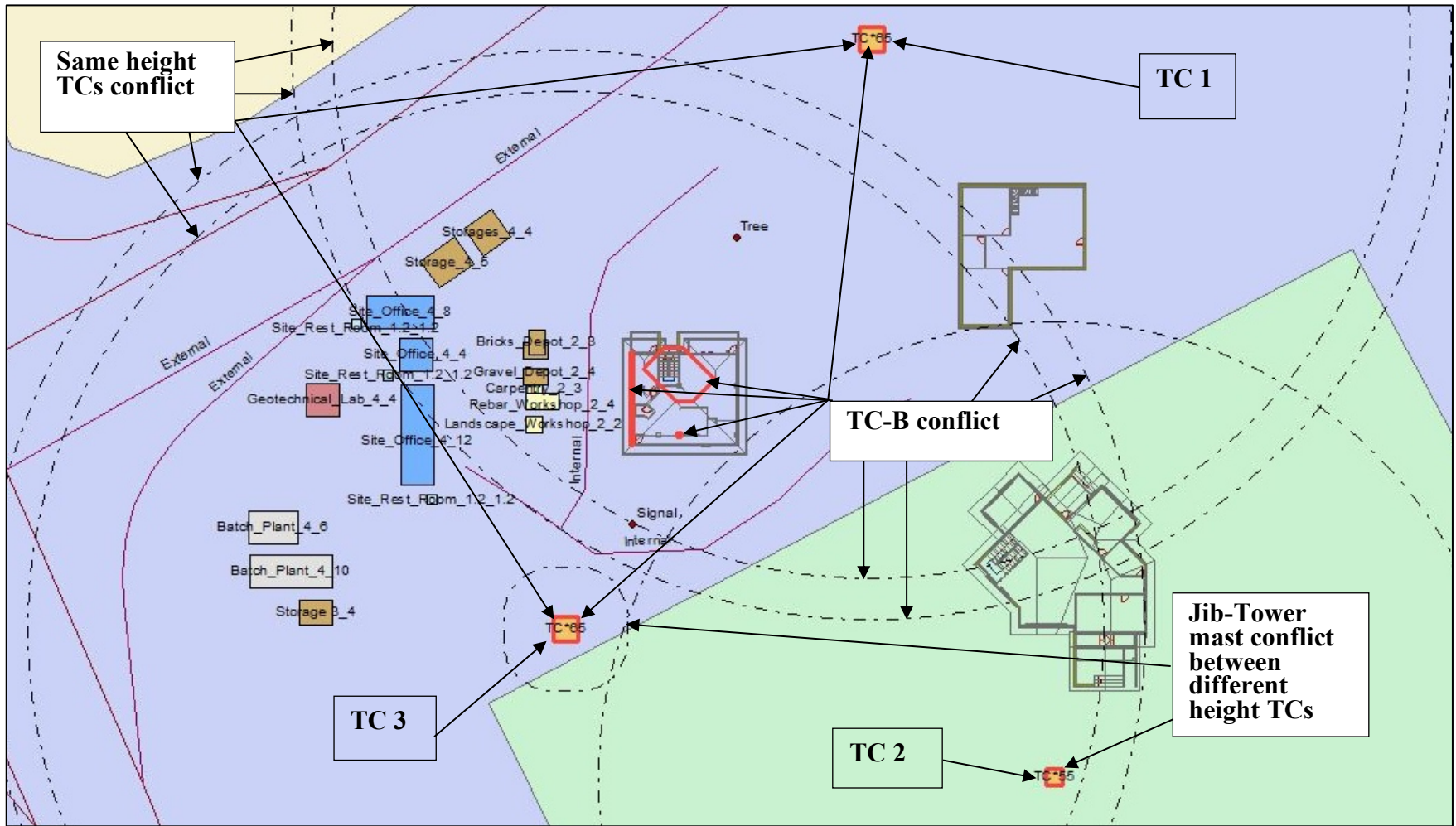


Figure 6.55: Conflicts of tower cranes were detected and visualized by the DCD module

In addition, as shown in Figure 6.55, both TC 1 and TC 3 have “TC-B” conflicts with some of the building components as the distance “V” (as depicted in Equation 4.7 and Figure 4.29) is less than the value of the safety distance (stored in the attribute tables for both TC 1 and TC 3) that must be between the jibs of both TC 1 and TC 3 and the IFC building components detected in the conflict. All the detected conflicts between tower cranes are reported by the module and included in the conflict report as shown in Figures 6.56, and 6.57.

The DCD module is tested many times on up to 35 different TFs in different site layouts. It is noticed that the number of TFs does not have any noticeable effect on the run time of the module to detect time-space conflicts. However, when the IFC building components are part of the test it is noticed that the processing time increases drastically especially when the values of the safety distance of the IFC components is changed from the default values included in the module. This can be due to two reasons 1) the IFC components are represented as 3D objects, which affects the processing time of the module; and 2) the way the module was programmed makes it check for the values of the safety distance of the IFC components and replaces those values with the new entered values for all the corresponding IFC components before checking the IFC components for potential rule violations.

Finally, the tests conducted on the DCD module developed in this study confirms the efficiency and capability of the DCD module to detect conflicts between site objects (temporary facilities and permanent facilities) dynamically in 2D and 3D while considering the different spatial relationships and constraints between the site objects in an efficient and timely manner. It also shows that, in an intuitive manner, the module is able to visualize those conflicts and highlight them on screen and in the attribute tables of those site objects and report them in a conflict report that holds detail information including the risk assessment for the detected conflicts.

| A | B | C | D | E |
|-------------------------------|--|---|--|---|
| NO_OF_CONFLICTS | 1 | 2 | 3 | 4 |
| FEATURE_NAME | TC*65 | TC*65 | TC*65 | TC*65 |
| FEATURE_TYPE | Tower crane | Tower crane | Tower crane | Tower crane |
| FEATURE_ID | 1 | 5 | 5 | 5 |
| FEATURE_GUID | | | | |
| LAYER_NAME | Cranes | Cranes | Cranes | Cranes |
| TAG_NO | | | | |
| FEATURE_EST | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM |
| FEATURE_EFT | 1/2/2019 5:00:00 PM | 1/29/2019 5:00:00 PM | 1/29/2019 5:00:00 PM | 1/29/2019 5:00:00 PM |
| FEATURE_Coordinate_X | 364969.472 | 364932.5571 | 364932.5571 | 364932.5571 |
| FEATURE_Coordinate_Y | 5023774.903 | 5023703.7015 | 5023703.7015 | 5023703.7015 |
| CONFLICT_FEATURE_NAME | Rectangular Column:18" x 18":640389 | Basic Wall:Exterior - kama-EEBS on Mtl. Stud:640531 | Rectangular Column:18" x 18":640389 | Basic Roof:Roof_GAF-Elk - Grand Slate over Wood Framed 1/2" CDX Deck:640549 |
| CONFLICT_FEATURE_TYPE | | | | |
| CONFLICT_FEATURE_ID | 76 | 111 | 76 | 20 |
| CONFLICT_LAYER_NAME | IfcColumn_surface | IfcWallStandardCase_surface | IfcColumn_surface | IfcSlab_surface |
| CONFLICT_FEATURE_GUID | 0y_Gt5mR11TxmYtyW4BKfj | 0y_Gt5mR11TxmYrye4BKdx | 0y_Gt5mR11TxmYtyW4BKfj | 0y_Gt5mR11TxmYty44BKdD |
| CONFLICT_FEATURE_TAG_NO | 640389 | 640531 | 640389 | 640549 |
| CONFLICT_FEATURE_EST | 12/10/2018 8:05:21 AM | 1/19/2019 8:11:26 AM | 12/10/2018 8:05:21 AM | 1/3/2019 8:41:28 AM |
| CONFLICT_FEATURE_EFT | 12/10/2018 4:45:42 PM | 1/21/2019 4:47:38 PM | 12/10/2018 4:45:42 PM | 1/13/2019 12:55:56 AM |
| CONFLICT_FEATURE_Coordinate_X | 364946.306121826 | 364940.535003662 | 364946.306121826 | 364946.30625301 |
| CONFLICT_FEATURE_Coordinate_Y | 5023727.16448964 | 5023731.506073 | 5023727.16448964 | 5023734.51971055 |
| CONFLICT_DURATION | 1 | 3 | 1 | 11 |
| CONFLICT_TYPE | Height Conflict with IfcColumn surface | Height Conflict with IfcWallStandardCase surface | Height Conflict with IfcColumn surface | Height Conflict with IfcSlab surface |
| DESCRIPTION | | | | |
| RISK_LEVEL | Urgent | Urgent | Urgent | Urgent |

Figure 6.56: Conflict report showing information about the TC-B conflicts

| F | G | H | I |
|---|--|--|---|
| 5 | 6 | 7 | 8 |
| TC*65 | TC*55 | TC*65 | TC*65 |
| Tower crane | Tower crane | Tower crane | Tower crane |
| 5 | 5 | 5 | 1 |
| | | | |
| Cranes | Cranes | Cranes | Cranes |
| | | | |
| 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM |
| 1/29/2019 5:00:00 PM | 12/13/2018 5:00:00 PM | 1/29/2019 5:00:00 PM | 1/2/2019 5:00:00 PM |
| 364932.5571 | 364991.6312 | 364932.5571 | 364969.472 |
| 5023703.7015 | 5023685.8021 | 5023703.7015 | 5023774.903 |
| TC*65 | TC*65 | TC*55 | TC*65 |
| Tower crane | Tower crane | Tower crane | Tower crane |
| 1 | 5 | 5 | 5 |
| Cranes | Cranes | Cranes | Cranes |
| | | | |
| 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM | 9/27/2018 8:00:00 AM |
| 1/2/2019 5:00:00 PM | 1/29/2019 5:00:00 PM | 12/13/2018 5:00:00 PM | 1/29/2019 5:00:00 PM |
| 364969.472 | 364932.5571 | 364991.6312 | 364932.5571 |
| 5023774.903 | 5023703.7015 | 5023685.8021 | 5023703.7015 |
| 98 | 78 | 78 | 98 |
| Height Conflict of TC (Same Level), space conflict with jibs of TCs | Height Conflict (Different level), space conflict jib with Tower Mast of highest TC. | Height Conflict (Different level), space conflict with TCs' jibs | Height Conflict of TC (Same Level), space conflict with jibs of TCs |
| Urgent | Urgent | Urgent | Urgent |

Figure 6.57: Conflict report showing information about the TC-TC conflicts

6.8 Summary

This chapter presented the testing and verification of the Integrated BIM-GIS model for site layout planning, which is designed in a modular format and consists of six modules 1) a 3D modeling module; 2) a route planning and hauling (RPH) module; 3) an execution schedule time entry (ESTE) module; 4) a 4D modeling module; 5) a temporary facilities library (TFL) module; and 6) a rule-based dynamic conflict detection (DCD). The presented SLP model was tested and verified by using a hypothetical case project for a residential building in the city of Ottawa, Ontario, Canada. A 3D BIM model was created by the author for three different buildings for the case project, including the building under construction, which is an eight-storey residential apartment building, and two other buildings surrounding it. Each of the six modules of the developed model was discussed in a step by step manner to deliver a clear idea on how each module is used and to demonstrate and examine the efficiency, capabilities, and functions of the modules. The test and verification of the developed BIM-GIS model for SLP proved its efficiency in conducting all the different tasks related to site layout planning including allocating time information to the 3D model, 4D visualization for the construction process, showing shortest routes, selecting and placing temporary facilities on the site, and dynamically detecting conflicts in 2D and 3D while considering the various relationships and constraints between site objects in an intuitive and timely manner.

CHAPTER 7

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

7.1 Summary

This study aimed towards developing a versatile and flexible site layout planning model that is based on BIM-GIS integration to assist practitioners making efficient decisions during the process of site layout planning (SLP). The information on the process of SLP, the requirements of integrating BIM and GIS to be implemented in the process of SLP, and the spatial relationships and constraints between site objects (temporary facilities and permanent facilities) are based on an intense literature review, including published data and interviews with practitioners. This research looked at the needs, gaps and expectations of the AEC industry for a solution to site layout planning and how integrating BIM and GIS would lay the foundation for a flexible and practical solution for the SLP process. Afterwards, an integration framework was established for the BIM-GIS SLP model and a gap analysis was conducted to identify the desirable functionalities that the current SLP solutions may be lacking and the BIM-GIS integration can provide or enhance. Accordingly, the integrated model was developed and designed in a modular format consisting of six main modules. This development and design approach allow the integrated model to be user-friendly and flexible, which enables users to tackle various tasks of SLP in an efficient and timely manner. To achieve the development of the integrated BIM-GIS SLP model some functions in both BIM tool (Revit) and GIS tool (ArcGIS desktop) were either used as they are, or were customized in order to achieve the development needs of the model; while new functions were created either as

an application/extension with a user interface (within the BIM or GIS tool), or as plugins that will be linked to the associated tool (BIM or GIS). Finally, the integrated SLP model was tested and verified by using a hypothetical case building project and it was proven to be capable of conducting a variety of tasks that are related to site layout planning in an efficient and timely manner.

The BIM-GIS model holds the following characteristics:

- Information intensive: it provides a data rich environment containing information about the topography and soil information of the construction site and its surroundings; the building and its surroundings; the transportation network; and temporary facilities to support users' decisions throughout the process of site layout planning (SLP).
- Versatile: it assists within the decision-making process of planners by supplying a variety of analyses and functionalities that are required for an efficient SLP. This includes route planning based on actual paths, selecting and placing of temporary facilities on suitable locations onsite, 4D visualization for the construction site and its surroundings and virtually reviewing the construction sequence and site layout, dynamic conflict detection in 2D and 3D, risk assessment, documenting the project, and providing users with a variety of outputs including graphical, textual and tabular, in an intuitive and timely fashion and all in one data-rich environment.
- Flexible: The modularity of the developed model allows it to be expanded to include more modules and functions, whether from past studies in the literature or through future research to achieve a more enhanced SLP model. In addition, it enables users to add and modify data in a user-friendly manner. This include modifying the physical and functional information of the temporary facilities and the safety distance values for the IFC components.

- **Efficient:** it allows users to apply their knowledge and experience while using the model to facilitate the different tasks related to SLP throughout the process of planning the site layout without having technical backgrounds, experience or any type of knowledge that is not common in the AEC industry.
- **Automatic:** it assists users in adding temporal information to the 3D building model and TFs based on visual selection and locational and functional information; selecting and placing different temporary facilities; 4D reviewing for the construction site and its surroundings, buildings and site objects; dynamically checking the site layout plan for potential conflicts in 2D and 3D for the entire duration of the project along with providing feedback and risk assessment in an automatic, intuitive, and timely fashion.

7.2 Research contributions

The contributions of this study stem from the following:

1. Implementing a methodology for developing an integrated site layout planning model based on the integration between BIM and GIS. The model insures assisting and engaging professionals in planning the layout for a construction site that is safe, efficient, and almost conflict-free by being comprehensive, intuitive, and effective.
2. Designing an integrated model, which is developed in a modular format (consisting of six modules) to maximize its flexibility. The model covers the essential requirements and functionalities for the process of SLP and can accommodate further modification and extension to include more modules and functions. The modular development approach provides a versatile and unified environment (solution) to the process of site layout planning,

which can contribute to solving the fragmented nature of the approaches used for realizing the models found in the literature.

3. Applying the approach of automatic rule-based checking in site layout planning, which dynamically detects conflicts in the site layout plan in 2D and 3D. The rule-based approach in this study considers the relationships and constraints between site objects while running risk assessment for the detected conflicts and providing users with information-rich feedback in an automatic, easy and quick manner. The algorithms developed in this study for the rule-based checking recognize both the IFC components and the TFs included in the TFL.
4. Developing a flexible parametric temporary facilities library that holds 2D and 3D physical and functional information about temporary facilities (TFs) in a Geodatabase, which allows for conducting spatial-temporal analysis on the TFs in 2D and in 3D.
5. Implementing a 4D realistic representation for the construction progress and the construction site and its surroundings in SLP. Also, this study includes route planning based on actual paths while providing users with a unified data rich environment (for the building, transportation network, topographical and soil information on the construction site) and spatial-temporal analysis capabilities in site layout planning.

7.3 Limitations of the presented model

This research has the following limitations:

- 1- The tools selected for both BIM and GIS (Autodesk Revit, and ESRI ArcGIS desktop respectively) are the most common tools used in the AEC industry; however, experience and knowledge about both is still required, as the adoption rate for both BIM and GIS concepts in the AEC industry is still lower than expected for the industry.

- 2- The temporary facilities library (TFL) module is currently sufficient for building construction projects as it includes most of the temporary facilities (TFs) that are required for such projects; however, expanding the current TFL and adding more types of TFs (e.g., moving resources such as trucks and moving cranes) is still required to include other types of construction projects (e.g., infrastructure projects).
- 3- Information loss due to interoperability issues between the domains (BIM and GIS) hinders the data management and analytical capabilities of the model and, in some cases, manual data entry is still required by users.
- 4- In case of design changes during the project's construction (construction phase) the modified 3D BIM model must be exported again from the BIM tool as an IFC file and then imported once again into the GIS tool. This means that all the steps required for creating the 4D model have to be redone, which is time consuming.
- 5- The presented in its current state does not enable users to identify the least cost route when planning the most efficient route between two points. Having such capability will increase the efficiency of site layout plan and the construction site. However, the GIS tool used in this study (ESRI ArcGIS) offers such analysis which can be used to enhance the presented model in the future.

7.4 Recommendations for future research

This research can be expanded as follows:

- In the temporary facilities library (TFL) module, more data collection is needed on the temporary facilities, their operation distance and safety distance requirements, and other related information to enhance the module and its functionality. This information can be collected by

reviewing published data and interviews with experts. In addition, more research should focus on including moving facilities (e.g., mobile cranes) in the TFL. Also, efforts can be put towards developing the TFL module in ArcScene (the 3D application of GIS). This area needs more research and development work because in spite of ArcMap and ArcScene belongs to the same package (ArcGIS from ESRI) they are developed independently with different programming requirements to fit the needs of 3D analysis.

- In the ESTE module, automatically schedule all the temporary facilities and calculate the periods they are required onsite, based on the temporal information included in the 4D model created by the ESTE module.
- Future studies can focus on calculating the total cost of the site objects onsite. This can be based on the cost of every individual TF for the period it exists onsite and whether it is rented, owned, or bought.
- Future research should focus on how to integrate LEED with the BIM-GIS model to incorporate the concept of sustainability in the process of SLP.
- Future research should focus on including site layout planning for the interiors of buildings, which can be used for storage, as this can become very important, especially when construction sites are congested and less space is available.
- Future research should focus on extending the developed model to include additional types of analysis related to BIM and GIS applications (e.g., solar analysis, wind, ground water, flood, noise, thermal comfort, and line of sight). Such topics are also useful for the site layout planning process and would increase its efficiency.
- Future studies can focus on calculating the least cost path for transportation by taking advantage of the built-in spatial analysis tools offered by the GIS tool used in this study (ESRI ArcGIS).

- Future research can focus on having the model provide users with a suggestion list for the temporary facilities and their types and sizes that might be needed for a construction project, based on the data provided by the 3D BIM model.
- Practitioners should be invited to try and test the developed model in real projects in order to provide comments on its usability, practicality, functionalities, and the overall user experience so that the model can be further enhanced.

CHAPTER 8

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Appendixes

Appendix I

Codes for the developed toolbar extensions using Microsoft Visual Studio

Coding for the Temporary Facilities Library (TFL) module.

```
36     private void settingsToolStripMenuItem_Click(object sender, EventArgs e)
37     {
38         EnvironmentForm settingsForm = new EnvironmentForm();
39         var result = settingsForm.ShowDialog(m_WindowWrapper);
40         if (result == System.Windows.Forms.DialogResult.OK)
41             LoadForm();
42     }
43
44     0 references
45     private void LayerForm_Load(object sender, EventArgs e)
46     {
47         try
48         {
49             m_WindowWrapper = new WindowWrapperClass(this.Handle);
50             CreateFeatureStaticClass.LoadDrawTool();
51             LoadForm();
52         }
53         catch (Exception ex)
54         {
55             throw;
56         }
57     }
58
59 }
```

```

26 private void btnLibGDB_Click(object sender, EventArgs e)
27 {
28     try
29     {
30         CreateFeatureStaticClass.TemplateWS = ToolUtilsClass.SelectFileGeodatabase("Select template FGDB", "Select", this.Handle.ToInt32());
31         if (CreateFeatureStaticClass.TemplateWS != null)
32             txtBxLibLoc.Text = CreateFeatureStaticClass.TemplateWS.PathName;
33
34         //Load all the templates
35     }
36     catch (Exception ex)
37     {
38
39
40         MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
41     }
42 }
43
44 0 references
45 private void btnOutGDB_Click(object sender, EventArgs e)
46 {
47     try
48     {
49         CreateFeatureStaticClass.OutputWS = ToolUtilsClass.SelectFileGeodatabase("Select Output FGDB", "Select", this.Handle.ToInt32());
50         if (CreateFeatureStaticClass.OutputWS != null)
51         {
52             txtBxOutputLoc.Text = CreateFeatureStaticClass.OutputWS.PathName;
53             string sr = ""; //((CreateFeatureStaticClass.OutSpatialReference != null) ? CreateFeatureStaticClass.OutSpatialReference.Name : "");
54             PopulateSpatialReferenceDD(sr);
55         }
56     }
57     catch (Exception ex)
58     {
59         MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
60     }
61 }

```

```

13 public static IWorkspace SelectFileGeodatabase(string title,string buttonCaption,int parentWindow)
14 {
15     IWorkspace pWS = null;
16     IEnumGxObject pGxEnum = null;
17
18     IGxDIALOG pGxDlg = new GxDIALOGClass();
19     pGxDlg.ButtonCaption = buttonCaption;
20     pGxDlg.Title = title;
21
22     //Set the filter to restrict the user to making a file geodatabase selection.
23     pGxDlg.ObjectFilter = new GxFilterFileGeodatabases();
24
25     //Open the modal window
26     bool isSelected = pGxDlg.DoModalOpen(parentWindow, out pGxEnum);
27     if (isSelected)
28     {
29         //Get the first item in the Enum
30         IGxObject pGxObject = pGxEnum.Next();
31
32
33         IGxDatabase pGxDatabase = pGxObject as IGxDatabase;
34
35         //Get the workspace object
36         pWS = pGxDatabase.Workspace;
37     }
38
39     return pWS;
40 }
41 }
42
43 }
44 }
45

```

```

31 public static bool LoadLibrary(IWorkspace inputWorkspace)
32 {
33
34     List<TF_FamilyClass> lib = new List<TF_FamilyClass>();
35
36     try
37     {
38         IFeatureWorkspace pFW = inputWorkspace as IFeatureWorkspace;
39         IEnumDatasetName pEnumDsNames = inputWorkspace.DatasetNames[esriDatasetType.esriDTFeatureClass];
40         IDatasetName pDSName = null;
41         while ((pDSName = pEnumDsNames.Next()) != null)
42         {
43             IFeatureClass pFClass = pFW.OpenFeatureClass(pDSName.Name);
44             TF_FamilyClass familyObj = new TF_FamilyClass();
45             familyObj.LayerName = pDSName.Name;
46
47             ISubtypes pSubTypes = pFClass as ISubtypes;
48             if (!pSubTypes.HasSubtype)
49                 continue;
50
51             List<TF_TypeClass> typeList = new List<TF_TypeClass>();
52
53             //Load the subtypes
54             IEnumSubtype pEnumSubtype = pSubTypes.Subtypes;
55             string fieldName = pSubTypes.SubtypeFieldName;
56             int subtypeCode = -1;
57             string subtypeName;
58             while ((subtypeName = pEnumSubtype.Next(out subtypeCode)) != null)
59             {
60                 //Populate TF_Types
61                 TF_TypeClass tf_type = new TF_TypeClass();
62                 tf_type.Code = subtypeCode;
63                 tf_type.Description = subtypeName;
64                 tf_type.FieldName = fieldName;
65
66                 List<TF_SubtypesClass> subTypeList = new List<TF_SubtypesClass>();
67                 //Get the Domains
68                 IDomain pDomain = pSubTypes.Domain[subtypeCode, CreateFeatureStaticClass.TEPORARY_FACILITY_NAME];
69                 ICodedValueDomain codedValueDomain = pDomain as ICodedValueDomain;
70                 for (int i = 0; i < codedValueDomain.CodeCount; i++)
71                 {
72
73                     TF_SubtypesClass tf_subtype = new TF_SubtypesClass();
74                     tf_subtype.Description = codedValueDomain.Name[i];
75                     tf_subtype.Code = int.Parse(codedValueDomain.Value[i].ToString());
76                     subTypeList.Add(tf_subtype);
77                 }
78                 //Add the list of domains associated with this type.
79                 tf_type.Subtypes = subTypeList;
80                 typeList.Add(tf_type);
81             }
82             familyObj.Types = typeList;
83             lib.Add(familyObj);
84         }
85     }
86     Library = lib;
87 }
88 catch (Exception ex)
89 {
90     throw ex;
91 }
92
93 return (lib.Count > 0);
94 }

```

```

269 private void LoadForm()
270 {
271
272     try
273     {
274         CreateFeatureStaticClass.RemoveLocationSymbol();
275         //Check the environment settings before proceeding
276         bool isValid = settingsManager.ValidateEnvironmentSettings();
277
278         if (!isValid)
279         {
280             MessageBox.Show(m_WindowWrapper, "Please select the Temporary facilities library and output Geodatabase", "Setup", MessageBoxButtons.OK, MessageBoxIcon.Error);
281             return;
282         }
283
284         //Check if the temporary facilities library exists
285         IWorkspace2 pTWS2 = CreateFeatureStaticClass.TemplateWS as IWorkspace2;
286         if (!pTWS2.NameExists[esriDatasetType.esriDTable, "Temporary_Facilities"])
287         {
288             MessageBox.Show(m_WindowWrapper, "Cannot find Temporary facilities table ", "Layer table", MessageBoxButtons.OK, MessageBoxIcon.Error);
289             return;
290         }
291     }
292
293     //Clear color code dictionary
294     CreateFeatureStaticClass.LAYER_COLOR.Clear();
295
296     //Create the parent and the child nodes to display in the tree view
297
298     categoryTreeView.Nodes.Clear();
299     TreeNode OPTFNode = new TreeNode("Operation and Processing Temporary Facilities");
300     OPTFNode.NodeFont = new Font(categoryTreeView.Font, FontStyle.Bold);
301     categoryTreeView.Nodes.Add(OPTFNode);
302     OPTFNode.Text = OPTFNode.Text;
303     OPTFNode.ForeColor = Color.FromArgb(95, 29, 13);
304
305     OPTFNode.Expand();
306
307     TreeNode RTFNode = new TreeNode("Residence Temporary Facilities");
308     RTFNode.NodeFont = new Font(categoryTreeView.Font, FontStyle.Bold);
309     categoryTreeView.Nodes.Add(RTFNode);
310     RTFNode.Text = RTFNode.Text;
311     RTFNode.ForeColor = Color.FromArgb(19, 49, 102);
312
313     RTFNode.Expand();
314
315     TreeNode STFNode = new TreeNode("Storages Temporary Facilities");
316     STFNode.NodeFont = new Font(categoryTreeView.Font, FontStyle.Bold);
317     categoryTreeView.Nodes.Add(STFNode);
318     STFNode.Text = STFNode.Text;
319     STFNode.ForeColor = Color.FromArgb(71, 47, 8);
320     STFNode.Expand();
321
322     bool isLibLoaded = CreateFeatureStaticClass.LoadLibrary(CreateFeatureStaticClass.TemplateWS);
323     if (!isLibLoaded)
324     {
325         MessageBox.Show(m_WindowWrapper, "Library not Config", "Configuration load", MessageBoxButtons.OK, MessageBoxIcon.Error);
326         return;
327     }
328 }

```

```

330 //Query the temporary facility tables to get the configuration of the layers to include
331 ITable pTF_Table = ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS).OpenTable("Temporary_Facilities");
332 using (ComReleaser comReleaser = new ComReleaser())
333 {
334     ICursor pTFCursor = pTF_Table.Search(null, true);
335     comReleaser.ManageLifetime(pTFCursor);
336
337     int layerFieldIndex = pTF_Table.FindField("Layer");
338     int categoryFieldIndex = pTF_Table.FindField("Category");
339     int RFieldIndex = pTF_Table.FindField("R");
340     int GFieldIndex = pTF_Table.FindField("G");
341     int BFieldIndex = pTF_Table.FindField("B");
342
343     ISubtypes pSubtype = (ISubtypes)pTF_Table;
344
345     IRow pRow = null;
346
347
348     //Sort the layers based on the category..
349     while ((pRow = pTFCursor.NextRow()) != null)
350     {
351         string layerName = pRow.Value[layerFieldIndex].ToString();
352         int categoryCode = int.Parse(pRow.Value[categoryFieldIndex].ToString());
353         int RCode = int.Parse(pRow.Value[RFieldIndex].ToString());
354         int GCode = int.Parse(pRow.Value[GFieldIndex].ToString());
355         int BCode = int.Parse(pRow.Value[BFieldIndex].ToString());
356
357         CreateFeatureStaticClass.LAYER_COLOR.Add(layerName, LayerUtils.SetRGBColor(RCode, GCode, BCode));
358
359         var category = pSubtype.SubtypeName[categoryCode];
360
361         if (!pTWS2.NameExists[esriDatasetType.esriDTFeatureClass, layerName]) { continue; }
362
363         IFeatureClass pFClass = ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS).OpenFeatureClass(layerName);
364         int categoryNodeIndex = -1;
365

```

```

361 if (!pTWS2.NameExists[esriDatasetType.esriDTFeatureClass, layerName]) { continue; }
362
363 IFeatureClass pFClass = ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS).OpenFeatureClass(layerName);
364 int categoryNodeIndex = -1;
365
366
367 switch (category)
368 {
369     case "OPTF":
370         categoryNodeIndex = 0;
371
372         break;
373     case "RTF":
374         categoryNodeIndex = 1;
375
376         break;
377     case "STF":
378         categoryNodeIndex = 2;
379         break;
380 }
381 if (categoryNodeIndex == -1) { continue; }
382
383 categoryTreeView.Nodes[categoryNodeIndex].Nodes.Add(layerName);
384
385 int familyIndex = categoryTreeView.Nodes[categoryNodeIndex].Nodes.Count - 1;
386
387 TreeNode familyNode = categoryTreeView.Nodes[categoryNodeIndex].Nodes[familyIndex];
388 familyNode.ImageIndex = GetImageIndex(familyNode.Text);
389
390 Color parentNodeColor = categoryTreeView.Nodes[categoryNodeIndex].ForeColor;
391
392
393
394 List<TF_FamilyClass> FamilyList = CreateFeatureStaticClass.Library;
395 TF_FamilyClass family = (from item in FamilyList.Cast<TF_FamilyClass>() where item.LayerName == layerName select item).FirstOrDefault();

```

```

392 List<TF_FamilyClass> FamilyList = CreateFeatureStaticClass.Library;
393 TF_FamilyClass family = (from item in FamilyList.Cast<TF_FamilyClass>() where item.LayerName == layerName select item).FirstOrDefault();
394 var types = (from item in family.Types.Cast<TF_TypeClass>() orderby item.Code ascending select item);
395 foreach (var type in types)
396 {
397     //Add the type to the tree
398     //The index must correspond to the type code value
399     int lastFamilyIndex = categoryTreeView.Nodes[categoryNodeIndex].Nodes.Count - 1;
400
401     categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].ForeColor = parentNodeColor;
402     categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes.Add(type.Description);
403
404     //Get the newly added type node and set its colour
405     int typeIndex = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes.Count - 1;
406     TreeNode typeNode = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes[typeIndex];
407     typeNode.ForeColor = parentNodeColor;
408     typeNode.ImageIndex = GetImageIndex(typeNode.Text);
409
410     if (type.HasSubtypes())
411     {
412         //Add the subtype to the tree
413         //The index must correspond to the type code value
414         int lastTypeIndex = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes.Count - 1;
415         var subTypes = (from item in type.Subtypes.Cast<TF_SubtypesClass>() orderby item.Code ascending select item);
416         foreach (var subtype in subTypes)
417         {
418             //Set the description and Fore colour of the subtype node
419             categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes[lastTypeIndex].Nodes.Add(subtype.Description);
420             int subtypeIndex = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes[lastTypeIndex].Nodes.Count - 1;
421
422             TreeNode subtypeNode = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes[lastTypeIndex].Nodes[subtypeIndex];
423
424             subtypeNode.ForeColor = parentNodeColor;
425             subtypeNode.ImageIndex = GetImageIndex(subtypeNode.Text);
426         }
427     }
428 }
429

```

```
421
422     TreeNode subtypeNode = categoryTreeView.Nodes[categoryNodeIndex].Nodes[lastFamilyIndex].Nodes[lastTypeIndex].Nodes[subtypeIndex];
423
424     subtypeNode.ForeColor = parentNodeColor;
425     subtypeNode.ImageIndex = GetImageIndex(subtypeNode.Text);
426
427     }
428 }
429 }
430
431 }
432 }
433     foreach (TreeNode node in categoryTreeView.Nodes)
434     {
435         if (node.Level == 0)
436         {
437             node.Expand();
438         }
439     }
440 }
441 }
442 }
443 }
444 }
445 }
446 catch (Exception ex)
447 {
448     MessageBox.Show(m_WindowWrapper, ex.Message, "Could not load layers", MessageBoxButtons.OK, MessageBoxIcon.Error);
449 }
450 finally
451 {
452     CreateFeatureStaticClass.DeactivateDrawTool();
453     lblDrawToolActive.Text = "";
454 }
455 }
456 }
```

```
3 references
459 private int GetImageIndex(string objectName)
460 {
461     int index = -1;
462
463     string newName = objectName.Replace(" ", "_").ToUpper();
464
465
466     for (int i = 0; i < imageList1.Images.Count; i++)
467     {
468
469         string imageName = System.IO.Path.GetFileNameWithoutExtension(imageList1.Images.Keys[i].ToString());
470
471         if (imageName == newName)
472         {
473             index = i;
474             break;
475         }
476     }
477
478     if (index == -1)
479         index = 0;
480
481     return index;
482
483 }
484
```

```
63 private void categoryTreeView_NodeMouseClicked(object sender, TreeNodeMouseClickEventArgs e)
64 {
65     if (e.Node.LastNode == null)
66     {
67         //Activate Draw tool
68         CreateFeatureStaticClass.DeactivateDrawTool();
69         CreateFeatureStaticClass.ActivateDrawTool();
70         DrawToolActiveText(DRAWTOOL_ACTIVE);
71
72
73
74         TreeNode subtypeNode = e.Node;
75         TreeNode typeNode = subtypeNode.Parent;
76         string familyName = typeNode.Parent.Text;
77
78
79         IWorkspace2 pOutWS2 = CreateFeatureStaticClass.OutputWS as IWorkspace2;
80         IFeatureClass pFCClass = (pOutWS2.NameExists(esriDatasetType.esriDTFeatureClass, familyName)) ? ((IFeatureWorkspace)CreateFeatureStaticClass.OutputWS).OpenFeatureClass(familyName) : ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS).OpenFeatureClass(familyName);
81         CreateFeatureStaticClass.SELECTED_GEODATASET = ((IGeoDataset)pFCClass);
82     }
83     else
84     {
85         CreateFeatureStaticClass.DeactivateDrawTool();
86         CreateFeatureStaticClass.RemoveLocationSymbol();
87         DrawToolActiveText("");
88     }
89 }
90 }
```

The rest of this part of the code is provided in the figure below

```
ickEventArgs e)
ce2;
eatureClass, familyName)) ? ((IFeatureWorkspace)CreateFeatureStaticClass.OutputWS).OpenFeatureClass(familyName) : ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS)
s);
```

```

1 reference
95 private IFeatureClass CreateOutputFeatureClass(IFeatureClass templateFeatureClass, IWorkspace outputWorkspace)
96 {
97     IFeatureClass pFeatureClass = null;
98     try
99     {
100         IFeatureClassDescription fcDesc = new FeatureClassDescriptionClass();
101         IObjectClassDescription ocDesc = (IObjectClassDescription)fcDesc;
102
103         string outputTableName = ((IDataset)templateFeatureClass).Name;
104
105         IFeatureWorkspace pFeatureWorkspace = outputWorkspace as IFeatureWorkspace;
106         string subtypeFieldName = ((ISubtypes)templateFeatureClass).SubtypeFieldName;
107
108
109         //Create the fields for the final output table
110         IFields pFields = new Fields();
111         IFieldsEdit pFieldsEdit = pFields as IFieldsEdit;
112         int fieldCount = templateFeatureClass.Fields.FieldCount;
113
114         pFieldsEdit.FieldCount_2 = templateFeatureClass.Fields.FieldCount;
115
116         //Create and OBJECTID Field
117         IField oidField = new FieldClass();
118         IFieldEdit oidFieldEdit = (IFieldEdit)oidField;
119         oidFieldEdit.Name_2 = "OBJECTID";
120         oidFieldEdit.AliasName_2 = "OBJECTID";
121         oidFieldEdit.Type_2 = esriFieldType.esriFieldTypeOID;
122         pFieldsEdit.set_Field(0, oidField);
123
124
125
126
127         for (int i = 1; i < fieldCount; i++)
128         {
129             IField pField = templateFeatureClass.Fields.Field[i];
130
131
132             if (pField.Name.ToUpper() == CreateFeatureStaticClass.TEPORARY_FACILITY_NAME)
133             {
134                 IField nameField = new FieldClass();
135                 IFieldEdit nameFieldEdit = (IFieldEdit)nameField;
136                 nameFieldEdit.Name_2 = pField.Name;
137                 nameFieldEdit.AliasName_2 = pField.AliasName;
138                 nameFieldEdit.Type_2 = esriFieldType.esriFieldTypeString;
139                 nameFieldEdit.Length_2 = 255;
140                 pFieldsEdit.set_Field(i, nameField);
141
142
143             }
144             else if (pField.Name == subtypeFieldName)
145             {
146                 IField subtypeField = new FieldClass();
147                 IFieldEdit subtypeFieldEdit = (IFieldEdit)subtypeField;
148                 subtypeFieldEdit.Name_2 = subtypeFieldName;
149                 subtypeFieldEdit.AliasName_2 = pField.AliasName;
150                 subtypeFieldEdit.Type_2 = esriFieldType.esriFieldTypeString;
151                 subtypeFieldEdit.Length_2 = 255;
152                 pFieldsEdit.set_Field(i, subtypeField);
153
154             }
155             else
156             {

```

```
173
174         pFieldsEdit.set_Field(i, pField);
175     }
176 }
177
178
179     pFeatureClass = pFeatureWorkspace.CreateFeatureClass(outputTableName, pFields, ocDesc.InstanceCLSID, ocDesc.ClassExtensionCLSID, esriFeatureType.esriFTSimple, "Shape", "");
180 }
181
182     catch (Exception ex)
183     {
184         throw ex;
185     }
186 }
187
188     return pFeatureClass;
189 }
```

```

197 private IFeatureClass AddFeatures()
198 {
199     IFeatureClass pOutputFC = null;
200
201     IWorkspaceEdit outWSEdit = null;
202     try
203     {
204         this.UseWaitCursor = true;
205
206         outWSEdit = CreateFeatureStaticClass.OutputWS as IWorkspaceEdit;
207
208         //Get the locations clicked by the user
209         List<IPoint> locList = CreateFeatureStaticClass.LocationList;
210
211         IFeatureClass pTemplateFC = ((IFeatureWorkspace)CreateFeatureStaticClass.TemplateWS).OpenFeatureClass(this.LayerName);
212         ISubtypes pFCSubtypes = (ISubtypes)pTemplateFC;
213         string currentLayerName = ((IDataset)pTemplateFC).Name;
214
215         IWorkspace2 pWS2 = CreateFeatureStaticClass.OutputWS as IWorkspace2;
216
217         //Check if the output feature class exists
218         if (!pWS2.NameExists(esriDatasetType.esriDTFeatureClass, currentLayerName))
219         {
220             var entry = MessageBox.Show(new WindowWrapperClass(this.Handle), currentLayerName + " does not exists in the output workspace \nDo you wish to create it?", "Alert!", MessageBoxButtons.YesNo, MessageBoxIcon.Exclamation);
221             if (entry == DialogResult.Yes)
222             {
223                 lblMessage.Text = "Creating output Featureclass";
224                 pOutputFC = CreateOutputFeatureClass(pTemplateFC, CreateFeatureStaticClass.OutputWS);
225             }
226             else
227             {
228                 return null;
229             }
230         }
231         else
232             pOutputFC = ((IFeatureWorkspace)CreateFeatureStaticClass.OutputWS).OpenFeatureClass(currentLayerName);
233
234         IGeoDataset pOutGeodataset = pOutputFC as IGeoDataset;
235
236         IProjectedCoordinateSystem pPCS = pOutGeodataset.SpatialReference as IProjectedCoordinateSystem;
237         if (pPCS != null)
238             isGeographicCS = false;
239         else
240         {
241             IGeographicCoordinateSystem pGCS = pOutGeodataset.SpatialReference as IGeographicCoordinateSystem;
242             double conver = pGCS.CoordinateUnit.ConversionFactor;
243
244             int fieldIndex = pOutputFC.FindField(areaFieldName);
245
246             if (fieldIndex == -1)
247                 pOutputFC.AddField(LayerUtils.CreateField(areaFieldName, areaFieldName, 0, 0, 0, esriFieldType.esriFieldTypeDouble));
248
249             fieldIndex = pOutputFC.FindField(lengthFieldName);
250
251             if (fieldIndex == -1)
252                 pOutputFC.AddField(LayerUtils.CreateField(lengthFieldName, lengthFieldName, 0, 0, 0, esriFieldType.esriFieldTypeDouble));
253
254         }
255
256         if (pOutGeodataset.SpatialReference.Name.ToUpper() == "UNKNOWN")
257         {
258             var entry = MessageBox.Show(new WindowWrapperClass(this.Handle), "Output dataset does not contain a spatial reference. \nKindly set the spatial reference before proceeding.", "Alert!",
259                 MessageBoxButtons.YesNo, MessageBoxIcon.Exclamation);
260             return null;
261         }

```

```

263 var result = MessageBox.Show(new WindowWrapperClass(this.Handle), "This action will save " + locList.Count + " " + this.LayerName + " to the output geodatabase \nDo you wish to continue?", "Note!",
264 MessageBoxButtons.YesNo, MessageBoxIcon.Exclamation);
265
266 if (result == DialogResult.Yes)
267 {
268     //Proceed if the user approves.
269
270     outWSEdit.StartEditing(false);
271     outWSEdit.StartEditOperation();
272
273     //Query Geometry from the template GDB.
274     string whereClause = pFCSubtypes.SubtypeFieldName + " = " + this.TypeCode + " AND " + CreateFeatureStaticClass.TEPORARY_FACILITY_NAME + " = " + this.SubtypeCode;
275     IQueryFilter pQueryFilter = new QueryFilter();
276     pQueryFilter.WhereClause = whereClause;
277
278     int recordCount = pTemplateFC.FeatureCount(pQueryFilter);
279     if (recordCount == 0)
280     {
281         MessageBox.Show(new WindowWrapperClass(this.Handle), currentLayerName + "Template geometry does not exists for " + SubtypeDesc, "Alert!", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
282         return null;
283     }
284
285     using (ComReleaser comReleaser = new ComReleaser())
286     {
287         IFeatureBuffer pOutFeatureBuffer = pOutputFC.CreateFeatureBuffer();
288
289         //Get the cursor based on the query filter
290         IFeatureCursor pFeatureCursor = pTemplateFC.Search(pQueryFilter, false);
291         comReleaser.ManageLifetime(pFeatureCursor);
292
293         IFeatureCursor pInsertFeatureCursor = pOutputFC.Insert(true);
294         comReleaser.ManageLifetime(pInsertFeatureCursor);
295
296         int templateFieldCount = pTemplateFC.Fields.FieldCount;
297
298         IFeature pTmpltFeature = null;
299
300         int count = 0;
301
302         int areaFieldIndex = pOutputFC.FindField(areaFieldName);
303         int lengthFieldIndex = pOutputFC.FindField(lengthFieldName);
304
305         while ((pTmpltFeature = pFeatureCursor.NextFeature()) != null)
306         {
307             foreach (IPoint pt in locList)
308             {
309                 lblMessage.Text = "Inserting " + count + " of " + locList.Count;
310                 count++;
311
312                 //Get library geo area
313                 IPolygon libShape = pTmpltFeature.Shape as IPolygon;
314                 double area = ((IArea)libShape).Area;
315
316                 //Get the perimeter
317                 ICurve pPolyCurve = libShape as ICurve;
318                 double perimeter = pPolyCurve.Length;
319
320                 //Reproject the point
321                 ((IGeometry)pt).Project(pOutGeodataset.SpatialReference);
322
323                 //Reproject the template geometry
324                 IPolygon pPolygon = pTmpltFeature.ShapeCopy as IPolygon;
325                 pPolygon.Project(pOutGeodataset.SpatialReference);
326
327                 //Get the centroid of the template geometry

```

```

328 //Get the centroid of the template geometry
329 IArea pArea = pPolygon as IArea;
330 double currX = pArea.Centroid.X;
331 double currY = pArea.Centroid.Y;
332
333 //Measure the distance of the shift
334 double newLocationX = pt.X - currX;
335 double newLocationY = pt.Y - currY;
336
337 //Move the polygon to the new location
338 ITransform2D transform2D = pPolygon as ITransform2D;
339 transform2D.Move(newLocationX, newLocationY);
340
341 //Apply the transformed shape
342 pOutFeatureBuffer.Shape = pPolygon;
343
344 //Map the fields of the destination and template feature class and insert values.
345 for (int i = 0; i < templateFieldCount; i++)
346 {
347     IField pTemplateField = pTemplateFC.Fields.Field[i];
348     int outFieldIndex = pOutFeatureBuffer.Fields.FindField(pTemplateField.Name);
349
350     //Check if the field exists in the output feature class.
351     if (outFieldIndex != -1)
352     {
353         IField outField = pOutFeatureBuffer.Fields.Field[outFieldIndex];
354
355         if (!outField.Editable) { continue; }
356         if (outField.Type == esriFieldType.esriFieldTypeGeometry) { continue; }
357
358         if (pTemplateField.Name == pFCSubtypes.SubtypeFieldName)
359             pOutFeatureBuffer.Value[outFieldIndex] = this.TypeDesc;
360         else if (pTemplateField.Name.ToUpper() == CreateFeatureStaticClass.TEPORARY_FACILITY_NAME)
361             pOutFeatureBuffer.Value[outFieldIndex] = this.SubtypeDesc;
362         else
363             pOutFeatureBuffer.Value[outFieldIndex] = pTmplFeature.Value[i];
364     }
365 }
366
367 //Insert shape area and length
368 if (isGeographicCS)
369 {
370     //Populate original area and perimeter values
371     if (areaFieldIndex != -1)
372         pOutFeatureBuffer.Value[areaFieldIndex] = area;
373
374     if (lengthFieldIndex != -1)
375         pOutFeatureBuffer.Value[lengthFieldIndex] = perimeter;
376 }
377
378 pInsertFeatureCursor.InsertFeature(pOutFeatureBuffer);
379
380 }
381
382 pInsertFeatureCursor.Flush();
383 CreateFeatureStaticClass.LocationList.Clear();
384
385 MessageBox.Show(new WindowWrapperClass(this.Handle), "All features saved to " + currentLayerName, "Complete", MessageBoxButtons.OK, MessageBoxIcon.Information);
386
387
388
389
390
391
392

```

```

390         pInsertFeatureCursor.Flush();
391         CreateFeatureStaticClass.LocationList.Clear();
392         MessageBox.Show(new WindowWrapperClass(this.Handle), "All features saved to " + currentLayerName, "Complete", MessageBoxButtons.OK, MessageBoxIcon.Information);
393
394         //Add layer to the map..
395         utils.AddLayerToMap(pOutputFC, ((IDataset)pOutputFC).Name);
396     }
397
398 }
399
400 }
401 catch (Exception ex)
402 {
403     throw ex;
404 }
405 }
406 finally
407 {
408     if (outWSEdit != null)
409     {
410         if (outWSEdit.IsBeingEdited())
411         {
412             outWSEdit.StopEditOperation();
413             outWSEdit.StopEditing(true);
414         }
415     }
416 }
417 }
418 this.UseWaitCursor = false;
419
420 ArcMap.Document.ActiveView.Refresh();
421
422 }
423 return pOutputFC;
424
425 }

```

Coding for the Dynamic Conflict Detection (DCD) module

```

61
62     private void CalculateDialog_Shown(object sender, EventArgs e)
63     {
64
65         try
66         {
67
68             progressBar.Minimum = 0;
69             progressBar.Maximum = 8;
70             int progressCount = 0;
71
72             CreateRiskLevelField();
73             progressBar.Value = progressCount++;
74
75             Crane_vs_Building_height_Conflict();
76             progressBar.Value = progressCount++;
77
78             CalculateHeightConflict_WithinCranes();
79             progressBar.Value = progressCount++;
80
81             CalculateCombustiveStorageVsOffice();
82             progressBar.Value = progressCount++;
83
84             CalculateBatchPlant_vs_Roads_Offices();
85             progressBar.Value = progressCount++;
86
87             CalculateConflict_OfficesVsWashrooms();
88             progressBar.Value = progressCount++;
89
90             CalculateSpaceConflict_BetweenLayers();
91             progressBar.Value = progressCount++;
92
93             CalculateSpaceConflict_WithinSameLayer();
94             progressBar.Maximum = 8;
95

```

Special spatial analysis (height) for certain temporary facilities (Tower cranes).

TC-B (a tower crane to a building)

```

126 private void Crane_vs_Building_height_Conflict()
127 {
128     ISpatialFilter pSpatialFilter = new SpatialFilter();
129     IQueryFilter pQueryFilter = new QueryFilter();
130
131
132     try
133     {
134         List<LayerClass> craneList = m_BIM_ObjectDic[BIM_Objects.CRANE];
135         List<LayerClass> buildingList = m_BIM_ObjectDic[BIM_Objects.BUILDING_POLY];
136
137         if (craneList.Count == 0 || buildingList.Count == 0) return;
138
139
140         LayerClass cranes = craneList[0];
141
142         IFeatureLayer pCraneFeatureLayer = _layerUtils.GetLayerByName(cranes.LayerName) as IFeatureLayer;
143         IFeatureClass pCraneFClass = pCraneFeatureLayer.FeatureClass;
144
145         //Select only the towe cranes
146         //IQueryFilter pTowerCraneQueryFilter = new QueryFilter();
147         //pTowerCraneQueryFilter.WhereClause = "UPPER(Type_of_Temporary_Facility) = 'TOWER CRANE'";
148
149         int towerCraneCount = pCraneFClass.FeatureCount(null);
150         if (towerCraneCount == 0)
151             return;
152
153         int craneOIDFieldIndex = pCraneFClass.FindField(pCraneFClass.OIDFieldName);
154         int jibLengthFieldIndex = pCraneFClass.FindField("Jib_Length");
155         int craneHeightFieldIndex = pCraneFClass.FindField("Jib_Height");
156         int craneTowerSafetyDistIndex = pCraneFClass.FindField("Tower_Safety_Distance");
157         int craneHeightSftyDistIndex = pCraneFClass.FindField("Height_Safety_Distance");
158         int craneJibSftyDistIndex = pCraneFClass.FindField("Jib_Safety_Distance");
159         int craneSftyDistIndex = pCraneFClass.FindField("Safety_Distance");
160         int craneTypeFieldIndex = pCraneFClass.FindField("Type_of_Temporary_Facility");
161         int crane_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pCraneFClass.Fields);
162         int crane_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pCraneFClass.Fields);
163
164
165         using (ComReleaser comReleaser = new ComReleaser())
166         {
167             IFeatureCursor pCraneFeatureCursor = pCraneFClass.Search(null, true);
168             comReleaser.ManageLifetime(pCraneFeatureCursor);
169
170             IFeature CraneFeature = null;
171             while ((CraneFeature = pCraneFeatureCursor.NextFeature()) != null)
172             {
173                 long oid = long.Parse(CraneFeature.get_Value(craneOIDFieldIndex).ToString());
174                 double jibLength = Convert.ToDouble(CraneFeature.get_Value(jibLengthFieldIndex).ToString());
175                 double craneHeight = Convert.ToDouble(CraneFeature.get_Value(craneHeightFieldIndex).ToString());
176
177                 double safetyDistance = Convert.ToDouble(CraneFeature.get_Value(craneSftyDistIndex).ToString());
178                 double jibSafetyDistance = Convert.ToDouble(CraneFeature.get_Value(craneJibSftyDistIndex).ToString());
179                 double heightSafetyDistance = Convert.ToDouble(CraneFeature.get_Value(craneHeightSftyDistIndex).ToString());
180

```

```

181 DateTime craneStartDate = Convert.ToDateTime(CraneFeature.get_Value(crane_startDateFieldIndex));
182
183 DateTime craneEndDate = Convert.ToDateTime(CraneFeature.get_Value(crane_endDateFieldIndex));
184
185 string name = "";
186 IGeometry bufferedCrane = ((ITopologicalOperator)GetCentroid(CraneFeature.ShapeCopy)).Buffer(jibLength + jibSafetyDistance);
187
188 pSpatialFilter.Geometry = bufferedCrane;
189 pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
190
191
192 // bufferedFeatures.Add(bufferedCrane);
193
194 //Loop throught the building featureClasses
195 foreach (LayerClass key in buildingList)
196 {
197     LayerClass LayerFClass = key;
198
199     IFeatureClass pLayerFClass = m_pFeatureWorkspace.OpenFeatureClass(LayerFClass.LayerName);
200
201     name = ((IDataset)pLayerFClass).Name;
202     DisplayMessage(CraneFeature.Class.AliasName + " vs " + pLayerFClass.AliasName);
203
204     int building_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pLayerFClass.Fields);
205
206     if (building_startDateFieldIndex == -1)
207         continue;
208
209     string building_startDateFieldName = pLayerFClass.Fields.get_Field(building_startDateFieldIndex).Name;
210
211     int building_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pLayerFClass.Fields);
212     string building_endDateFieldName = pLayerFClass.Fields.get_Field(building_endDateFieldIndex).Name;
213
214     pSpatialFilter.WhereClause = building_startDateFieldName + " <= date '" + craneEndDate.ToString() + "' AND " + building_endDateFieldName + " >= date'" + craneStartDate.ToString() + "'";
215
216     IFeatureCursor pBuildingFCursor = pLayerFClass.Search(pSpatialFilter, true);
217     comReleaser.ManageLifetime(pBuildingFCursor);
218
219
220     IFeature pBuildingFeature = null;
221
222     while ((pBuildingFeature = pBuildingFCursor.NextFeature()) != null)
223     {
224
225         double featureHeight = 0;
226         object value = null;
227
228         int heightFieldIndex = -1;
229
230         heightFieldIndex = CommonClass.GET_HEIGHT_FIELD_INDEX(pLayerFClass.Fields);
231         if (heightFieldIndex > -1)
232             value = pBuildingFeature.get_Value(heightFieldIndex).ToString();
233
234         if (value == null)
235             continue;

```

TC-TC (a tower crane to a tower crane)

```

235         continue;
236
237         bool isValid = double.TryParse(value.ToString(), out featureHeight);
238         if (isValid)
239         {
240
241             if (isBuildingCraneConflict(featureHeight, craneHeight, heightSafetyDistance))
242             {
243
244                 //Report a conflict
245                 conflictFeatures.Add(new ConflictFeature() { Geometry = CraneFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = CraneFeature.OID, LayerName = "Cranes" });
246                 conflictFeatures.Add(new ConflictFeature() { Geometry = pBuildingFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = pBuildingFeature.OID, LayerName = LayerFClass.LayerName });
247                 AddRecordToReportTable(CraneFeature, pBuildingFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " with " + LayerFClass.LayerName, RISK_LEVEL.RED);
248                 bufferedFeatures.Add(bufferedCrane);
249             }
250
251         }
252     }
253 }
254
255 }
256
257 }
258
259 }
260
261 }
262 catch (Exception ex)
263 {
264     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Crane vs building block", MessageBoxButtons.OK, MessageBoxIcon.Error);
265 }
266
267 }
268
269
270
271 1 reference
272 private bool isBuildingCraneConflict(double buildlingHeight, double craneHeight, double heightSafetyDistance)
273 {
274     int heightDifference = Math.Abs((int)(craneHeight - buildlingHeight));
275
276     if (buildlingHeight > craneHeight)
277         return true;
278     else
279     {
280         if (heightDifference > heightSafetyDistance)
281             return false;
282         else
283             return true;
284     }
285 }
286

```

```

288 private void CalculateHeightConflict_WithinCranes()
289 {
290     try
291     {
292         if (m_BIM_ObjectDic[BIM_Objects.CRANE].Count == 0) return;
293         LayerClass cranes = m_BIM_ObjectDic[BIM_Objects.CRANE][0];
294         IFeatureLayer pCraneFeatureLayer = _layerUtils.GetLayerByName(cranes.LayerName) as IFeatureLayer;
295         IFeatureClass pCraneFCClass = pCraneFeatureLayer.FeatureClass;
296
297         //Select only the tower cranes
298         IQueryFilter pTowerCraneQueryFilter = new QueryFilter();
299         pTowerCraneQueryFilter.WhereClause = "UPPER(Type_of_Temporary_Facility) = 'TOWER CRANE'";
300
301         int towerCraneCount = pCraneFCClass.FeatureCount(pTowerCraneQueryFilter);
302         if (towerCraneCount == 0)
303             return;
304
305
306
307         ISelectionSet pCraneSelectionSet = pCraneFCClass.Select(pTowerCraneQueryFilter, esriSelectionType.esriSelectionTypeHybrid, esriSelectionOption.esriSelectionOptionNormal, ((IDataset)pCraneFCClass).Workspace);
308
309
310         int craneOIDFieldIndex = pCraneFCClass.FindField(pCraneFCClass.OIDFieldName);
311         int jibLengthFieldIndex = pCraneFCClass.FindField("Jib_Length");
312         int craneHeightFieldIndex = pCraneFCClass.FindField("Jib_Height");
313         int craneTowerSafetyDistIndex = pCraneFCClass.FindField("Tower_Safety_Distance");
314         int craneHeightSftyDistIndex = pCraneFCClass.FindField("Height_Safety_Distance");
315         int craneJibSftyDistIndex = pCraneFCClass.FindField("Jib_Safety_Distance");
316         int craneSftyDistIndex = pCraneFCClass.FindField("Safety_Distance");
317         int craneTypeFieldIndex = pCraneFCClass.FindField("Type_of_Temporary_Facility");
318         int crane_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pCraneFCClass.Fields);
319         int crane_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pCraneFCClass.Fields);
320
321
322         int startIndex = CommonClass.GET_START_DATE_INDEX(pCraneFCClass.Fields);
323         int endIndex = CommonClass.GET_END_DATE_INDEX(pCraneFCClass.Fields);
324
325         string startDateFieldName = pCraneFCClass.Fields.Field[startIndex].Name;
326         string endDateFieldName = pCraneFCClass.Fields.Field[startIndex].Name;
327
328
329         IEnumIDs objIDEnum = pCraneSelectionSet.IDs;
330         int OID = -1;
331
332         List<int> usedIDLList = new List<int>();
333
334         while ((OID = objIDEnum.Next()) != -1)
335         {
336             usedIDLList.Add(OID);
337
338             IFeature QueryCrane = pCraneFCClass.GetFeature(OID);
339
340             IPoint pCraneCentroid = ((IArea)QueryCrane.Shape).Centroid;
341
342             ITopologicalOperator pTopoOperator = pCraneCentroid as ITopologicalOperator;
343
344             long nid = long.Parse(QueryCrane.get_Value(craneOIDFieldIndex).ToString());

```

```

344 long oid = long.Parse(QueryCrane.get_Value(craneOIDFieldIndex).ToString());
345 double jibLength_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(jibLengthFieldIndex).ToString());
346 double craneHeight_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(craneHeightFieldIndex).ToString());
347 double towerSafetyDistance_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(craneTowerSafetyDistIndex).ToString());
348 double safetyDistance_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(craneSftyDistIndex).ToString());
349 double jibSafetyDistance_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(craneJibSftyDistIndex).ToString());
350 double heightSafetyDistance_QueryCrane = Convert.ToDouble(QueryCrane.get_Value(craneHeightSftyDistIndex).ToString());
351 string craneType_QueryCrane = QueryCrane.get_Value(craneTypeFieldIndex).ToString().ToUpper();
352 object date = QueryCrane.get_Value(crane_startDateFieldIndex);
353
354 if (date is DBNull)
355     continue;
356
357 DateTime craneStartDate = Convert.ToDateTime(QueryCrane.get_Value(crane_startDateFieldIndex));
358
359 DateTime craneEndDate = Convert.ToDateTime(QueryCrane.get_Value(crane_endDateFieldIndex));
360
361 IQueryFilter pQueryFilter = new QueryFilter();
362
363 pQueryFilter.WhereClause = startDateFieldName + " <= date '" + craneEndDate.ToString() + "' AND " + endDateFieldName + " >= date '" + craneStartDate.ToString() + "'";
364
365 ISelectionSet towerCraneQuerySet = pCraneSelectionSet.Select(pQueryFilter, esriSelectionType.esriSelectionTypeHybrid, esriSelectionOption.esriSelectionOptionNormal, ((IDataset)pCraneFCClass).Workspace);
366 int subOID = -1;
367 IEnumIDs subObjIDEnum = towerCraneQuerySet.IDs;
368 while ((subOID = subObjIDEnum.Next()) != -1)
369 {
370     //if (subOID == OID) continue;
371
372     IFeature resultFeature = pCraneFCClass.GetFeature(subOID);
373     double resultCraneHeight = Convert.ToDouble(resultFeature.get_Value(craneHeightFieldIndex).ToString());
374     double rsltJSD = Convert.ToDouble(resultFeature.get_Value(craneJibSftyDistIndex).ToString());
375
376     double rsltJibLength = Convert.ToDouble(resultFeature.get_Value(jibLengthFieldIndex).ToString());
377     double rsltTowerSafetyDistance = Convert.ToDouble(resultFeature.get_Value(craneTowerSafetyDistIndex).ToString());
378     double rsltHeighSafetyDistance = Convert.ToDouble(resultFeature.get_Value(craneHeightSftyDistIndex).ToString());
379
380     double heightDifferenceBetweenCranes = Math.Abs(resultCraneHeight - craneHeight_QueryCrane);
381
382     //Get the largest the jib safety distance
383     double largestJibSD = (jibSafetyDistance_QueryCrane <= rsltJSD) ? rsltJSD : jibSafetyDistance_QueryCrane;
384
385     IGeometry pCraneWithL_JSD = null;
386     IGeometry pCraneWithS_JSD = null;
387
388     IGeometry bufferedGeo1 = null;
389     IGeometry bufferedGeo2 = null;
390     IGeometry bufferedGeo3 = null;

```

```

392 //check if crane heights is the same
393 if (resultCraneHeight == craneHeight_QueryCrane)
394 {
395
396
397     if (jibSafetyDistance_QueryCrane <= rsltJSD)
398     {
399         pCraneWithL_JSD = resultFeature.ShapeCopy;
400         pCraneWithS_JSD = QueryCrane.ShapeCopy;
401
402
403         bufferedGeo1 = (GetCentroid(pCraneWithL_JSD) as ITopologicalOperator).Buffer(rsltJibLength + rsltJSD);
404         bufferedGeo2 = (GetCentroid(pCraneWithS_JSD) as ITopologicalOperator).Buffer(jibLength_QueryCrane);
405
406
407     }
408     else
409     {
410         pCraneWithL_JSD = QueryCrane.ShapeCopy;
411         pCraneWithS_JSD = resultFeature.ShapeCopy;
412
413         bufferedGeo1 = (GetCentroid(pCraneWithL_JSD) as ITopologicalOperator).Buffer(jibLength_QueryCrane + jibSafetyDistance_QueryCrane);
414         bufferedGeo2 = (GetCentroid(pCraneWithS_JSD) as ITopologicalOperator).Buffer(rsltJibLength);
415
416     }
417
418     //Conflict occurs
419     if (((IRelationalOperator)bufferedGeo1).Overlaps(bufferedGeo2))
420     {
421         bufferedFeatures.Add(bufferedGeo1);
422         bufferedFeatures.Add(bufferedGeo2);
423         conflictFeatures.Add(new ConflictFeature() { Geometry = QueryCrane.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = QueryCrane.OID, LayerName = "Cranes" });
424         AddRecordToReportTable(resultFeature, QueryCrane, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " of TC (Same Level), space conflict with jibs of TCs", RISK_LEVEL.RED);
425     }
426
427 }
428 else
429 {
430     bool isNotJib_MastCase = false;
431     bool isJibsInConflict = false;
432     bool isJibsDisjoint = false;
433
434     if (usedIDList.Contains(subOID))
435         continue;
436
437     //Find taller crane and check if the shorter crane intersects with the mast of the taller crane
438     if (resultCraneHeight < craneHeight_QueryCrane)
439     {
440         //Taller crane (mast)
441         bufferedGeo1 = ((ITopologicalOperator)QueryCrane.ShapeCopy).Buffer(towerSafetyDistance_QueryCrane);
442
443         //Shorter crane buffer(jib)
444         bufferedGeo2 = ((ITopologicalOperator)GetCentroid(resultFeature.Shape)).Buffer(rsltJibLength);
445
446         //Taller crane buffer (jib)
447         bufferedGeo3 = ((ITopologicalOperator)GetCentroid(QueryCrane.ShapeCopy)).Buffer(jibLength_QueryCrane);

```

```

446 //Taller crane buffer (jib)
447 bufferedGeo3 = ((ITopologicalOperator)GetCentroid(QueryCrane.ShapeCopy)).Buffer(jibLength_QueryCrane);
448
449
450 //Conflict occurs
451
452 //JIB and Mast case
453 isNotJib_MastCase = ((IRelationalOperator)bufferedGeo2).Disjoint(bufferedGeo1);
454
455 //Jib case
456 isJibsDisjoint = ((IRelationalOperator)bufferedGeo2).Disjoint(bufferedGeo3);
457 isJibsInConflict = (heightSafetyDistance_QueryCrane <= heightDifferenceBetweenCranes) ? false : true;
458
459
460 }
461 else
462 {
463 //Taller crane (mast)
464 bufferedGeo1 = ((ITopologicalOperator)resultFeature.Shape).Buffer(rsltTowerSafetyDistance);
465
466 //Shorter crane
467 bufferedGeo2 = ((ITopologicalOperator)GetCentroid(QueryCrane.Shape)).Buffer(jibLength_QueryCrane);
468
469 //Taller crane
470 bufferedGeo3 = ((ITopologicalOperator)GetCentroid(resultFeature.ShapeCopy)).Buffer(rsltJibLength);
471
472 //Conflict occurs
473 isJibsDisjoint = ((IRelationalOperator)bufferedGeo2).Disjoint(bufferedGeo3);
474 isNotJib_MastCase = ((IRelationalOperator)bufferedGeo2).Disjoint(bufferedGeo1);
475 isJibsInConflict = (rsltHeighSafetyDistance <= heightDifferenceBetweenCranes) ? false : true;
476
477 }
478
479 IFeature tallerFeature = (resultCraneHeight < craneHeight_QueryCrane) ? QueryCrane : resultFeature;
480 IFeature shorterCrane = (resultCraneHeight < craneHeight_QueryCrane) ? resultFeature : QueryCrane;
481
482 //The mast of the taller crane intersects with the jib of the shorter crane and the height difference between them is less than the safety distance
483 if (!isNotJib_MastCase)
484 {
485 bufferedFeatures.Add(bufferedGeo1);
486 bufferedFeatures.Add(bufferedGeo2);
487 conflictFeatures.Add(new ConflictFeature() { Geometry = shorterCrane.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = shorterCrane.OID, LayerName = "Cranes" });
488 conflictFeatures.Add(new ConflictFeature() { Geometry = tallerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = tallerFeature.OID, LayerName = "Cranes" });
489 AddRecordToReportTable(shorterCrane, tallerFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " (Different level), space conflict jib with Tower Mast of highest TC.", RISK_LEVEL.RED);
490 }
491 if (isJibsInConflict && !isJibsDisjoint)
492 {
493
494 bufferedFeatures.Add(bufferedGeo2);
495 bufferedFeatures.Add(bufferedGeo3);
496 conflictFeatures.Add(new ConflictFeature() { Geometry = shorterCrane.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = shorterCrane.OID, LayerName = "Cranes" });
497 conflictFeatures.Add(new ConflictFeature() { Geometry = tallerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = tallerFeature.OID, LayerName = "Cranes" });
498 AddRecordToReportTable(tallerFeature, shorterCrane, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Height_Conflict) + " (Different level), space conflict with TCs' jibs", RISK_LEVEL.RED);
499
500 }
501

```

```

501
502     }
503
504     }
505
506     }
507
508     }
509
510     catch (Exception ex)
511     {
512
513         MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Tower crane height block", MessageBoxButtons.OK, MessageBoxIcon.Error);
514
515     }
516
517 }
518
519 1 reference
520 private void CalculateSpaceConflict_BetweenLayers()
521 {
522     if (m_BIM_ObjectDic == null)
523         return;
524
525     Dictionary<int, LayerClass> innerDic = null;
526
527     try
528     {
529         foreach (int outerKey in outerDic.Keys)
530         {
531             innerDic = new Dictionary<int, LayerClass>(outerDic);
532
533             innerDic.Remove(outerKey);
534
535             foreach (int innerKey in innerDic.Keys)
536             {
537                 LayerClass outerClass = outerDic[outerKey];
538                 LayerClass innerClass = innerDic[innerKey];
539
540                 if (IsBuildingFeature(outerClass.LayerName) && IsBuildingFeature(innerClass.LayerName))
541                     continue;
542
543                 Find(outerClass, innerClass);
544             }
545         }
546     }
547
548 }
549
550 catch (Exception ex)
551 {
552
553     throw ex;
554 }
555
556
557 }

```

Minimum distance

Combustive material storage and site office

```

1139 private void CalculateCombustiveStorageVsOffice()
1140 {
1141     ITopologicalOperator pTopoOperator = null;
1142     IFeature pOuterFeature = null;
1143     IGeometry pOuterBufferGeometry = null;
1144     ISpatialFilter pSpatialFilter = new SpatialFilter();
1145     IQueryFilter pQueryFilter = new QueryFilter();
1146
1147     try
1148     {
1149         List<LayerClass> tempFacilities = m_BIM_ObjectDic[BIM_Objects.TEMPORARY_FACILITIES];
1150
1151         LayerClass offices = (from item in tempFacilities
1152                               where item.LayerName.ToUpper() == "OFFICES"
1153                               select item).FirstOrDefault();
1154         LayerClass storages = (from item in tempFacilities
1155                                where item.LayerName.ToUpper() == "STORAGES"
1156                                select item).FirstOrDefault();
1157
1158         //Exit if any of the feature classes do not exists
1159         if (offices == null || storages == null)
1160             return;
1161
1162         //Storages
1163         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(storages.LayerName);
1164         pQueryFilter.WhereClause = "UPPER(Material_Status) = 'COMBUSTIVE MATERIALS'";
1165         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(pQueryFilter, true);
1166
1167         int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
1168         int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
1169
1170         //Select right safety distance
1171         int withinDistanceFieldIndex = -1;
1172
1173         withinDistanceFieldIndex = pOuterFeatureClass.FindField("Safety_Distance_from_Offices");
1174
1175         if (withinDistanceFieldIndex == -1)
1176         {
1177             MessageBox.Show(new WindowWrapperClass(this.Handle), "Safety_Distance_from_Offices Field does not exists in Storages", "Alert!", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
1178             return;
1179         }
1180
1181         if (outer_startDateFieldIndex < 0 || outer_endDateFieldIndex < 0)
1182         {
1183             return;
1184         }
1185     }

```

```
1183     return;
1184 }
1185
1186 //Office
1187 IFeatureClass pInnerFCClass = m_pFeatureWorkspace.OpenFeatureClass(offices.LayerName);
1188 DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFCClass.AliasName);
1189
1190 int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFCClass.Fields);
1191 if (inner_startDateFieldIndex < 0)
1192     return;
1193
1194 int inner_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pInnerFCClass.Fields);
1195 if (inner_endDateFieldIndex < 0)
1196     return;
1197
1198 string feature_startDateFieldName = pInnerFCClass.Fields.Field[inner_startDateFieldIndex].Name;
1199 string feature_endDateFieldName = pInnerFCClass.Fields.Field[inner_endDateFieldIndex].Name;
1200
1201 using (ComReleaser comReleaser = new ComReleaser())
1202 {
1203     comReleaser.ManageLifetime(pOuterFCursor);
1204
1205     while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
1206     {
1207         pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;
1208
1209         double withinDistance = 0.0;
1210
1211         if (!double.TryParse(pOuterFeature.Value[withinDistanceFieldIndex].ToString(), out withinDistance))
1212             continue;
1213
1214         pOuterBufferGeometry = pTopoOperator.Buffer(withinDistance);
1215
1216         object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
1217
1218         object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);
1219
1220         if (sdate is DBNull)
1221             continue;
1222
1223         DateTime outer_StartDate = Convert.ToDateTime(sdate);
1224
1225         DateTime outer_EndDate = Convert.ToDateTime(edate);
1226
1227         pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
1228         pSpatialFilter.Geometry = pOuterBufferGeometry;
1229         pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
1230
1231         IFeatureCursor pInnerFCursor = pInnerFCClass.Search(pSpatialFilter, true);
1232         comReleaser.ManageLifetime(pInnerFCursor);
1233
1234         IFeature pOfficeFeature = null;
1235
1236         while ((pOfficeFeature = pInnerFCursor.NextFeature()) != null)
1237         {
1238
```

```

1205 while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
1206 {
1207
1208     pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;
1209
1210     double withinDistance = 0.0;
1211
1212     if (!double.TryParse(pOuterFeature.Value[withinDistanceFieldIndex].ToString(), out withinDistance))
1213         continue;
1214
1215     pOuterBufferGeometry = pTopoOperator.Buffer(withinDistance);
1216
1217     object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
1218
1219     object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);
1220
1221     if (sdate is DBNull)
1222         continue;
1223
1224     DateTime outer_StartDate = Convert.ToDateTime(sdate);
1225
1226     DateTime outer_EndDate = Convert.ToDateTime(edate);
1227
1228     pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
1229     pSpatialFilter.Geometry = pOuterBufferGeometry;
1230     pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
1231
1232     IFeatureCursor pInnerFCursor = pInnerFCClass.Search(pSpatialFilter, true);
1233     comReleaser.ManageLifetime(pInnerFCursor);
1234
1235     IFeature pOfficeFeature = null;
1236
1237     while ((pOfficeFeature = pInnerFCursor.NextFeature()) != null)
1238     {
1239         conflictFeatures.Add(new ConflictFeature() { Geometry = pOfficeFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = pOfficeFeature.OID, LayerName = offices.LayerName });
1240         conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.RED, OID = pOuterFeature.OID, LayerName = storages.LayerName });
1241         AddRecordToReportTable(pOuterFeature, pOfficeFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Hazard_Within_Range) + " (" + offices.LayerName + ")", RISK_LEVEL.RED);
1242         bufferedFeatures.Add(pOuterBufferGeometry);
1243     }
1244
1245 }
1246
1247 }
1248
1249 }
1250
1251 catch (Exception ex)
1252 {
1253
1254     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Storages vs Offices", MessageBoxButtons.OK, MessageBoxIcon.Error);
1255
1256 }
1257

```

Batch plant and roads and a site office.

```
1266 private void CalculateBatchPlant_vs_Roads_Offices()
1267 {
1268     ITopologicalOperator pTopoOperator = null;
1269     IFeature pOuterFeature = null;
1270     IGeometry pOuterBufferGeometry = null;
1271     ISpatialFilter pSpatialFilter = new SpatialFilter();
1272     IQueryFilter pQueryFilter = new QueryFilter();
1273
1274     try
1275     {
1276         List<LayerClass> tempFacilities = m_BIM_ObjectDic[BIM_Objects.TEMPORARY_FACILITIES];
1277
1278         LayerClass batchPlants = (from item in tempFacilities
1279                                 where item.LayerName.ToUpper() == "BATCH_PLANTS"
1280                                 select item).FirstOrDefault();
1281         List<LayerClass> dependants = (from item in tempFacilities
1282                                     where item.LayerName.ToUpper() == "OFFICES" || item.LayerName.ToUpper() == "ROADS"
1283                                     select item).ToList();
1284
1285         //Exit if any of the feature classes do not exists
1286         if (batchPlants == null || dependants.Count == 0)
1287             return;
1288
1289         //Storage
1290         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(batchPlants.LayerName);
1291         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(null, true);
1292
1293         using (ComReleaser comReleaser = new ComReleaser())
1294         {
1295             comReleaser.ManageLifetime(pOuterFCursor);
1296             int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
1297             int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
1298
1299             //Select right safety distance
1300             int safteyDistanceFieldIndex = -1;
1301
1302             safteyDistanceFieldIndex = pOuterFeatureClass.FindField("Safety_Distance");
1303
1304             if (safteyDistanceFieldIndex == -1)
1305             {
1306                 MessageBox.Show(new WindowWrapperClass(this.Handle), "Safety_Distance Field does not exists in " + batchPlants.LayerName, "Alert!", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
1307                 return;
1308             }
1309
1310             if (outer_startDateFieldIndex < 0 || outer_endDateFieldIndex < 0)
1311             {
1312                 return;
1313             }
1314
1315             while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
1316             {
```

```

1315 while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
1316 {
1317     pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;
1318
1319     double safetyDistance = 0.0;
1320
1321     if (!double.TryParse(pOuterFeature.Value[safetyDistanceFieldIndex].ToString(), out safetyDistance))
1322         continue;
1323
1324     pOuterBufferGeometry = pTopoOperator.Buffer(safetyDistance);
1325
1326     object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
1327
1328     object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);
1329
1330     if (sdate is DBNull)
1331         continue;
1332
1333     DateTime outer_StartDate = Convert.ToDateTime(sdate);
1334
1335     DateTime outer_EndDate = Convert.ToDateTime(edate);
1336
1337     pSpatialFilter.Geometry = pOuterBufferGeometry;
1338     pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
1339
1340     foreach (LayerClass dependantFeatures in dependants)
1341     {
1342         IFeatureClass pInnerFCClass = m_pFeatureWorkspace.OpenFeatureClass(dependantFeatures.LayerName);
1343         DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFCClass.AliasName);
1344
1345         int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFCClass.Fields);
1346         if (inner_startDateFieldIndex < 0)
1347             return;
1348
1349         int inner_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pInnerFCClass.Fields);
1350
1351         string feature_startDateFieldName = pInnerFCClass.Fields.Field[inner_startDateFieldIndex].Name;
1352         string feature_endDateFieldName = pInnerFCClass.Fields.Field[inner_endDateFieldIndex].Name;
1353         pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
1354         IFeatureCursor pInnerFCursor = pInnerFCClass.Search(pSpatialFilter, true);
1355         comReleaser.ManageLifetime(pInnerFCursor);
1356
1357         IFeature pInnerFeature = null;
1358
1359         while ((pInnerFeature = pInnerFCursor.NextFeature()) != null)
1360         {
1361             AddRecordToReportTable(pOuterFeature, pInnerFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Vulnerable_TF_is_within_range) + " (" + dependantFeatures.LayerName + ")", RISK_LEVEL.ORANGE);
1362             conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.ORANGE, OID = pOuterFeature.OID, LayerName = batchPlants.LayerName });
1363             conflictFeatures.Add(new ConflictFeature() { Geometry = pInnerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.ORANGE, OID = pInnerFeature.OID, LayerName = ((IDataset)pInnerFCClass).Name });
1364             bufferedFeatures.Add(pOuterBufferGeometry);
1365         }
1366     }
1367 }

```

Within distance

A Site office and a washroom

```
707 private void CalculateConflict_OfficesVsWashrooms()
708 {
709
710     ITopologicalOperator pTopoOperator = null;
711     IFeature pOuterFeature = null;
712     IGeometry pOuterBufferGeometry = null;
713     ISpatialFilter pSpatialFilter = new SpatialFilter();
714     IQueryFilter pQueryFilter = new QueryFilter();
715
716     try
717     {
718     {
719         List<LayerClass> tempFacilities = m_BIM_ObjectDic[BIM_Objects.TEMPORARY_FACILITIES];
720
721         LayerClass offices = (from item in tempFacilities
722                               where item.LayerName.ToUpper() == "OFFICES"
723                               select item).FirstOrDefault();
724         LayerClass washrooms = (from item in tempFacilities
725                                  where item.LayerName.ToUpper() == "SANITARY_UNITS"
726                                  select item).FirstOrDefault();
727
728         //Exit if any of the feature classes do not exists
729         if (offices == null || washrooms == null)
730             return;
731
732         //Office
733         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(offices.LayerName);
734         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(null, true);
735
736         int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
737         int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
738
739         //Select right safety distance
740         int withinDistanceFieldIndex = -1;
741
742         withinDistanceFieldIndex = pOuterFeatureClass.FindField("Site_Washroom_within_distance");
743
744         if (withinDistanceFieldIndex == -1)
745         {
746             MessageBox.Show(new WindowWrapperClass(this.Handle), "Site_Washroom_within_distance Field missing in " + washrooms.LayerName.Replace("_", " "), "Alert", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
747             return;
748         }
749
750         if (outer_startDateFieldIndex < 0 || outer_endDateFieldIndex < 0)
751         {
752             return;
753         }
754
755         //Washrooms
756         IFeatureClass pInnerFClass = m_pFeatureWorkspace.OpenFeatureClass(washrooms.LayerName);
757         DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFClass.AliasName);
758
759         int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFClass.Fields);
760
761
```

```

757 //Washrooms
758 IFeatureClass pInnerFClass = m_pFeatureWorkspace.OpenFeatureClass(washrooms.LayerName);
759 DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFClass.AliasName);
760
761 int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFClass.Fields);
762 if (inner_startDateFieldIndex < 0)
763     return;
764
765 int inner_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pInnerFClass.Fields);
766
767 string feature_startDateFieldName = pInnerFClass.Fields.Field[inner_startDateFieldIndex].Name;
768 string feature_endDateFieldName = pInnerFClass.Fields.Field[inner_endDateFieldIndex].Name;
769
770 List<int> assignedOIDs = new List<int>();
771
772
773 using (ComReleaser comReleaser = new ComReleaser())
774 {
775     comReleaser.ManageLifetime(pOuterFCursor);
776
777
778     while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
779     {
780
781         pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;
782
783
784         double withinDistance = 0.0;
785
786         if (!double.TryParse(pOuterFeature.Value[withinDistanceFieldIndex].ToString(), out withinDistance))
787             continue;
788
789         pOuterBufferGeometry = pTopoOperator.Buffer(withinDistance);
790
791         object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
792
793         object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);
794
795         if (sdate is DBNull)
796             continue;
797
798         DateTime outer_StartDate = Convert.ToDateTime(sdate);
799
800         DateTime outer_EndDate = Convert.ToDateTime(edate);
801
802
803         pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
804         pSpatialFilter.Geometry = pOuterBufferGeometry;
805         pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
806
807
808         int washroomCount = pInnerFClass.FeatureCount(pSpatialFilter);
809         IFeatureCursor innerFeatureCursor = pInnerFClass.Search(pSpatialFilter, true);
810         comReleaser.ManageLifetime(innerFeatureCursor);

```

```

814 //If a washroom has no intersection with any office
815 if (washroomCount == 0)
816 {
817     AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
818     conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
819     bufferedFeatures.Add(pOuterBufferGeometry);
820 }
821 }
822 //else
823 if (washroomCount > 0)
824 {
825     IFeature pWashroomFeature = null;
826
827     //If it intersects with multiple washrooms process further
828     if (washroomCount == 1)
829     {
830         pWashroomFeature = innerFeatureCursor.NextFeature();
831         int oid = pWashroomFeature.OID;
832         if (!assignedOIDs.Contains(oid))
833             assignedOIDs.Add(oid);
834         else
835         {
836             AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
837             conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
838             bufferedFeatures.Add(pOuterBufferGeometry);
839         }
840     }
841     else
842     {
843         List<WashroomClass> conflictWashrooms = new List<WashroomClass>();
844
845         while ((pWashroomFeature = innerFeatureCursor.NextFeature()) != null)
846         {
847             IGeometry officeGeo = pOuterFeature.ShapeCopy;
848             IGeometry washroomGeo = pWashroomFeature.ShapeCopy;
849
850             double distance = ((IPximityOperator)officeGeo).ReturnDistance(washroomGeo);
851             if (!assignedOIDs.Contains(pWashroomFeature.OID))
852                 conflictWashrooms.Add(new WashroomClass() { DistanceFromOffice = distance, WashroomFeature = pWashroomFeature });
853         }
854     }
855 }
856
857 if (conflictWashrooms.Count == 0)
858 {
859     AddRecordToReportTable(pOuterFeature, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Required_Facilites_not_within_range) + " (" + washrooms.LayerName + ")", RISK_LEVEL.YELLOW);
860     conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = offices.LayerName });
861     bufferedFeatures.Add(pOuterBufferGeometry);
862     continue;
863 }
864 }
865
866 //Find the minimum distance from the site washroom
867 double minDistance = (from x in conflictWashrooms select x.DistanceFromOffice).Min();
868

```

```

866 //Find the minimum distance from the site washroom
867 double minDistance = (from x in conflictWashrooms select x.DistanceFromOffice).Min();
868
869 //Get all the features that are not equal to the minimum distance
870 //List<WashroomClass> conflictOfficeFinal = conflictOffices.Where(item => item.DistanceFromOffice != minDistance).ToList();
871
872 int multipleFeaturesWithSameMinDis = conflictWashrooms.Where(item => item.DistanceFromOffice == minDistance).Count();
873
874 //Get all the features having same minimum distances from offices
875 List<WashroomClass> conflictWashrooms_WithMinDistance = conflictWashrooms.Where(item => item.DistanceFromOffice == minDistance).ToList();
876 if (conflictWashrooms_WithMinDistance.Count > 0)
877 {
878     int oid = 0;
879
880     if (conflictWashrooms_WithMinDistance.Count == 1)
881     {
882         oid = conflictWashrooms_WithMinDistance[0].OID;
883     }
884     else
885     {
886         //Select one oid which has not yest been assigned and flag the rest of the features as conflict.
887         oid = conflictWashrooms_WithMinDistance.Where(e => !assignedOIDs.Contains(e.OID)).ToList()[0].OID;
888     }
889     assignedOIDs.Add(oid);
890 }
891 }
892 }
893 }
894 }
895 }
896 }
897 }
898 //Flag Offices
899 IFeatureCursor pWashroomFCursor = null;
900 if (assignedOIDs.Count > 0)
901 {
902     string assignedOfficeOIDList = string.Join(",", assignedOIDs);
903
904     pWashroomFCursor = pInnerFCClass.Search(new QueryFilter() { WhereClause = pInnerFCClass.OIDFieldName + " NOT IN (" + assignedOfficeOIDList + ")", true});
905 }
906 else
907     pWashroomFCursor = pInnerFCClass.Search(null, true);
908
909 comReleaser.ManageLifetime(pWashroomFCursor);
910 IFeature pWashroom = null;
911 while ((pWashroom = pWashroomFCursor.NextFeature()) != null)
912 {
913     AddRecordToReportTable(pWashroom, null, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.No_Main_TF_Assigned) + " (" + offices.LayerName + ")", RISK_LEVEL.YELLOW);
914     conflictFeatures.Add(new ConflictFeature() { Geometry = pWashroom.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pWashroom.OID, LayerName = washrooms.LayerName });
915 }
916 }
917 }
918 }
919 }
920 }
921 }
922 }

```

```

921     }
922     }
923     catch (Exception ex)
924     {
925     }
926     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Offices vs Washrooms", MessageBoxButtons.OK, MessageBoxIcon.Error);
927 }
928 }
929 }
930 }
931 }
932 #endregion
933 #region
934

```

General checking rule for space conflict between site objects

```

519     private void CalculateSpaceConflict_BetweenLayers()
520     {
521         if (m_BIM_ObjectDic == null)
522             return;
523
524         Dictionary<int, LayerClass> innerDic = null;
525
526         try
527         {
528
529             foreach (int outerKey in outerDic.Keys)
530             {
531
532                 innerDic = new Dictionary<int, LayerClass>(outerDic);
533
534                 innerDic.Remove(outerKey);
535
536                 foreach (int innerKey in innerDic.Keys)
537                 {
538                     LayerClass outerClass = outerDic[outerKey];
539                     LayerClass innerClass = innerDic[innerKey];
540
541                     if (IsBuildingFeature(outerClass.LayerName) && IsBuildingFeature(innerClass.LayerName))
542                         continue;
543
544                     Find(outerClass, innerClass);
545
546                 }
547
548             }
549
550         }
551         catch (Exception ex)
552         {
553
554             throw ex;
555         }
556
557     }

```

```

559     /// <summary>
560     /// buffers each feature and checks if any other features within the same feature class
561     /// fall within the same time period and within the buffer distance.
562     /// </summary>
563     1 reference
564     private void CalculateSpaceConflict_WithinSameLayer()
565     {
566         ISpatialFilter pSpatialFilter = new SpatialFilter();
567         ITopologicalOperator pTopoOperator = null;
568         try
569         {
570             foreach (int key in outerDic.Keys)
571             {
572                 LayerClass layer = outerDic[key];
573
574                 if (IsBuildingFeature(layer.LayerName)) continue;
575
576                 DisplayMessage("Comparing " + layer.LayerName.Replace("_", " ")");
577
578                 IFeatureClass pFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(layer.LayerName);
579                 IFeatureCursor pFeatureCursor = pFeatureClass.Search(null, true);
580
581                 IFeature selectedFeature = null;
582
583                 int startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pFeatureClass.Fields);
584                 int endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pFeatureClass.Fields);
585                 int operationalDistanceFieldIndex = -1;
586
587                 operationalDistanceFieldIndex = pFeatureClass.FindField("Operational_Distance");
588                 if (operationalDistanceFieldIndex == -1)
589                 {
590                     MessageBox.Show(new WindowWrapperClass(this.Handle), "Operational Distance Field missing in " + layer.LayerName.Replace("_", " ") + "Alert", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
591                     continue;
592                 }
593                 if (startDateFieldIndex < 0 || endDateFieldIndex < 0)
594                 {
595                     continue;
596                 }
597
598                 //Get the start date feature name from the query feature class
599                 string feature_startDateFieldName = pFeatureClass.Fields.Field[startDateFieldIndex].Name;
600                 string feature_endDateFieldName = pFeatureClass.Fields.Field[endDateFieldIndex].Name;
601
602                 using (ComReleaser comReleaser = new ComReleaser())
603                 {
604                     comReleaser.ManageLifetime(pFeatureCursor);
605
606                     while ((selectedFeature = pFeatureCursor.NextFeature()) != null)
607                     {
608                         object date = selectedFeature.get_Value(startDateFieldIndex);
609
610                         if (date is DBNull)
611                             continue;
612
613                         DateTime startDate = Convert.ToDateTime(date);
614
615                         DateTime endDate = Convert.ToDateTime(selectedFeature.get_Value(endDateFieldIndex));
616
617                         pTopoOperator = selectedFeature.Shape as ITopologicalOperator;
618
619                         double operationalDistance = 0.0;
620                         if (!double.TryParse(selectedFeature.Value[operationalDistanceFieldIndex].ToString(), out operationalDistance))
621                             continue;

```

```

622     double operationalDistance = 0.0;
623     if (!double.TryParse(selectedFeature.Value[operationalDistanceFieldName].ToString(), out operationalDistance))
624         continue;
625
626     IGeometry pBufferGeometry = pTopoOperator.Buffer(operationalDistance);
627
628     pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + endDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + startDate.ToString() + "'";
629     pSpatialFilter.Geometry = pBufferGeometry;
630     pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
631
632     IFeatureCursor pQueryFCursor = pFeatureClass.Search(pSpatialFilter, true);
633     comReleaser.ManageLifetime(pQueryFCursor);
634     IFeature resultFeature = null;
635
636     while ((resultFeature = pQueryFCursor.NextFeature()) != null)
637     {
638         if (resultFeature.OID == selectedFeature.OID)
639             continue;
640
641         bufferedFeatures.Add(pBufferGeometry);
642         conflictFeatures.Add(new ConflictFeature() { Geometry = selectedFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = selectedFeature.OID, LayerName = layer.LayerName });
643         conflictFeatures.Add(new ConflictFeature() { Geometry = resultFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = resultFeature.OID, LayerName = layer.LayerName });
644         AddRecordToReportTable(resultFeature, selectedFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Space_Conflict), RISK_LEVEL.YELLOW);
645     }
646 }
647
648 }
649 }
650 }
651
652 }
653
654 }
655 catch (Exception ex)
656 {
657     throw ex;
658 }
659
660 }
661
662 }

```

```

1345 private void Find(LayerClass inputLayerClass, LayerClass queryFClass)
1346 {
1347     ITopologicalOperator pTopoOperator = null;
1348     IFeature pOuterFeature = null;
1349     IGeometry pOuterBufferGeometry = null;
1350     ISpatialFilter pSpatialFilter = new SpatialFilter();
1351     IQueryFilter pQueryFilter = new QueryFilter();
1352
1353
1354     try
1355     {
1356     {
1357
1358         //Get the featureClass
1359         IFeatureClass pOuterFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(inputLayerClass.LayerName);
1360         IFeatureCursor pOuterFCursor = pOuterFeatureClass.Search(null, true);
1361
1362         int outer_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pOuterFeatureClass.Fields);
1363         int outer_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pOuterFeatureClass.Fields);
1364
1365         //Select right safety distance
1366         int operationalDistanceFieldIndex = -1;
1367
1368         operationalDistanceFieldIndex = pOuterFeatureClass.FindField("Operational_Distance");
1369         if (operationalDistanceFieldIndex == -1 && !IsBuildingFeature(pOuterFeatureClass.AliasName))
1370         {
1371             MessageBox.Show(new WindowWrapperClass(this.Handle), "Operational Distance field missing in " + inputLayerClass.LayerName, "Space conflict", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
1372             return;
1373         }
1374
1375         if (outer_startDateFieldIndex < 0 || outer_endDateFieldIndex < 0)
1376         {
1377             return;
1378         }
1379
1380         //Inner FeatureClass
1381         IFeatureClass pInnerFClass = m_pFeatureWorkspace.OpenFeatureClass(queryFClass.LayerName);
1382         DisplayMessage(pOuterFeatureClass.AliasName + " vs " + pInnerFClass.AliasName);
1383
1384         int inner_startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pInnerFClass.Fields);
1385         int inner_endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pInnerFClass.Fields);
1386
1387         if (inner_startDateFieldIndex < 0)
1388         {
1389             return;
1390         }
1391
1392         string feature_startDateFieldName = pInnerFClass.Fields.Field[inner_startDateFieldIndex].Name;
1393         string feature_endDateFieldName = pInnerFClass.Fields.Field[inner_endDateFieldIndex].Name;
1394
1395
1396
1397
1398
1399
1400
1401
1402         using (ComReleaser comReleaser = new ComReleaser())

```

```

1398 string feature_startDateFieldName = pInnerFClass.Fields.Field[inner_startDateFieldIndex].Name;
1399 string feature_endDateFieldName = pInnerFClass.Fields.Field[inner_endDateFieldIndex].Name;
1400
1401
1402 using (ComReleaser comReleaser = new ComReleaser())
1403 {
1404     comReleaser.ManageLifetime(pOuterFCursor);
1405
1406
1407     while ((pOuterFeature = pOuterFCursor.NextFeature()) != null)
1408     {
1409         pTopoOperator = pOuterFeature.Shape as ITopologicalOperator;
1410
1411         double operationalDistance = 0.0;
1412
1413         if (IsBuildingFeature(((IDataset)pOuterFeatureClass).Name))
1414         {
1415             operationalDistance = CommonClass.SafetyDistanceDict(((IDataset)pOuterFeatureClass).Name);
1416         }
1417         else
1418         {
1419             if (!double.TryParse(pOuterFeature.Value[operationalDistanceFieldIndex].ToString(), out operationalDistance))
1420                 continue;
1421         }
1422     }
1423
1424
1425     pOuterBufferGeometry = pTopoOperator.Buffer(operationalDistance);
1426
1427     object sdate = pOuterFeature.get_Value(outer_startDateFieldIndex);
1428
1429     object edate = pOuterFeature.get_Value(outer_endDateFieldIndex);
1430
1431     if (sdate is DBNull)
1432         continue;
1433
1434     DateTime outer_StartDate = Convert.ToDateTime(sdate);
1435
1436     DateTime outer_EndDate = Convert.ToDateTime(edate);
1437
1438
1439     pSpatialFilter.WhereClause = feature_startDateFieldName + " <= date '" + outer_EndDate.ToString() + "' AND " + feature_endDateFieldName + " >= date '" + outer_StartDate.ToString() + "'";
1440     pSpatialFilter.Geometry = pOuterBufferGeometry;
1441     pSpatialFilter.SpatialRel = esriSpatialRelEnum.esriSpatialRelIntersects;
1442
1443
1444
1445     IFeatureCursor pInnerFCursor = pInnerFClass.Search(pSpatialFilter, true);
1446     comReleaser.ManageLifetime(pInnerFCursor);
1447
1448     IFeature pInnerFeature = null;
1449
1450     while ((pInnerFeature = pInnerFCursor.NextFeature()) != null)
1451     {
1452         AddRecordToReportTable(pOuterFeature, pInnerFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Space_Conflict), RISK_LEVEL.YELLOW);
1453         conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = inputLayerClass.LayerName });
1454         conflictFeatures.Add(new ConflictFeature() { Geometry = pInnerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pInnerFeature.OID, LayerName = queryFClass.LayerName });
1455         bufferedFeatures.Add(pOuterBufferGeometry);

```

```
1444
1445     IFeatureCursor pInnerFCursor = pInnerFClass.Search(pSpatialFilter, true);
1446     comReleaser.ManageLifetime(pInnerFCursor);
1447
1448     IFeature pInnerFeature = null;
1449
1450     while ((pInnerFeature = pInnerFCursor.NextFeature()) != null)
1451     {
1452         AddRecordToReportTable(pOuterFeature, pInnerFeature, Enum.GetName(typeof(CONFLICT_TYPE), CONFLICT_TYPE.Space_Conflict), RISK_LEVEL.YELLOW);
1453         conflictFeatures.Add(new ConflictFeature() { Geometry = pOuterFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pOuterFeature.OID, LayerName = inputLayerClass.LayerName });
1454         conflictFeatures.Add(new ConflictFeature() { Geometry = pInnerFeature.ShapeCopy, ConflictColor = RISK_LEVEL.YELLOW, OID = pInnerFeature.OID, LayerName = queryFClass.LayerName });
1455         bufferedFeatures.Add(pOuterBufferGeometry);
1456     }
1457 }
1458 }
1459 }
1460 }
1461 }
1462 }
1463 catch (Exception ex)
1464 {
1465     throw ex;
1466 }
1467 }
1468 }
1469 }
1470 }
```

Safety distance dialogue for IFC components

```
14 public partial class SafetyDistDialog : Form
15 {
16     3 references
17     Dictionary<string, double> safetyDistDic = null;
18
19     0 references
20     public SafetyDistDialog()
21     {
22         safetyDistDic = CommonClass.SafetyDistanceDict;
23         InitializeComponent();
24     }
25
26     0 references
27     private void SafetyDistanceDialog_Load(object sender, EventArgs e)
28     {
29         dgGrid.Rows.Clear();
30
31         foreach (string key in safetyDistDic.Keys)
32         {
33             int rowIndex = dgGrid.Rows.Add();
34
35             DataGridViewRow dgRow = dgGrid.Rows[rowIndex];
36             dgRow.Cells[0].Value = key;
37             dgRow.Cells[1].Value = safetyDistDic[key];
38         }
39     }
40
41     0 references
42     private void btnApply_Click(object sender, EventArgs e)
43     {
44         try
45         {
46             foreach (DataGridViewRow row in dgGrid.Rows)
47             {
48                 double value = 0.0;
49                 // bool isValid = double.TryParse("", out value);
50                 object distObj = row.Cells[1].Value;
51                 if (distObj != null)
52                 {
53                     bool isValid = double.TryParse(row.Cells[1].Value.ToString(), out value);
54                 }
55                 CommonClass.SafetyDistanceDict[row.Cells[0].Value.ToString()] = value;
56             }
57         }
58         catch (Exception ex)
59         {
60             MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
61         }
62
63         this.DialogResult = System.Windows.Forms.DialogResult.OK;
64     }
65
66     0 references
67     private void dgGrid_EditingControlShowing(object sender, DataGridViewEditingControlShowingEventArgs e)
68     {
69         if (e.Control is DataGridViewTextBoxEditingControl)
70         {
71             DataGridViewTextBoxEditingControl txtDist = e.Control as DataGridViewTextBoxEditingControl;
72             txtDist.KeyPress -= txtDist_KeyPress;
73             txtDist.KeyPress += new KeyPressEventHandler(txtDist_KeyPress);
74         }
75     }
76 }
```

```
72     private void txtDist_KeyPress(object sender, KeyPressEventArgs e)
73     {
74         if (!(char.IsDigit(e.KeyChar) || e.KeyChar == (char)Keys.Back || e.KeyChar == '.'))
75             { e.Handled = true; }
76         TextBox txtDecimal = sender as TextBox;
77         if (e.KeyChar == '.' && txtDecimal.Text.Contains("."))
78             {
79                 e.Handled = true;
80             }
81     }
82 }
83 }
84 }
```

Safety distance information set up when loading site objects from geodatabase

```
162 private void SortLayer(string featureClassName)
163 {
164
165
166     IFeatureClass pFeatureClass = m_pFeatureWorkspace.OpenFeatureClass(featureClassName);
167
168     LayerClass layerObject = new LayerClass();
169     layerObject.LayerName = featureClassName;
170
171     DisplayMessage("Processing " + featureClassName);
172
173     switch (featureClassName.ToUpper())
174     {
175     case "IFCWALLSTANDARDCASE_LINE":
176         this.progressBar.Value++;
177         layerObject.SafetyDistance = 2;
178         BuldingLinesFClassNames.Add(layerObject);
179         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
180         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
181         break;
182
183     case "IFCWALLSTANDARDCASE_SURFACE":
184         this.progressBar.Value++;
185         layerObject.SafetyDistance = 2;
186         BuildingPolyFClassNames.Add(layerObject);
187         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
188         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
189         break;
190
191     case "IFCCOVERING_SURFACE":
192         this.progressBar.Value++;
193         layerObject.SafetyDistance = 2;
194         BuildingPolyFClassNames.Add(layerObject);
195         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
196         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
197         break;
198
199
200     case "IFCWALL_LINE":
201         this.progressBar.Value++;
202         layerObject.SafetyDistance = 2;
203         BuldingLinesFClassNames.Add(layerObject);
204         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
205         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
206         break;
207
208     case "IFCWALL_SURFACE":
209         this.progressBar.Value++;
210         layerObject.SafetyDistance = 2;
211         BuildingPolyFClassNames.Add(layerObject);
212         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
213         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
214         break;
215
216     case "IFCCOLUMN_SURFACE":
217         this.progressBar.Value++;
218         layerObject.SafetyDistance = 1;
219         BuildingPolyFClassNames.Add(layerObject);
220         CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
221         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
222         break;
```

```

224 case "IFCSLAB_SURFACE":
225     this.progressBar.Value++;
226     layerObject.SafetyDistance = 2;
227     BuildingPolyFCClassNames.Add(layerObject);
228     CommonClass.SafetyDistanceDict.Add(layerObject.LayerName, layerObject.SafetyDistance);
229     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
230     break;
231
232 case "CRANES":
233     this.progressBar.Value++;
234     CraneFCClassNames.Add(layerObject);
235     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
236     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
237     break;
238
239 case "SITE_OBJECTS":
240     this.progressBar.Value++;
241     SiteObjectsList.Add(layerObject);
242     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
243     LabelLayer(featureClassName, "Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
244     break;
245
246 case "ROADS":
247     this.progressBar.Value++;
248     TemporaryFacilities.Add(layerObject);
249     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
250     LabelLayer(featureClassName, "Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
251     break;
252
253 case "STORAGES":
254     this.progressBar.Value++;
255     TemporaryFacilities.Add(layerObject);
256     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
257     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
258     break;
259
260 case "BATCH_PLANTS":
261     this.progressBar.Value++;
262     TemporaryFacilities.Add(layerObject);
263     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
264     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
265     break;
266
267 case "OFFICES":
268     this.progressBar.Value++;
269     TemporaryFacilities.Add(layerObject);
270     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
271     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
272     break;
273
274 case "LABS":
275     this.progressBar.Value++;
276     TemporaryFacilities.Add(layerObject);
277     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
278     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
279     break;
280
281 case "SANITARY_UNITS":
282     this.progressBar.Value++;
283     TemporaryFacilities.Add(layerObject);
284     _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
285     LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
286     break;
287
288

```

```
288
289     case "WORKSHOPS":
290         this.progressBar.Value++;
291         TemporaryFacilities.Add(layerObject);
292         _layerUtils.AddLayerToMap(pFeatureClass, featureClassName);
293         LabelLayer(featureClassName, "Temporary_Facility_Name", LayerUtils.SetRGBColor(0, 0, 0), 0);
294         break;
295     }
296
297     //Add symbol
298     SetSymbol(pFeatureClass);
299
300 }
301
```

Conflict report

```
12 public class CommonClass
13 {
14
15     //Report table Field Names
16     public static string OBJECTID = "NO_OF_CONFLICTS";
17     public static string FEATURE_NAME = "FEATURE_NAME";
18     public static string LAYER_TYPE = "FEATURE_TYPE";
19     public static string LAYER_ID = "FEATURE_ID";
20     public static string LAYER_NAME = "LAYER_NAME";
21     public static string GUID = "FEATURE_GUID";
22     public static string TAG_NO = "TAG_NO";
23     public static string LAYER_EST = "FEATURE_EST";
24     public static string LAYER_EFT = "FEATURE_EFT";
25     public static string LAYER_X = "FEATURE_Coordinate_X";
26     public static string LAYER_Y = "FEATURE_Coordinate_Y";
27
28
29     public static string CONFLICT_FEATURE = "CONFLICT_FEATURE_NAME";
30     public static string CONFLICT_LAYER_TYPE = "CONFLICT_FEATURE_TYPE";
31     public static string CONFLICT_LAYER_ID = "CONFLICT_FEATURE_ID";
32     public static string CONFLICT_LAYER_NAME = "CONFLICT_LAYER_NAME";
33     public static string CONFLICT_GUID = "CONFLICT_FEATURE_GUID";
34     public static string CONFLICT_TAG_NO = "CONFLICT_FEATURE_TAG_NO";
35     public static string CONFLICT_LAYER_EST = "CONFLICT_FEATURE_EST";
36     public static string CONFLICT_LAYER_EFT = "CONFLICT_FEATURE_EFT";
37     public static string CONFLICT_LAYER_X = "CONFLICT_FEATURE_Coordinate_X";
38     public static string CONFLICT_LAYER_Y = "CONFLICT_FEATURE_Coordinate_Y";
39
40     public static string CONFLICT_DURATION = "CONFLICT_DURATION";
41     public static string CONFLICT_TYPE = "CONFLICT_TYPE";
42     public static string DESCRIPTION = "DESCRIPTION";
43     public static string RISK_LEVEL = "RISK_LEVEL";
44
45
46     public static string RED_RISK = "Red";
47     public static string ORANGE_RISK = "Orange";
48     public static string YELLOW_RISK = "Yellow";
49
50     public static string RISK_LEVEL_FIELD_NAME = "Risk_Level";
51
52
53     public static List<string> FieldNames = new List<string>()
54     {
```

```

1462 //Adds a conflcit record to the report table.
1463 //12 references
1464 public bool AddRecordToReportTable(IFeature pFeature, IFeature conflictFeature, string conflict_type, RISK_LEVEL riskLevel)
1465 {
1466     IWorkspaceEdit pWorkspaceEdit = null;
1467     bool isAdded = false;
1468
1469     IPoint pFeatureCentroid = null;
1470     IPoint pConflictCentroid = null;
1471
1472     try
1473     {
1474         bool isNotTFName = IsNotTFFeature(((IDataset)pFeature.Class).Name);
1475
1476         pWorkspaceEdit = m_Workspace as IWorkspaceEdit;
1477         pWorkspaceEdit.StartEditing(true);
1478         pWorkspaceEdit.StartEditOperation();
1479
1480         using (ComReleaser comReleaser = new ComReleaser())
1481         {
1482             ICursor pTableCursor = this._ReportTable.Insert(true);
1483             IRow pRow = this._ReportTable.CreateRow();
1484             // IRowBuffer pRowBuffer = this._ReportTable.CreateRowBuffer();
1485             comReleaser.ManageLifetime(pTableCursor);
1486
1487             DateTime featureStartDate = new DateTime();
1488             DateTime featureEndDate = new DateTime();
1489             DateTime cnfltFStartDate = new DateTime();
1490             DateTime cnfltFEndDate = new DateTime();
1491
1492             pFeatureCentroid = GetCentroid(pFeature.Shape);
1493
1494             //The field indexes of the layers present in the report table
1495             int layerName_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_NAME);
1496             int featureName_FieldIndex = _ReportTable.FindField(CommonClass.FEATURE_NAME);
1497             int id_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_ID);
1498             int layer_type_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_TYPE);
1499             int layerGUID_FieldIndex = _ReportTable.FindField(CommonClass.GUID);
1500             int layer_Tag_No_FiledIndex = _ReportTable.FindField(CommonClass.TAG_NO);
1501             int layer_startDate_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_EST);
1502             int layer_endDate_FiedlIndex = _ReportTable.FindField(CommonClass.LAYER_EFT);
1503             int layer_x_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_X);
1504             int layer_y_FieldIndex = _ReportTable.FindField(CommonClass.LAYER_Y);
1505             int description_FieldIndex = _ReportTable.FindField(CommonClass.DESCRPTION);
1506             int riskLevel_FieldIndex = _ReportTable.FindField(CommonClass.RISK_LEVEL);
1507             int conflict_type_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_TYPE);
1508
1509             if (featureName_FieldIndex != -1)
1510             {
1511                 int nameFieldIndex = -1;
1512                 if (!isNotTFName)
1513                     nameFieldIndex = pFeature.Fields.FindField("Temporary_Facility_Name");
1514                 else
1515                     nameFieldIndex = pFeature.Fields.FindField("Name");
1516
1517                 if (nameFieldIndex != -1)
1518                     pRow.set_Value(featureName_FieldIndex, pFeature.get_Value(nameFieldIndex));
1519             }
1520
1521             if (layerName_FieldIndex != -1)
1522             {
1523                 pRow.set_Value(layerName_FieldIndex, ((IDataset)pFeature.Class).Name);
1524             }
1525
1526             if (id_FieldIndex != -1)
1527             {

```

```

1526     if (id_FieldIndex != -1)
1527     {
1528         |   pRow.set_Value(id_FieldIndex, pFeature.OID);
1529     }
1530
1531     if (layer_type_FieldIndex != -1)
1532     {
1533         |   int nameFieldIndex = pFeature.Fields.FindField("Type_of_Temporary_facility");
1534         |   if (nameFieldIndex != -1)
1535         |   |   pRow.set_Value(layer_type_FieldIndex, pFeature.get_Value(nameFieldIndex));
1536     }
1537
1538     if (layerGUID_FieldIndex != -1)
1539     {
1540         |   int GUIDFieldIndex = pFeature.Fields.FindField("GlobalId");
1541         |   if (GUIDFieldIndex != -1)
1542         |   |   pRow.set_Value(layerGUID_FieldIndex, pFeature.get_Value(GUIDFieldIndex));
1543     }
1544
1545     if (layer_Tag_No_FiledIndex != -1)
1546     {
1547         |   int TagNoFieldIndex = pFeature.Fields.FindField("Tag");
1548         |   if (TagNoFieldIndex != -1)
1549         |   |   pRow.set_Value(layer_Tag_No_FiledIndex, pFeature.get_Value(TagNoFieldIndex));
1550     }
1551
1552
1553     if (layer_startDate_FieldIndex != -1)
1554     {
1555         |
1556         |   int startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(pFeature.Fields);
1557         |   if (startDateFieldIndex != -1)
1558         |   {
1559         |   |   featureStartDate = Convert.ToDateTime(pFeature.get_Value(startDateFieldIndex));
1560         |   |   pRow.set_Value(layer_startDate_FieldIndex, pFeature.get_Value(startDateFieldIndex));
1561         |   }
1562     }
1563
1564     if (layer_endDate_FiedlIndex != -1)
1565     {
1566         |   int endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(pFeature.Fields);
1567         |   if (endDateFieldIndex != -1)
1568         |   {
1569         |   |   featureEndDate = Convert.ToDateTime(pFeature.get_Value(endDateFieldIndex));
1570         |   |   pRow.set_Value(layer_endDate_FiedlIndex, pFeature.get_Value(endDateFieldIndex));
1571         |   }
1572     }
1573
1574     if (layer_x_FieldIndex != -1)
1575     {
1576         |
1577         |   if (pFeatureCentroid != null)
1578         |   |   pRow.set_Value(layer_x_FieldIndex, pFeatureCentroid.X);
1579     }
1580
1581     if (layer_y_FieldIndex != -1)
1582     {
1583         |   if (pFeatureCentroid != null)
1584         |   |   pRow.set_Value(layer_y_FieldIndex, pFeatureCentroid.Y);
1585     }
1586
1587     if (description_FieldIndex != -1)
1588     {
1589         |   int DescFieldIndex = pFeature.Fields.FindField("Description");
1590         |   if (DescFieldIndex != -1)
1591         |   |   pRow.set_Value(description_FieldIndex, pFeature.get_Value(DescFieldIndex));
1592     }

```

```

1590         pRow.set_Value(description_FieldIndex, pFeature.get_Value(DescFieldIndex));
1591     }
1592 }
1593 if (conflict_type_FieldIndex != -1)
1594 {
1595
1596
1597     pRow.set_Value(conflict_type_FieldIndex, conflict_type.Replace("_", " "));
1598 }
1599
1600 if (conflictFeature != null)
1601 {
1602     pConflictCentroid = GetCentroid(conflictFeature.Shape);
1603
1604
1605     //The field indexes of the conflict layers present in the report table
1606     int conflict_featureName_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_FEATURE);
1607     int conflict_layerName_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_NAME);
1608     int conflict_id_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_ID);
1609     int conflict_layer_type_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_TYPE);
1610     int conflict_layerGUID_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_GUID);
1611     int conflict_layer_Tag_No_FiledIndex = _ReportTable.FindField(CommonClass.CONFLICT_TAG_NO);
1612     int conflict_layer_startDate_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_EST);
1613     int conflict_layer_endDate_FiedlIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_EFT);
1614     int conflict_layer_x_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_X);
1615     int conflict_layer_y_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_LAYER_Y);
1616
1617     int conflict_duration_FieldIndex = _ReportTable.FindField(CommonClass.CONFLICT_DURATION);
1618
1619
1620     IsNotTFName = IsNotTFFeature(((IDataset)conflictFeature.Class).Name);
1621
1622     if (conflict_featureName_FieldIndex != -1)
1623     {
1624         int nameFieldIndex = -1;
1625         if (!IsNotTFName)
1626             nameFieldIndex = conflictFeature.Fields.FindField("Temporary_Facility_Name");
1627         else
1628             nameFieldIndex = conflictFeature.Fields.FindField("Name");
1629
1630         if (nameFieldIndex != -1)
1631             pRow.set_Value(conflict_featureName_FieldIndex, conflictFeature.get_Value(nameFieldIndex));
1632     }
1633 }
1634
1635
1636 if (conflict_layerName_FieldIndex != -1)
1637 {
1638     pRow.set_Value(conflict_layerName_FieldIndex, ((IDataset)conflictFeature.Class).Name);
1639 }
1640
1641 if (conflict_id_FieldIndex != -1)
1642 {
1643     pRow.set_Value(conflict_id_FieldIndex, conflictFeature.OID);
1644 }
1645
1646
1647 if (conflict_layer_type_FieldIndex != -1)
1648 {
1649     int nameFieldIndex = conflictFeature.Fields.FindField("Type_of_Temporary_facility");
1650     if (nameFieldIndex != -1)
1651         pRow.set_Value(conflict_layer_type_FieldIndex, conflictFeature.get_Value(nameFieldIndex));
1652 }
1653 }
1654 if (conflict_layerGUID_FieldIndex != -1)
1655 {
1656

```

```

1656     {
1657         int GUIDFieldIndex = conflictFeature.Fields.FindField("GlobalId");
1658         if (GUIDFieldIndex != -1)
1659             pRow.set_Value(conflict_layerGUID_FieldIndex, conflictFeature.get_Value(GUIDFieldIndex));
1660     }
1661 }
1662 if (conflict_layer_Tag_No_FiledIndex != -1)
1663 {
1664     int TagNoFieldIndex = conflictFeature.Fields.FindField("Tag");
1665     if (TagNoFieldIndex != -1)
1666         pRow.set_Value(conflict_layer_Tag_No_FiledIndex, conflictFeature.get_Value(TagNoFieldIndex));
1667 }
1668 }
1669
1670 if (conflict_layer_startDate_FieldIndex != -1)
1671 {
1672     int startDateFieldIndex = CommonClass.GET_START_DATE_INDEX(conflictFeature.Fields);
1673     if (startDateFieldIndex != -1)
1674     {
1675         cnfltFStartDate = Convert.ToDateTime(conflictFeature.get_Value(startDateFieldIndex));
1676         pRow.set_Value(conflict_layer_startDate_FieldIndex, conflictFeature.get_Value(startDateFieldIndex));
1677     }
1678 }
1679 }
1680
1681 if (conflict_layer_endDate_FiedlIndex != -1)
1682 {
1683     int endDateFieldIndex = CommonClass.GET_END_DATE_INDEX(conflictFeature.Fields);
1684     if (endDateFieldIndex != -1)
1685     {
1686         cnfltFEndDate = Convert.ToDateTime(conflictFeature.get_Value(endDateFieldIndex));
1687         pRow.set_Value(conflict_layer_endDate_FiedlIndex, conflictFeature.get_Value(endDateFieldIndex));
1688     }
1689 }
1690
1691
1692 if (conflict_layer_x_FieldIndex != -1)
1693 {
1694     if (pConflictCentroid != null)
1695         pRow.set_Value(conflict_layer_x_FieldIndex, pConflictCentroid.X);
1696 }
1697
1698
1699 if (conflict_layer_y_FieldIndex != -1)
1700 {
1701     if (pConflictCentroid != null)
1702         pRow.set_Value(conflict_layer_y_FieldIndex, pConflictCentroid.Y);
1703 }
1704
1705 ConflictDateTimeClass conflictDateTimeCal = new ConflictDateTimeClass(featureStartDate, featureEndDate, cnfltFStartDate, cnfltFEndDate);
1706
1707 if (conflict_duration_FieldIndex != -1)
1708 {
1709     pRow.set_Value(conflict_duration_FieldIndex, conflictDateTimeCal.GetConflictDays());
1710 }
1711
1712 }
1713
1714
1715 }
1716
1717 if (riskLevel_FieldIndex != -1)
1718 {
1719     string riskLev = riskLevel.ToString();
1720     string value = "";
1721     switch (riskLev)
1722     {

```

```

1717  1717  if (riskLevel_FieldIndex != -1)
1718  1718  {
1719  1719      string riskLev = riskLevel.ToString();
1720  1720      string value = "";
1721  1721      switch (riskLev)
1722  1722      {
1723  1723          case "RED":
1724  1724              value = "Urgent";
1725  1725              break;
1726  1726          case "ORANGE":
1727  1727              value = "Very Important";
1728  1728              break;
1729  1729          case "YELLOW":
1730  1730              value = "Important";
1731  1731              break;
1732  1732      }
1733  1733
1734  1734
1735  1735      pRow.set_Value(riskLevel_FieldIndex, value);
1736  1736  }
1737  1737
1738  1738      pRow.Store();
1739  1739
1740  1740  }
1741  1741
1742  1742      pWorkspaceEdit.StopEditOperation();
1743  1743      pWorkspaceEdit.StopEditing(true);
1744  1744
1745  1745  }
1746  1746  catch (Exception ex)
1747  1747  {
1748  1748
1749  1749      throw ex;
1750  1750  }
1751  1751  finally
1752  1752  {
1753  1753      if (pWorkspaceEdit != null)
1754  1754      {
1755  1755          if (pWorkspaceEdit.IsBeingEdited())
1756  1756          {
1757  1757              pWorkspaceEdit.StopEditOperation();
1758  1758              pWorkspaceEdit.StopEditing(true);
1759  1759          }
1760  1760      }
1761  1761  }
1762  1762
1763  1763  }
1764  1764
1765  1765
1766  1766      return isAdded;
1767  1767
1768  1768
1769  1769
1770  1770
1771  1771  }

```

```
640     public enum CONFLICT_TYPE
641     {
642     |
643         Space_Conflict,
644         Height_Conflict,
645         Hazard_Within_Range,
646         Required_Facilites_not_within_range,
647         Vulnerable_TF_is_within_range,
648         No_Main_TF_Assigned
649     |
650     }
651 }
```

```
653     public enum RISK_LEVEL
654     {
655     |
656         RED = 0,
657         ORANGE = 1,
658         YELLOW = 2
659     |
660     }
```

Visualization of conflicts on the map

```
1953     private void DisplayBuffereElements()
1954     {
1955         foreach (IGeometry buffer in bufferedFeatures)
1956         {
1957             {
1958                 IFillShapeElement pFillShapeElement = new PolygonElementClass();
1959                 pFillShapeElement.Symbol = (IFillSymbol)CommonClass.SET_POLY_SELECTION_SYMBOL(LayerUtils.SetRGBColor(0, 128, 255), LayerUtils.SetRGBColor(0, 0, 0), 255, esriSimpleFillStyle.esriSFSHollow, esriSimpleLineStyle.esriSLSDashDot, 1);
1960                 IElement pBufferElement = (IElement)pFillShapeElement;
1961                 pBufferElement.Geometry = buffer;
1962                 _graphicsContainer.AddElement(pBufferElement, 0);
1963             }
1964         }
1965     }
1966 }
1967 }
1968 }
```

```

2096     private void SelectFeaturesInAttributeTable(List<List<ConflictFeature>> conflictLayerList)
2097     {
2098     }
2099     string layerName = "";
2100     foreach (List<ConflictFeature> layerNameList in conflictLayerList)
2101     {
2102         try
2103         {
2104             layerName = layerNameList[0].LayerName;
2105             var oidList = layerNameList.Select(p => p.OID)
2106                 .Distinct().ToList();
2107
2108             string oids = string.Join(",", oidList);
2109
2110             IFeatureLayer pFeatureLayer = _layerUtils.GetLayerByName(layerName) as IFeatureLayer;
2111
2112             IFeatureClass pFClass = pFeatureLayer.FeatureClass;
2113
2114             ISymbol pSymbol = null;
2115             switch (pFClass.ShapeType)
2116             {
2117                 case esriGeometryType.esriGeometryPoint:
2118                 case esriGeometryType.esriGeometryMultipoint:
2119                     pSymbol = CommonClass.SET_POINT_SELECTION_SYMBOL(LayerUtils.SetRGBColor(0, 0, 0));
2120                     break;
2121                 case esriGeometryType.esriGeometryLine:
2122                 case esriGeometryType.esriGeometryPolyline:
2123                     pSymbol = CommonClass.SET_POLYLINE_SELECTION_SYMBOL(LayerUtils.SetRGBColor(0, 0, 0), esriSimpleLineStyle.esriSLSNull);
2124                     break;
2125                 case esriGeometryType.esriGeometryPolygon:
2126                 case esriGeometryType.esriGeometryMultiPatch:
2127                     pSymbol = CommonClass.SET_POLY_SELECTION_SYMBOL(LayerUtils.SetRGBColor(0, 0, 0), LayerUtils.SetRGBColor(255, 255, 255), 100, esriSimpleFillStyle.esriSFSNull, esriSimpleLineStyle.esriSLSNull, 2);
2128                     break;
2129             }
2130
2131             IFeatureSelection featSelect = pFeatureLayer as IFeatureSelection;
2132             featSelect.SetSelectionSymbol = true;
2133             IQueryFilter pqf = new QueryFilter();
2134             pqf.WhereClause = pFClass.OIDFieldName + " IN (" + oids + ")";
2135             featSelect.SelectionSymbol = pSymbol;
2136             featSelect.SelectFeatures(pqf, esriSelectionResultEnum.esriSelectionResultNew, false);
2137
2138         }
2139         catch (Exception ex)
2140         {
2141             MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Selecting Attribute Block in " + layerName, MessageBoxButtons.OK, MessageBoxIcon.Error);
2142         }
2143     }
2144 }
2145
2146
2147
2148
2149
2150

```

```

1971 private void DisplayConflictFeaturesElements()
1972 {
1973     List<ConflictFeature> finalfeatureList = new List<ConflictFeature>();
1974
1975     List<List<ConflictFeature>> layerNameLists = conflictFeatures
1976         .GroupBy(u => u.LayerName)
1977         .Select(grp => grp.ToList())
1978         .ToList();
1979
1980
1981     foreach (List<ConflictFeature> layerNameList in layerNameLists)
1982     {
1983         var oidLists = layerNameList
1984             .GroupBy(u => u.OID)
1985             .Select(grp => grp.ToList())
1986             .ToList();
1987
1988         foreach (List<ConflictFeature> oidList in oidLists)
1989         {
1990             int min = oidList.Min(x => (int)x.ConflictColor);
1991
1992             ConflictFeature feature = oidList.Where(entry => (int)entry.ConflictColor == min).First();
1993             if (feature != null)
1994                 finalfeatureList.Add(feature);
1995         }
1996     }
1997
1998
1999
2000
2001     IElementCollection pElementCollection = new ElementCollectionClass();
2002
2003     foreach (ConflictFeature conflictFeature in finalfeatureList)
2004     {
2005         try
2006         {
2007
2008             IGeometry Geom = conflictFeature.Geometry;
2009
2010             RISK_LEVEL riskLevel = conflictFeature.ConflictColor;
2011
2012             IRgbColor outlineColour = null;
2013
2014             string risk = "";
2015
2016             switch (riskLevel)
2017             {
2018                 case RISK_LEVEL.RED:
2019                     outlineColour = LayerUtils.SetRGBColor(254, 68, 56);
2020                     risk = "Urgent";
2021                     break;
2022                 case RISK_LEVEL.ORANGE:
2023                     outlineColour = LayerUtils.SetRGBColor(243, 134, 61);
2024                     risk = "Very Important";
2025                     break;
2026                 case RISK_LEVEL.YELLOW:
2027                     outlineColour = LayerUtils.SetRGBColor(255, 195, 0);
2028                     risk = "Important";
2029                     break;
2030             }
2031
2032
2033             ISymbol pSymbol = CommonClass.SET_SYMBOL(Geom.GeometryType, outlineColour);
2034
2035             IElement pElement = null;
2036             IMarkerElement markerElement = null;

```

```

2036 IMarkerElement markerElement = null;
2037 ILineElement lineElement = null;
2038 IFillShapeElement fillShapeElement = null;
2039
2040 switch (Geom.GeometryType)
2041 {
2042
2043     case esriGeometryType.esriGeometryPoint:
2044     case esriGeometryType.esriGeometryMultipoint:
2045         markerElement = new MarkerElementClass();
2046         markerElement.Symbol = (IMarkerSymbol)pSymbol;
2047         pElement = (IElement)markerElement;
2048         break;
2049     case esriGeometryType.esriGeometryLine:
2050     case esriGeometryType.esriGeometryPolyline:
2051         lineElement = new LineElementClass();
2052         lineElement.Symbol = (ILineSymbol)pSymbol;
2053         pElement = (IElement)lineElement;
2054         break;
2055     case esriGeometryType.esriGeometryPolygon:
2056         fillShapeElement = new PolygonElementClass();
2057         fillShapeElement.Symbol = (IFillSymbol)pSymbol;
2058         pElement = (IElement)fillShapeElement;
2059         break;
2060     case esriGeometryType.esriGeometryMultiPatch:
2061         IMultiPatch pMultipatch = Geom as IMultiPatch;
2062         IPoint planarOriginPoint = new PointClass();
2063         planarOriginPoint.X = 0;
2064         planarOriginPoint.Y = 0;
2065         planarOriginPoint.Z = 0;
2066         //Construct A Vector3D Corresponding To The Positive X Vector
2067         IVector3D planarPositiveXVector3D = ConstructVector3D(10, 0, 0);
2068
2069         //Construct A Vector3D Corresponding To The Normal Vector
2070         IVector3D planarNormalVector3D = ConstructVector3D(0, 0, 10);
2071         ITransform3D pTransform3D = pMultipatch as ITransform3D;
2072         IGeometry pnewGeo = pTransform3D.ProjectToPlane(planarOriginPoint, planarPositiveXVector3D, planarNormalVector3D);
2073         Geom = pnewGeo;
2074         fillShapeElement = new PolygonElementClass();
2075         fillShapeElement.Symbol = (IFillSymbol)pSymbol;
2076         pElement = (IElement)fillShapeElement;
2077         break;
2078
2079 }
2080
2081 pElement.Geometry = Geom;
2082 _graphicsContainer.AddElement(pElement, 0);
2083 UpdateRiskField(conflictFeature, risk);
2084
2085 }
2086
2087 catch (Exception ex)
2088 {
2089 }
2090
2091 }
2092 SelectFeaturesInAttributeTable(layerNameLists);
2093 _layerUtils.Document.ActiveView.Refresh();
2094
2095 }

```

Coding for the user interface (UI) for the developed DCD toolbar extension

```
33 namespace BIM.SpaceTimeForms
34 {
35     public partial class SpaceTimeConflictForm : Form
36     {
37
38         IMap _pMap = null;
39         IMxDocument _pMxDocument = null;
40         IGxDialog gxDialog = new GxDialogClass();
41
42         IWorkspace m_Workspace = null;
43         IFeatureWorkspace m_pFeatureWorkspace = null;
44         Geoprocessor pgp = new Geoprocessor();
45         Dictionary<BIM_Objects, List<LayerClass>> m_BIM_ObjectDic = null;
46         LayerUtils _layerUtils = null;
47         ITable _ReportTable = null;
48         string excelFileLocation = "";
49
50         IGraphicsContainer pGraphicsContainer = null;
51
52         public SpaceTimeConflictForm()
53         {
54             InitializeComponent();
55             _pMxDocument = ArcMap.Document;
56             _pMap = ArcMap.Document.FocusMap;
57             _layerUtils = new LayerUtils(_pMxDocument);
58
59             pGraphicsContainer = (IGraphicsContainer)_pMap;
60
61         }
62
63     }
64
65     private void SpaceTimeConflictForm_Load(object sender, EventArgs e)
66     {
67         pgp.ToolExecuted += new EventHandler<ToolExecutedEventArgs>(pgp_ToolExecuted);
68         pgp.ToolExecuting += new EventHandler<ToolExecutingEventArgs>(pgp_ToolExecuting);
69
70     }
71
72
73     void pgp_ToolExecuting(object sender, ToolExecutingEventArgs e)
74     {
75         try
76         {
77             IGeoProcessorResult2 pGPRResult2 = (IGeoProcessorResult2)e.GPResult;
78             string msg = "";
79             if (pGPRResult2.Status == esriJobStatus.esriJobExecuting)
80             {
81                 this.Cursor = Cursors.WaitCursor;
82
83                 // DisplayMessage("Executing " + pGPRResult2.Process.Tool.DisplayName);
84
85             }
86         }
87         catch (Exception ex)
88         {
89             this.Cursor = Cursors.Default;
90         }
91     }
92
93
94
95     void pgp_ToolExecuted(object sender, ToolExecutedEventArgs e)
96     {
97         IGeoProcessorResult2 pGPRResult2 = (IGeoProcessorResult2)e.GPResult;
98         string msg = "";
99         try
```

```

98     string msg = "";
99     try
100     {
101         this.Cursor = Cursors.Default;
102
103         if (pGPResult2.Status == esriJobStatus.esriJobFailed)
104         {
105             // DisplayMessage(pGPResult2.Process.Tool.DisplayName + " Failed.");
106
107             for (var i = 0; i < pGPResult2.MessageCount; i++)
108             {
109                 msg += pGPResult2.GetMessage(i);
110             }
111             // DisplayMessage(msg);
112         }
113         else if (pGPResult2.Status == esriJobStatus.esriJobSucceeded)
114         {
115             // DisplayMessage("");
116
117         }
118     }
119
120 }
121 catch (Exception ex)
122 {
123     this.Cursor = Cursors.Default;
124 }
125 }
126 }
127 }
128

```

0 references

```

129 private void btnOpenFgb_Click(object sender, EventArgs e)
130 {
131
132     //Clear all the graphics from the map
133     ClearAllGraphicElements();
134
135     string fgdbLocationPath = SelectFdb();
136     if (fgdbLocationPath == "")
137         return;
138     else
139     {
140         txtfgblocation.Text = fgdbLocationPath;
141
142         txtfgblocation.Refresh();
143     }
144     if (m_Workspace == null)
145     {
146         MessageBox.Show("Select an input file geodatabase", "Alert", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
147         return;
148     }
149
150
151     try
152     {
153         //Clear all feaature layer selections if any
154         _layerUtils.ClearMapSelection();
155
156         //Remove all the layers from the map
157         //_layerUtils.RemoveAllLayersFromMap();
158
159         UseWaitCursor = true;
160
161         //Get the workspace
162         m_pFeatureWorkspace = m_Workspace as IFeatureWorkspace;

```

```

165 //Open the process dialog..
166 ProcessingDataDialog processingDataDialog = new ProcessingDataDialog(m_Workspace, _pMxDocument);
167 processingDataDialog.StartPosition = FormStartPosition.CenterParent;
168 var result = processingDataDialog.ShowDialog(new WindowWrapperClass(this.Handle));
169 if (result == System.Windows.Forms.DialogResult.OK)
170 {
171     m_BIM_ObjectDic = processingDataDialog.BIM_ObjectDic;
172
173     UseWaitCursor = false;
174     btnProcess.Enabled = true;
175     btnSafetyDistance.Enabled = true;
176 }
177 else
178 {
179     UseWaitCursor = false;
180     MessageBox.Show(new WindowWrapperClass(this.Handle), "Could load layers", "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
181 }
182 }
183
184 }
185 catch (Exception ex)
186 {
187     UseWaitCursor = false;
188     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Loading fgb failure", MessageBoxButtons.OK, MessageBoxIcon.Error);
189 }
190 }
191
192 }

```

```

196 private void btnRefresh_Click(object sender, EventArgs e)
197 {
198
199     if (string.IsNullOrEmpty(txtfgblocation.Text))
200         return;
201
202
203     if (m_Workspace == null)
204     {
205         MessageBox.Show("Select an input file geodatabase", "Alert", MessageBoxButtons.OK, MessageBoxIcon.Exclamation);
206         return;
207     }
208
209
210     try
211     {
212         //Clear all feaature layer selections if any
213         _layerUtils.ClearMapSelection();
214
215         //Remove all the layers from the map
216         //_layerUtils.RemoveAllLayersFromMap();
217
218         UseWaitCursor = true;
219
220         //Get the workspace
221         m_pFeatureWorkspace = m_Workspace as IFeatureWorkspace;
222
223
224         //Open the process dialog..
225         ProcessingDataDialog processingDataDialog = new ProcessingDataDialog(m_Workspace, _pMxDocument);
226         processingDataDialog.StartPosition = FormStartPosition.CenterParent;
227         var result = processingDataDialog.ShowDialog(new WindowWrapperClass(this.Handle));
228         if (result == System.Windows.Forms.DialogResult.OK)
229         {
230             m_BIM_ObjectDic = processingDataDialog.BIM_ObjectDic;
231
232             UseWaitCursor = false;
233             btnProcess.Enabled = true;
234             btnSafetyDistance.Enabled = true;
235         }
236         else
237         {
238             UseWaitCursor = false;
239             MessageBox.Show(new WindowWrapperClass(this.Handle), "Could load layers", "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
240         }
241     }
242
243 }
244 catch (Exception ex)
245 {
246     UseWaitCursor = false;
247     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Loading fgb failure", MessageBoxButtons.OK, MessageBoxIcon.Error);
248 }
249 }
250
251 }

```

```

254     /// <summary>
255     /// Dialog for selecting a File Geodatabase...
256     /// </summary>
257     /// <returns>Location of the FGDB</returns>
258     1 reference
259     private string SelectFdb()
260     {
261         string outputLocation = "";
262
263         try
264         {
265             IEnumGxObject pEnumGxObject = null;
266             gxDialog.ObjectFilter = new GxFilterFileGeodatabasesClass();
267
268             gxDialog.AllowMultiSelect = false;
269             gxDialog.RememberLocation = true;
270             gxDialog.Title = "Select a Output File Geodatabase";
271
272
273             if (gxDialog.DoModalOpen(this.Handle.ToInt32(), out pEnumGxObject))
274             {
275                 IGxObject pGxObject = pEnumGxObject.Next();
276
277                 IGxDatabase pGxDatabase = pGxObject as IGxDatabase;
278
279                 m_Workspace = pGxDatabase.Workspace;
280
281                 outputLocation = pGxDatabase.Workspace.PathName;
282             }
283         }
284
285         catch (Exception ex)
286         {
287             outputLocation = "";
288         }
289         finally
290         {
291         }
292     }
293
294     return outputLocation;
295 }
296
297
298 0 references
299 private void SpaceTimeConflictForm_FormClosing(object sender, FormClosingEventArgs e)
300 {
301     CommonClass.SafetyDistanceDict.Clear();
302     pgp.ToolExecuting -= pgp_ToolExecuting;
303     pgp.ToolExecuted -= pgp_ToolExecuted;
304
305     ClearAllGraphicElements();
306 }
307
308
309 0 references
310 private void btnProcess_Click(object sender, EventArgs e)
311 {
312     Microsoft.Office.Interop.Excel.Application xlApp = null;
313     Workbook xlWorkBook = null;
314     Worksheet xlWorkSheet = null;
315     Worksheet xlWorksheet_Transposed = null;
316

```

```

317 if (m_BIM_ObjectDic != null)
318 {
319     if (textBoxExcelPath.Text == "")
320     {
321         MessageBox.Show(new WindowWrapperClass(this.Handle), "Select an Excel output location", "Alert!", MessageBoxButtons.OK, MessageBoxIcon.Error);
322         return;
323     }
324
325     try
326     {
327         //Clear the graphics container
328         ClearAllGraphicElements();
329
330         //Create the report table in the workspace
331         _ReportTable = CommonClass.CREATE_REPORT_TABLE(m_Workspace);
332
333         //Display calculate Dialog
334         CalculateDialog calDialog = new CalculateDialog(m_Workspace, pGraphicsContainer, m_BIM_ObjectDic, _layerUtils, _ReportTable);
335         calDialog.StartPosition = FormStartPosition.CenterParent;
336         calDialog.ShowDialog(new WindowWrapperClass(this.Handle));
337
338         int rowCount = _ReportTable.RowCount(null);
339
340         if (rowCount > 0)
341         {
342             //HightLightFeatures();
343
344             ppp.OverwriteOutput = true;
345
346             DisplayMessage("Generating Report");
347             TableToExcel pTableToExcel = new TableToExcel();
348             pTableToExcel.Input_Table = m_Workspace.PathName + "\\\" + "Report_Table";
349             pTableToExcel.Output_Excel_File = textBoxExcelPath.Text;
350             ppp.Execute(pTableToExcel, null);
351
352             string dir = System.IO.Path.GetDirectoryName(textBoxExcelPath.Text);
353
354             xlApp = new Microsoft.Office.Interop.Excel.Application();
355             xlWorkBook = xlApp.Workbooks.Open(textBoxExcelPath.Text);
356             xlWorkSheet = xlWorkBook.ActiveSheet;
357
358             Range usedRange = xlWorkSheet.UsedRange;
359             object misValue = System.Reflection.Missing.Value;
360
361             //Copy and transpose the Excel sheet it onto a new sheet.
362             usedRange.Copy();
363             xlWorksheet_Transposed = (Worksheet)xlWorkBook.Worksheets.Add();
364             xlWorksheet_Transposed.Name = "Conflict Report";
365
366             Range Paste_Range = xlWorksheet_Transposed.get_Range("A1");
367             Paste_Range.PasteSpecial(xlPasteType.xlPasteAll, xlPasteSpecialOperation.xlPasteSpecialOperationNone, false, true);
368             Clipboard.Clear();
369             xlApp.DisplayAlerts = false;
370
371             //Delete the old sheet
372             xlWorkSheet.Delete();
373
374             //Resize the columns based on the max width
375             xlWorksheet_Transposed.UsedRange.Columns.AutoFit();
376
377             // xlWorkBook.Save();
378
379             Range riskLevelRange = xlWorksheet_Transposed.UsedRange.Rows[25];
380
381

```

```

381 Range riskLevelRange = xlWorksheet_Transposed.UsedRange.Rows[25];
382
383 bool isFirst = true;
384 foreach (Range cell in riskLevelRange.Cells)
385 {
386     if (!isFirst)
387     {
388         if (cell.Value2 != null)
389         {
390             string riskLevel = cell.Value2.ToString();
391             switch (riskLevel)
392             {
393                 case "Urgent":
394                     cell.Interior.Color = ColorTranslator.ToOle(System.Drawing.Color.Red);
395
396                     break;
397                 case "Very Important":
398                     cell.Interior.Color = ColorTranslator.ToOle(System.Drawing.Color.DarkOrange);
399                     break;
400                 case "Important":
401                     cell.Interior.Color = ColorTranslator.ToOle(System.Drawing.Color.Yellow);
402                     break;
403             }
404
405             cell.Font.Bold = true;
406             xlWorkBook.Save();
407         }
408     }
409     else
410     {
411         isFirst = false;
412     }
413 }
414
415 xlWorkBook.Close(true, misValue, misValue);
416 xlApp.DisplayAlerts = true;
417
418 }
419 string message = "";
420 int recordCount = _ReportTable.RowCount(null);
421 if (recordCount > 0)
422 {
423     message = (recordCount==1)? +recordCount+" conflict":recordCount+" conflicts";
424     message += " detected please check Report !";
425 }
426 else
427 {
428     message = "No conflicts Detected";
429 }
430
431 MessageBox.Show(new WindowWrapperClass(this.Handle), message, "Completed", MessageBoxButtons.OK, MessageBoxIcon.Information);
432
433 }
434 catch (Exception ex)
435 {
436     MessageBox.Show(new WindowWrapperClass(this.Handle), ex.Message, "Error", MessageBoxButtons.OK, MessageBoxIcon.Error);
437 }
438
439 finally
440 {
441

```

```

442
443         if (xlApp != null)
444         {
445             xlApp.Quit();
446             Marshal.ReleaseComObject(xlWorkBook);
447             Marshal.ReleaseComObject(xlWorkSheet);
448             Marshal.ReleaseComObject(xlWorksheet_Transposed);
449             Marshal.ReleaseComObject(xlApp);
450         }
451         DisplayMessage("");
452     }
453 }
454
455 }
456
457 /// <summary>
458 /// Button that allows the user to select an output location for the report excel sheet.
459 /// </summary>
460 /// <param name="sender"></param>
461 /// <param name="e"></param>
462 0 references
463 private void btnExcelLoc_Click(object sender, EventArgs e)
464 {
465     SaveFileDialog saveExcelFileDialog = new SaveFileDialog();
466     saveExcelFileDialog.Title = "Save excel Report";
467     saveExcelFileDialog.Filter = "Excel File(*.xls)|*.xls";
468     saveExcelFileDialog.FileName = "Report";
469     saveExcelFileDialog.ValidateNames = true;
470
471
472     if (saveExcelFileDialog.ShowDialog() == DialogResult.OK)
473     {
474
475         string fileLocation = saveExcelFileDialog.FileName;
476         if (fileLocation != "")
477         {
478
479             excelFileLocation = fileLocation;
480             txtBoxExcelPath.Text = excelFileLocation;
481         }
482     }
483     else if (saveExcelFileDialog.ShowDialog() == DialogResult.Cancel && saveExcelFileDialog.FileName == "")
484     {
485         excelFileLocation = "";
486     }
487 }
488
489
490
491 3 references
492 public void ClearAllGraphicElements()
493 {
494     if (this.pGraphicsContainer != null)
495     {
496         this.pGraphicsContainer.DeleteAllElements();
497         _pMxDocument.ActiveView.Refresh();
498     }
499 }

```

```

501 //Highlight the features present in the report table.
    0 references
502 private void HightLightFeatures()
503 {
504     IFeatureSelection pFeatureSelection = null;
505     IFeatureLayer pFeatureLayer = null;
506     IQueryFilter pQueryFilter = new QueryFilter();
507
508     try
509     {
510         //Get the distinct layers from the conflict layer column present in the report table
511         IQueryDef pQueryDef = m_pFeatureWorkspace.CreateQueryDef();
512         pQueryDef.Tables = "Report_Table";
513         pQueryDef.SubFields = "DISTINCT(" + CommonClass.CONFLICT_FEATURE + ")";
514
515         ICursor pCursor = pQueryDef.Evaluate() ;
516
517         using (ComReleaser comReleaser = new ComReleaser())
518         {
519             comReleaser.ManageLifetime(pCursor);
520
521             IRow pRow = null;
522
523             while ((pRow = pCursor.NextRow()) != null)
524             {
525                 string layerName = pRow.get_Value(0).ToString();
526                 if (layerName == "")
527                     continue;
528                 //Get the object id of each type of layer to generate a query
529                 IQueryDef pQueryDef2 = m_pFeatureWorkspace.CreateQueryDef();
530                 pQueryDef2.Tables = "Report_Table";
531                 pQueryDef2.SubFields = "DISTINCT(" + CommonClass.CONFLICT_LAYER_ID + ")";
532                 pQueryDef2.WhereClause = CommonClass.CONFLICT_FEATURE + " = '" + layerName + "'";
533
534                 ICursor recordCursor = pQueryDef2.Evaluate();
535                 comReleaser.ManageLifetime(recordCursor);
536
537                 IRow record = null;
538
539                 string OIDSString = "(";
540                 bool isFirst = true;
541                 while((record = recordCursor.NextRow())!= null)
542                 {
543                     if (isFirst)
544                     {
545                         OIDSString += record.get_Value(0).ToString();
546                         isFirst = false;
547                     }
548                     else
549                     {
550                         OIDSString += ","+record.get_Value(0).ToString();
551                     }
552                 }
553                 OIDSString += ")";
554
555                 //Get the feature layer from the map
556                 // and make a selection based on the where clause.
557                 if (CommonClass.TEMP_FACILITIES.Contains(layerName))
558                 {
559                     pFeatureLayer = _layerUtils.GetLayerByName("Temporary_Facilities") as IFeatureLayer;
560                 }
561                 else
562                 {
563
564

```

```

566         pFeatureLayer = _layerUtils.GetLayerByName(layerName) as IFeatureLayer;
567     }
568     pFeatureSelection = pFeatureLayer as IFeatureSelection;
569     // pFeatureSelection.SelectionSymbol = SelectSymbol(pFeatureLayer.FeatureClass.ShapeType);
570     //pFeatureSelection.SetSelectionSymbol = true;
571     pQueryFilter.WhereClause = pFeatureLayer.FeatureClass.OIDFieldName + " IN " + OIDSString;
572     pFeatureSelection.SelectFeatures(pQueryFilter, esriSelectionResultEnum.esriSelectionResultAdd, false);
573     _pMxdDocument.ActiveView.Refresh();
574 }
575
576 }
577
578 }
579 catch (Exception ex)
580 {
581
582     throw ex;
583
584 }
585
586 }
587
588
589 2 references
590 private void DisplayMessage(string message)
591 {
592     lblMessage.Text = message;
593     lblMessage.Refresh();
594 }
595
596
597 0 references
598 private void btnSafetyDistance_Click(object sender, EventArgs e)
599 {
600     SafetyDistDialog safetDistDlg = new SafetyDistDialog();
601     safetDistDlg.StartPosition = FormStartPosition.CenterParent;
602     safetDistDlg.ShowDialog(new WindowWrapperClass(this.Handle));
603
604 }
605
606 }

```

Appendix II

**Questions, results and discussion of the interviews conducted while
collecting data for this study**

Introduction

During the data collection phase for this study a face-to-face interviews were conducted with professionals, including engineers, site supervisors and contractors from different parts of the world, namely, Ottawa, Canada; Dubai, UAE; Cairo, Egypt; and Jeddah and Makkah, Saudi Arabia to collect data on the process of site layout planning (SLP) and temporary facilities (TFs) and to provide comments on the functionalities included in the presented model and what other requirements professionals need in an SLP model.

The total number of the interviews conducted are 27. The questions of the oral interviews are written in this section and the results of those questions are given and discussed for further clarification.

Q1: What best describes your job/position?

- Architect.
- Construction/project manager.
- Site manager/super intendent.
- Quality control/quality assurance.
- Structural engineer.
- Academia/education.

Q2: How many years of experience you have?

- 1-5 years.
- 5-10 years.
- 10-15 years.
- 15-20 years.

- 20 + years.

Q3: Have you been involved in construction site layout planning (locating temporary facilities, materials, and equipment onsite to support construction activities)?

- Yes.
- No.

Q4: Based on your experience, what are the most important factors that should be considered when planning the construction site layout?

| Factor | Not important | Less important | Normal | Important | Very important |
|--|----------------------|-----------------------|---------------|------------------|-----------------------|
| Reduce travel distance between site objects | | | | | |
| Identify and avoid conflicts for the whole duration of the project (short term and long term). | | | | | |
| Safety | | | | | |
| Visibility | | | | | |
| Environment protection (pollution, noise, etc.) | | | | | |
| Construction site and its surrounding environment | | | | | |
| Accessibility & route planning (onsite, outside construction site and inside the building under construction). | | | | | |

Q 5: Are you aware of any tool available in the industry that is dedicated for site layout planning (SLP) to assists practitioners during planning the construction site layout?

- Yes.
- No.

Q 6: What tools/software you use to plan/design the site layout?

- Manual sketching/drafting on paper.
- CAD.
- BIM.
- GIS
- Civil 3D CAD
- Other.

Q 7: What tools/software you use to schedule the activities of the construction project?

- Primavera.
- Microsoft project.
- Other.

Q 8: Do you agree that there is a need for a tool to support practitioners' decisions during planning the construction site layout?

- Strongly agree.
- Agree.
- Neither agree nor disagree.
- Disagree
- Strongly Disagree.

Q 9: Do you prefer a tool that makes the decisions related to site layout planning (e.g., locating temporary facilities, materials, equipment etc.) or a tool that support your decisions by assisting you in planning the site layout?

- A decision-making tool.
- A decision support tool.

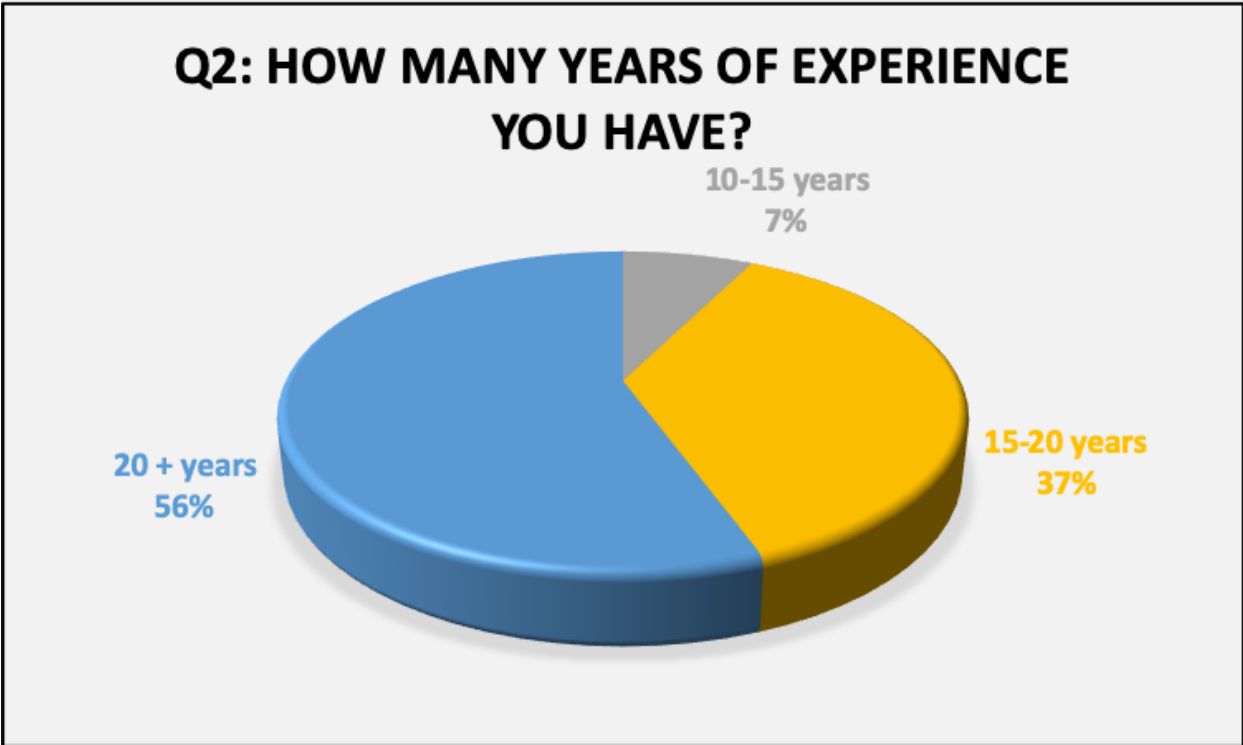
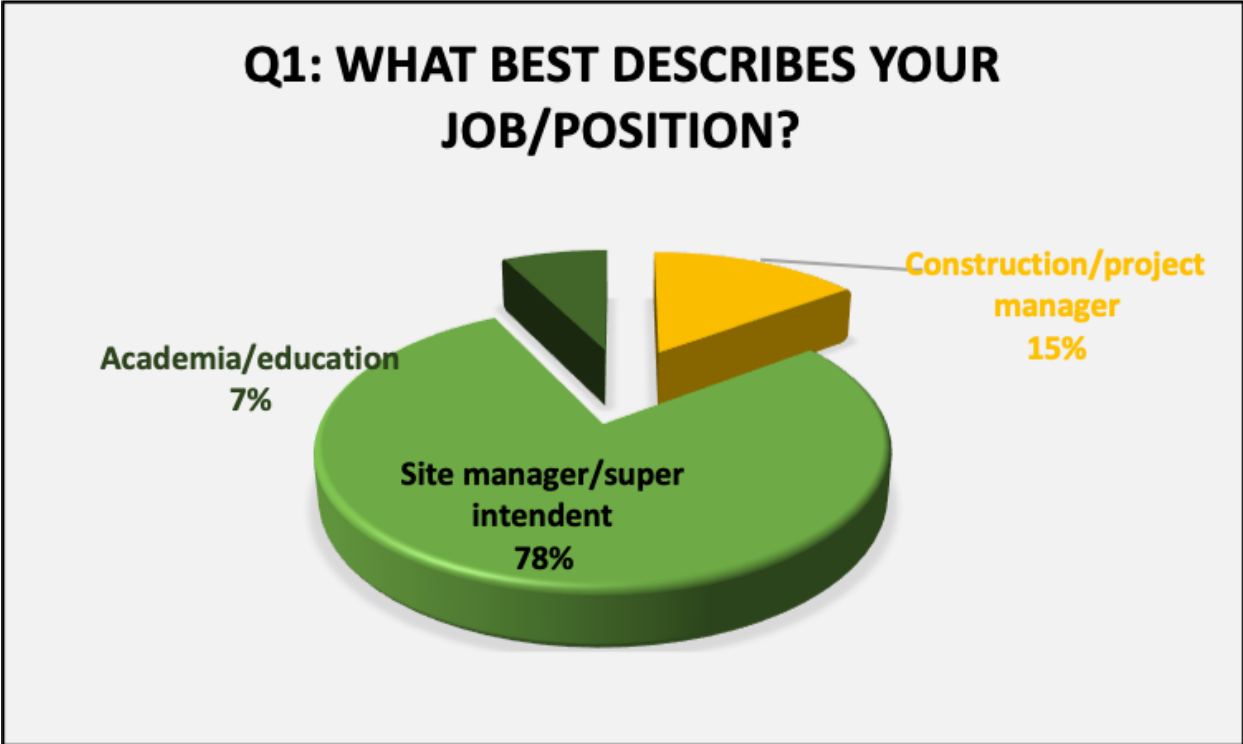
Q 10: From the following, what are the challenges that practitioners can face during site layout planning?

- Change of project requirements/design.
- Nature of construction site (terrain).
- Minimizing/calculating travel distance.
- Identifying required number of temporary facilities to support construction activities.
- Strategically locating temporary facilities, materials, equipment, etc. on the construction site.
- Foreseeing the consequences/impact of decisions made regarding placing temporary facilities, materials, equipment etc. on the construction site.
- Congested site (limited space for locating temporary facilities, materials, equipment on the construction site).

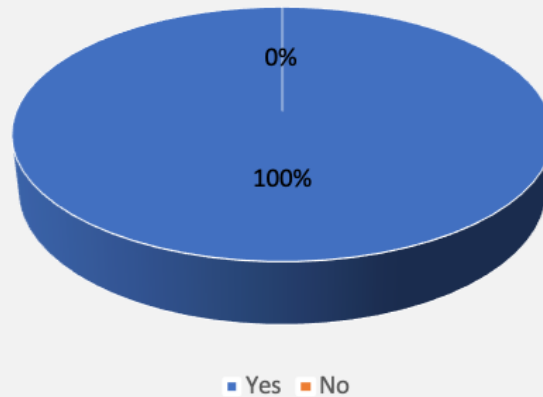
Q 11: What are the most important functions/features an SLP tool should have to assist practitioners and support their decisions during the planning of construction site layout?

| Function/feature | Not important | Less important | Normal | Important | Very important |
|--|----------------------|-----------------------|---------------|------------------|-----------------------|
| Identifying required number of temporary facilities | | | | | |
| Strategically locating temporary facilities, materials, equipment, etc. on the construction site. | | | | | |
| Identify conflicts in the site layout plan in 2D and 3D for the whole duration of the project (short term and long term). | | | | | |
| Visibility | | | | | |
| A temporary facilities library that holds geometric (e.g., dimensions) and functional (e.g., operational distance, safety distance, capacity, etc.) information about temporary facilities | | | | | |
| 4D simulation for the construction process and the construction site and its surrounding environment | | | | | |
| Planning routes efficiently while considering safety and minimizing distance. | | | | | |
| Provide various feedback output including graphical (e.g., drawings), textual (e.g., messages), and tabular (e.g., reports). | | | | | |
| Minimizing/calculating distance between site objects (e.g., temporary facilities) | | | | | |
| Clarity of analysis and results | | | | | |
| Simple to use | | | | | |
| Easy to learn | | | | | |

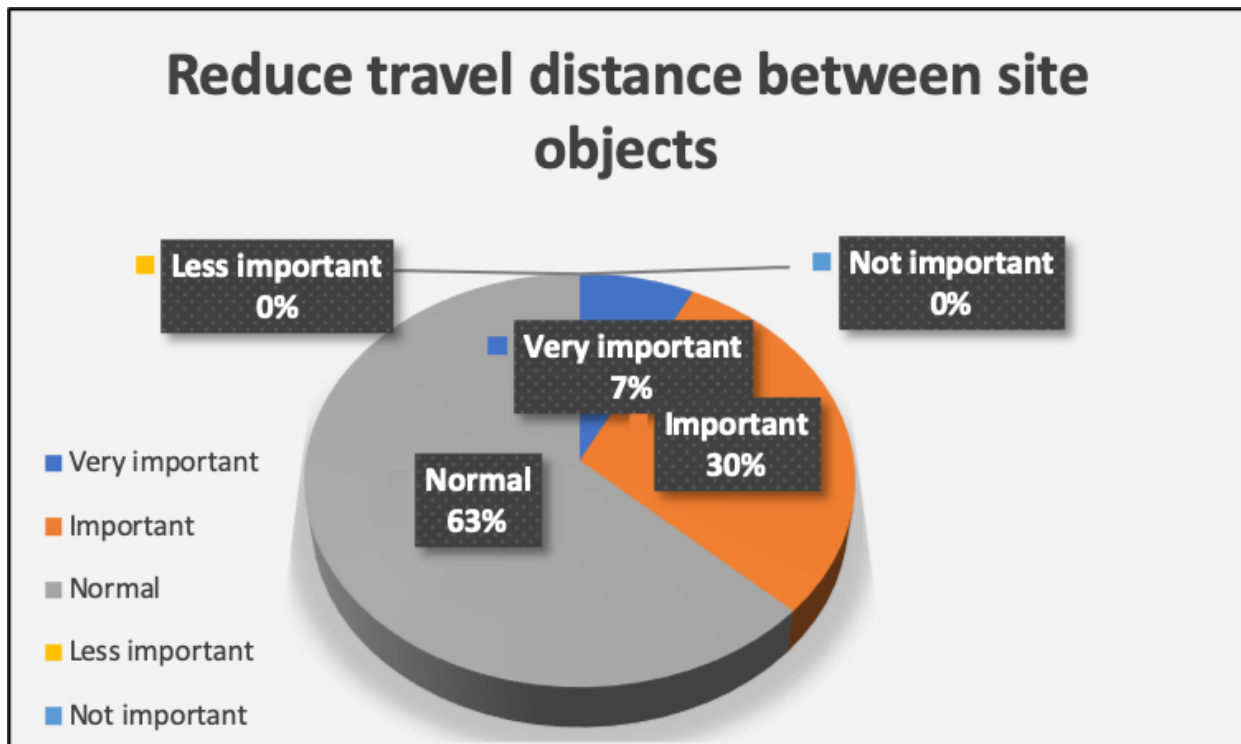
Results of the interviews questions



Q3: Have you been involved in construction site layout planning (locating temporary facilities, materials, and equipment onsite to support construction activities)?

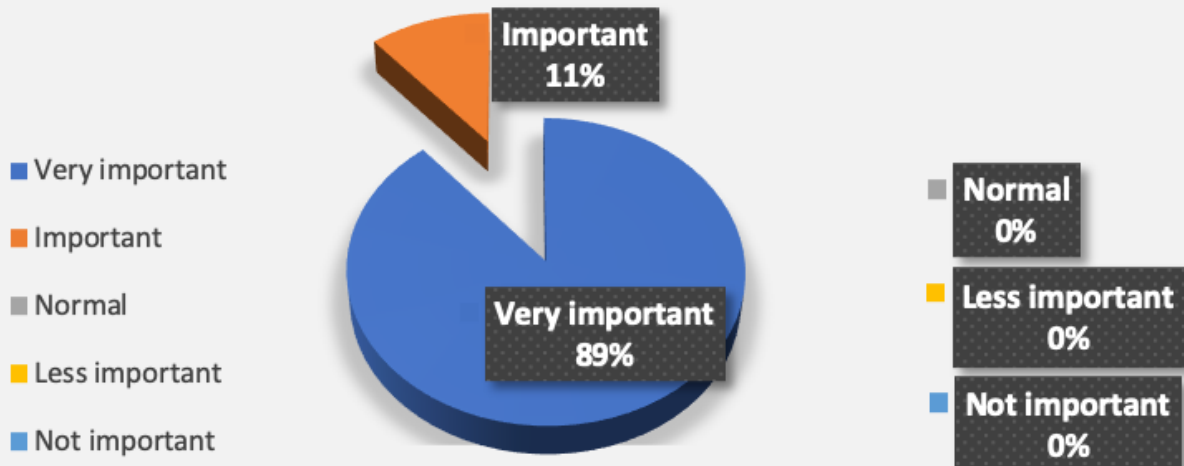


Q4: Based on your experience, what are the most important factors that should be considered when planning the construction site layout?



Results for question 4 - Chart 1 (factor 1)

Identify and avoid conflicts for the whole duration of the project (short term and long term)

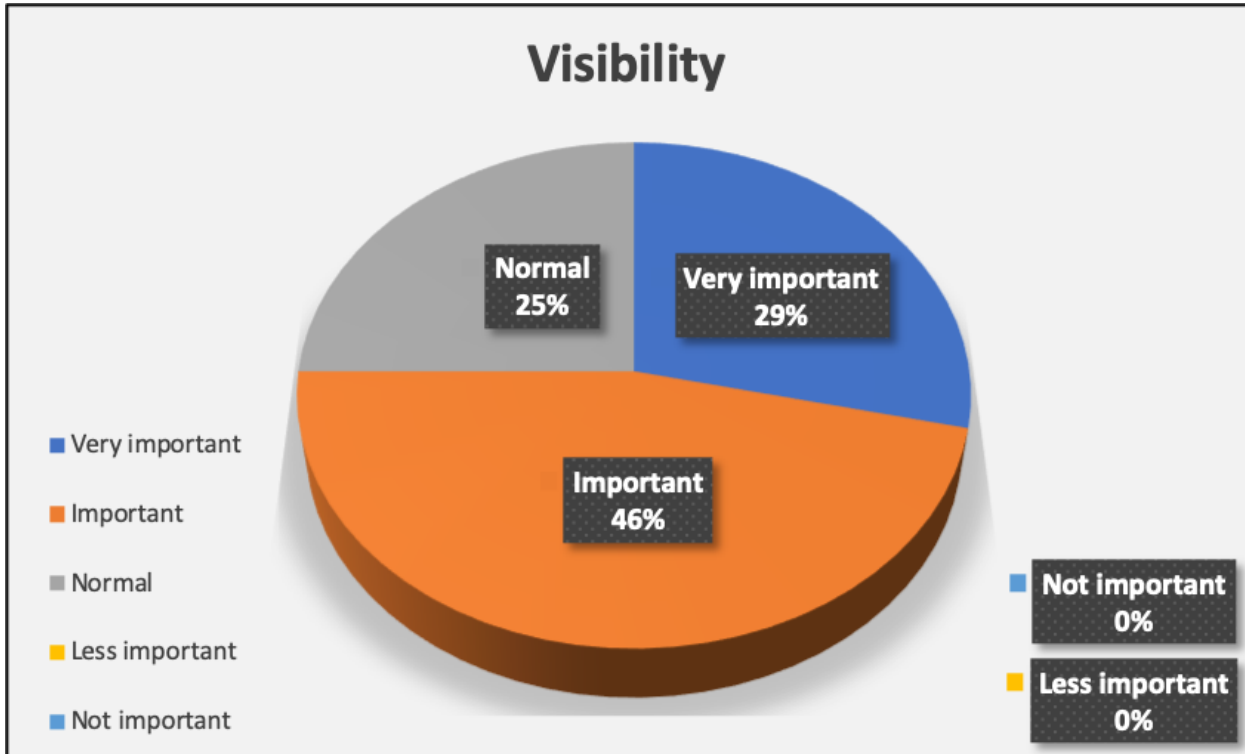


Results for question 4 - Chart 2 (factor 2)

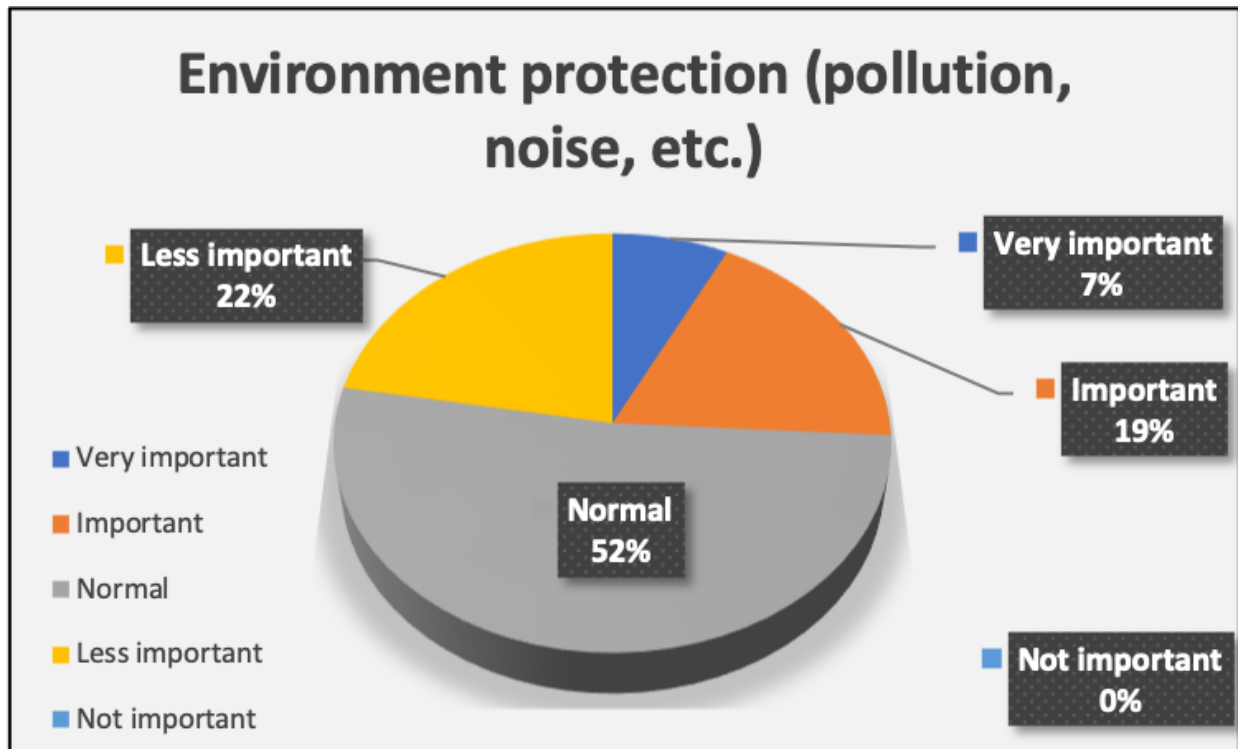
Safety



Results for question 4 - Chart 3 (factor 3)

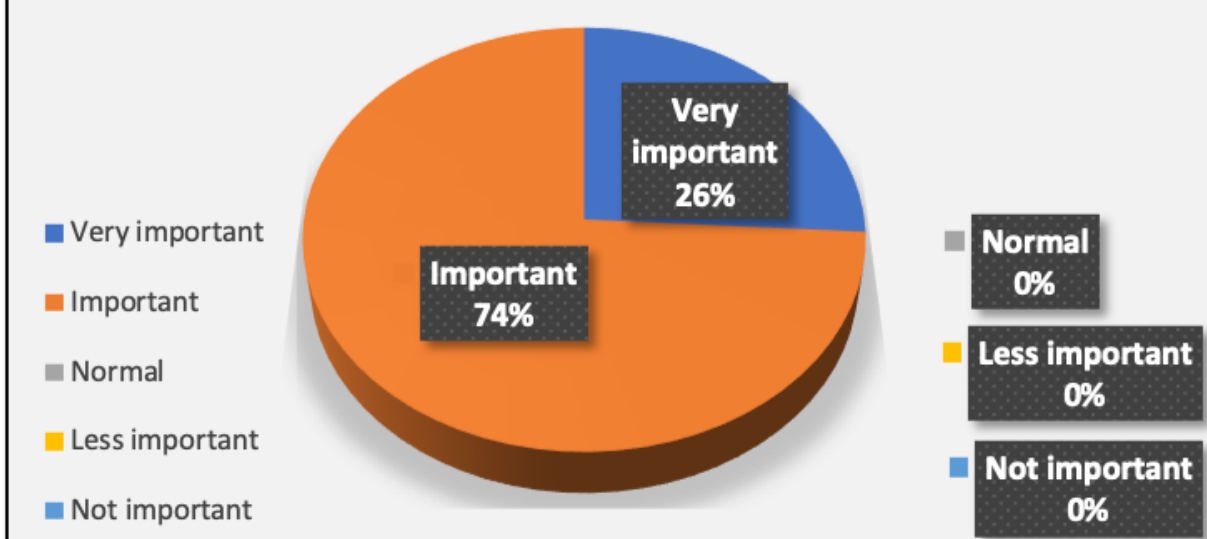


Results for question 4 - Chart 4 (factor 4)



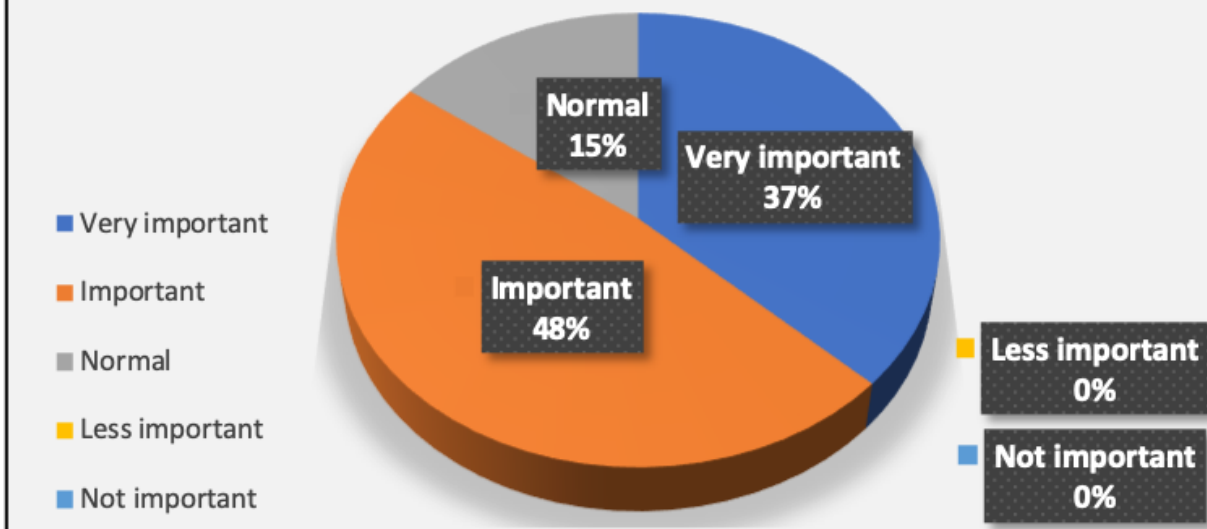
Results for question 4 - Chart 5 (factor 5)

Construction site and its surrounding environment



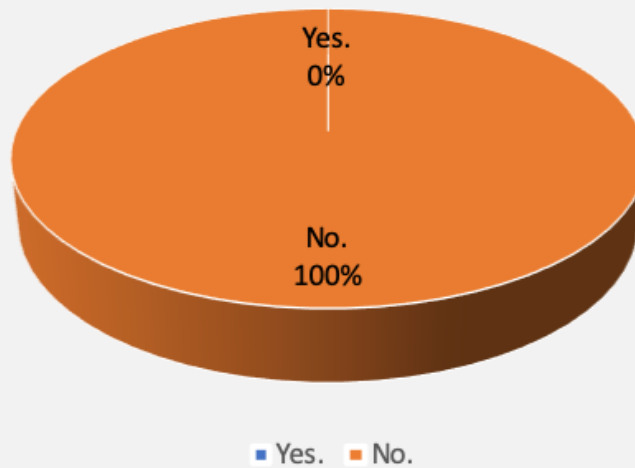
Results for question 4 - Chart 6 (factor 6)

Accessibility & route planning (onsite, outside construction site and inside the building under construction).

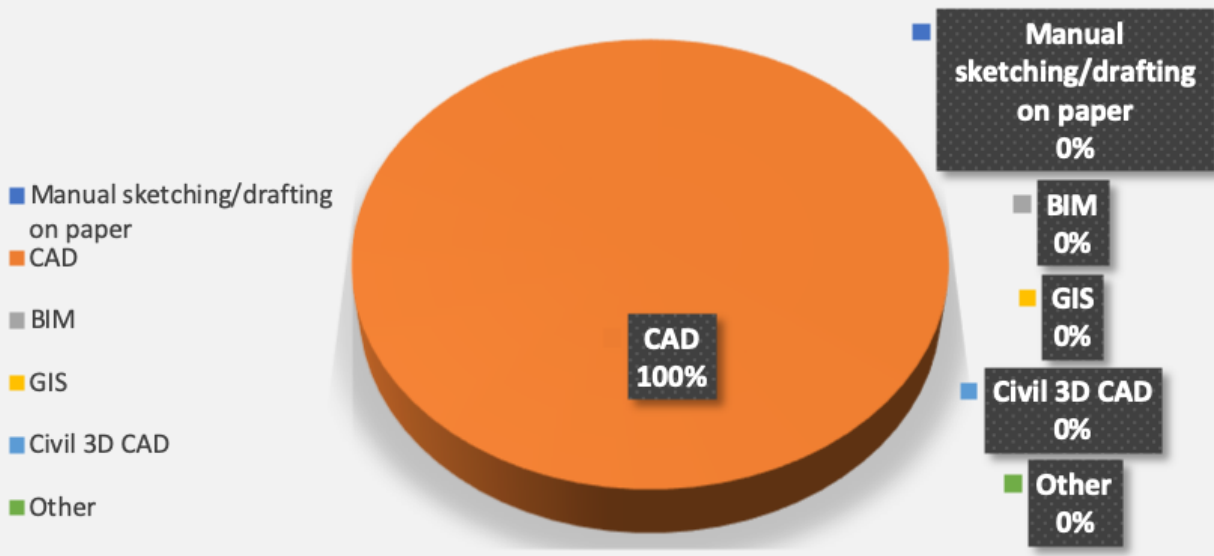


Results for question 4 - Chart 7 (factor 7)

Q 5: Are you aware of any tool available in the industry that is dedicated for site layout planning (SLP) to assists practitioners during planning the construction site layout?



Q 6: What tools/software you use to plan/design the site layout?



Q 7: What tools/software you use to schedule the activities of the construction project?



Q 8: Do you agree that there is a need for a tool to support practitioners' decisions during planning the construction site layout?

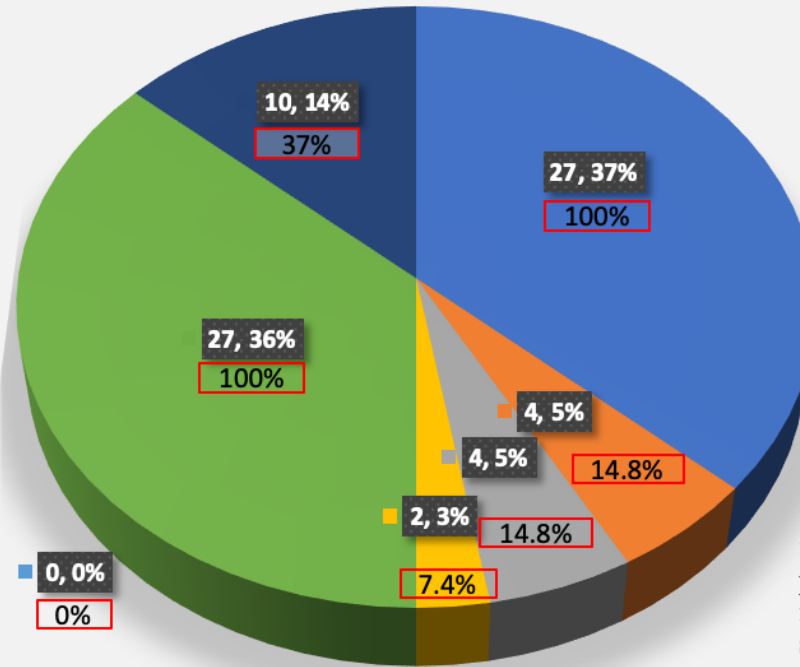


Q 9: Do you prefer a tool that makes the decisions related to site layout planning (e.g., locating temporary facilities, materials, equipment etc.) or a tool that support your decisions by assisting you in planning the site layout?



Q 10: From the following, what are the challenges that practitioners can face during site layout planning?

- Change of project requirements/design
- Nature of construction site (terrain)
- Minimizing/calculating travel distance
- Identifying required number of temporary facilities to support construction activities
- Strategically locating temporary facilities, materials, equipment, etc. on the construction site
- Foreseeing the consequences/impact of decisions made regarding placing temporary facilities, materials, equipment etc. on the construction site
- Congested site (limited space for locating temporary facilities, materials, equipment on the construction site)

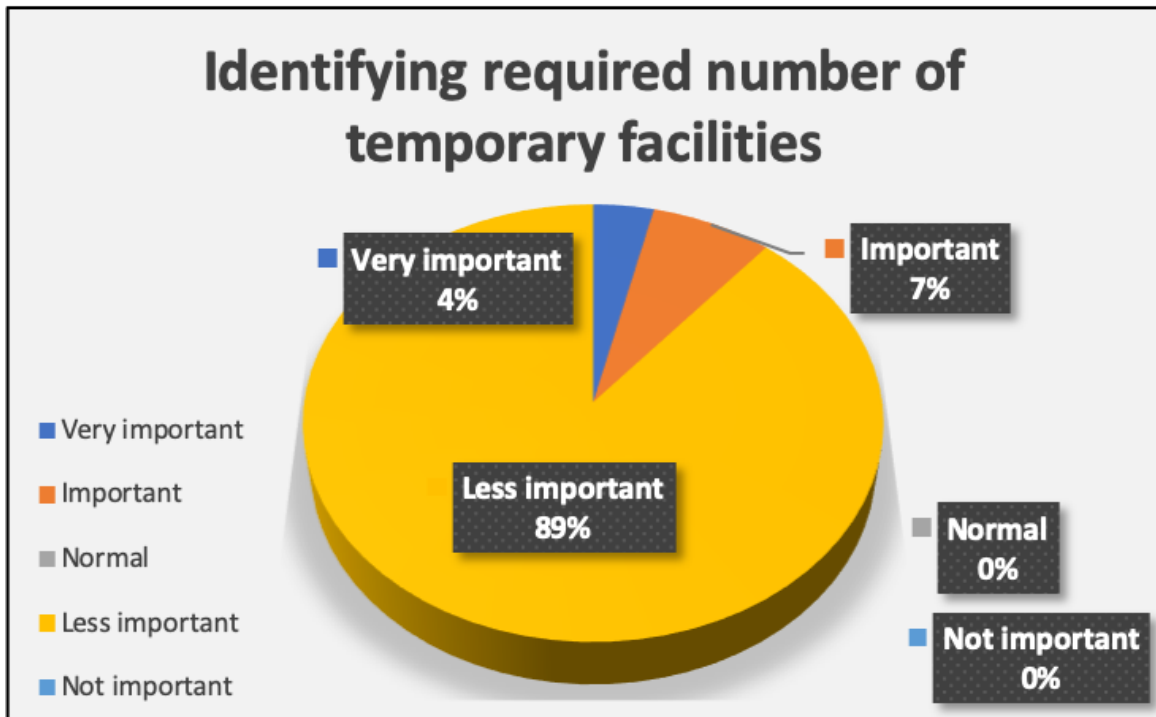


*The percentage in the red box represents the percentage of interviewee who selected this answer

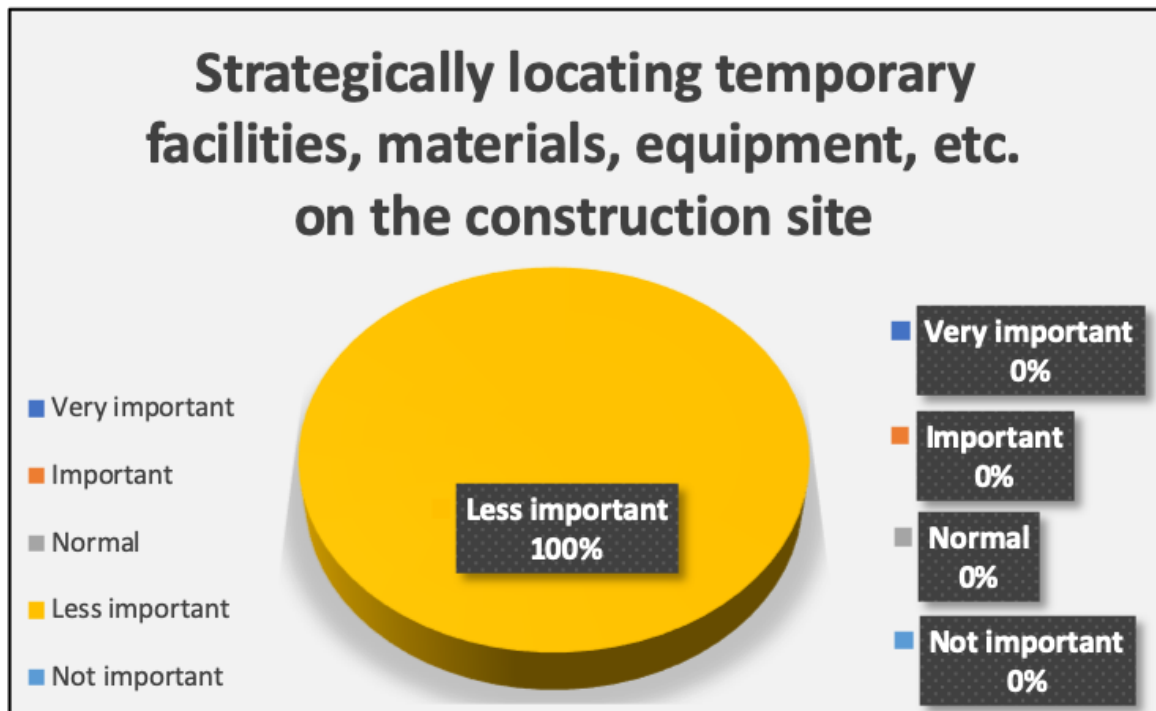
*The numbers to the left of the coma represents how many times the answer was selected by the 27 interviewee

*The percentage to the right of the coma represents the percentage of the answer when compared with other answers

Q 11: What are the most important functions/features an SLP tool should have to assist practitioners and support their decisions during the planning of construction site layout?



Results for question 11 - Chart 1 (function/feature 1)



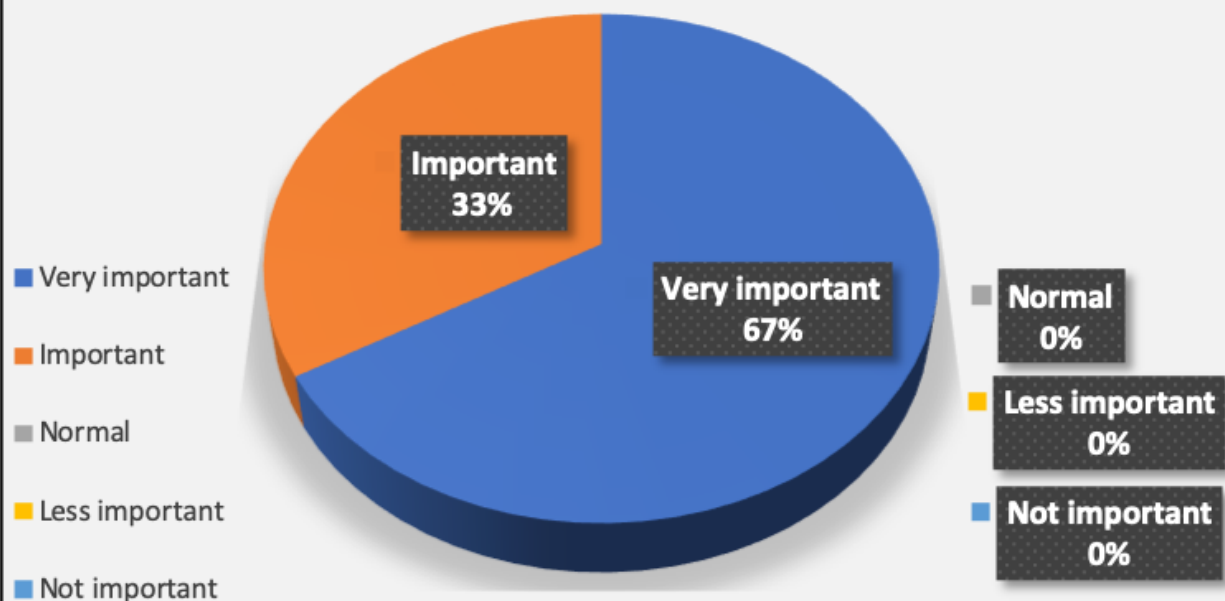
Results for question 11 - Chart 2 (function/feature 2)

Identify conflicts in the site layout plan in 2D and 3D for the whole duration of the project (short term and long term)



Results for question 11 - Chart 3 (function/feature 3)

Visibility



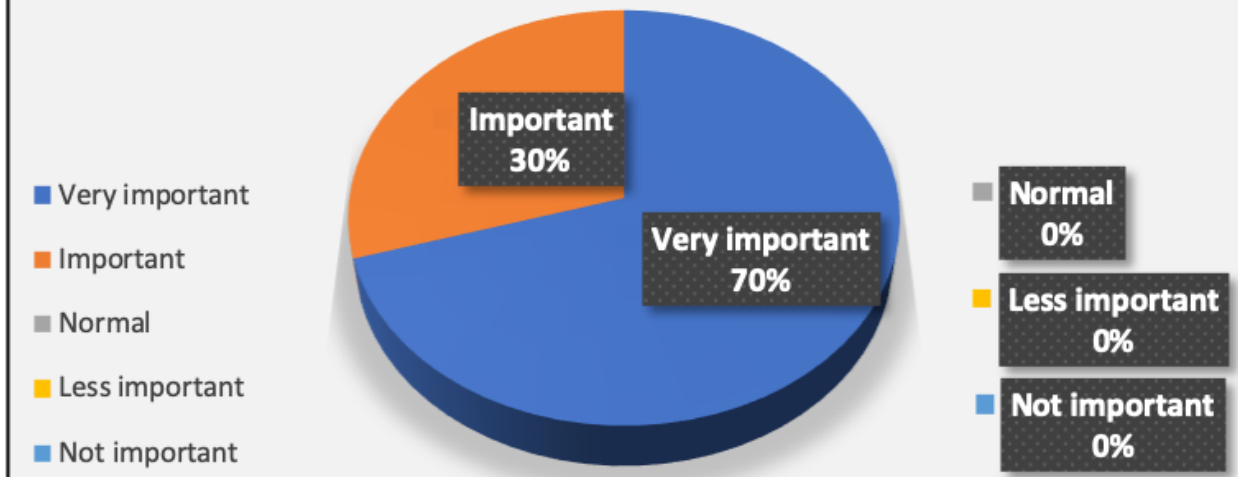
Results for question 11 - Chart 4 (function/feature 4)

A temporary facilities library that holds geometric (e.g., dimensions) and functional (e.g., operational distance, safety distance, capacity, etc.) information about temporary facilities



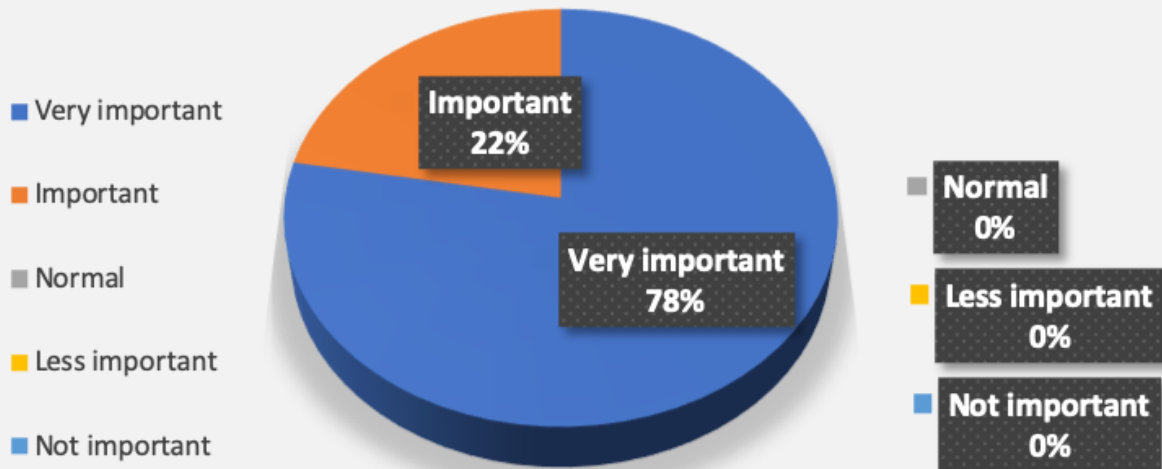
Results for question 11 - Chart 5 (function/feature 5)

4D simulation for the construction process and the construction site and its surrounding environment



Results for question 11 - Chart 6 (function/feature 6)

Planning routes efficiently while considering safety and minimizing distance.

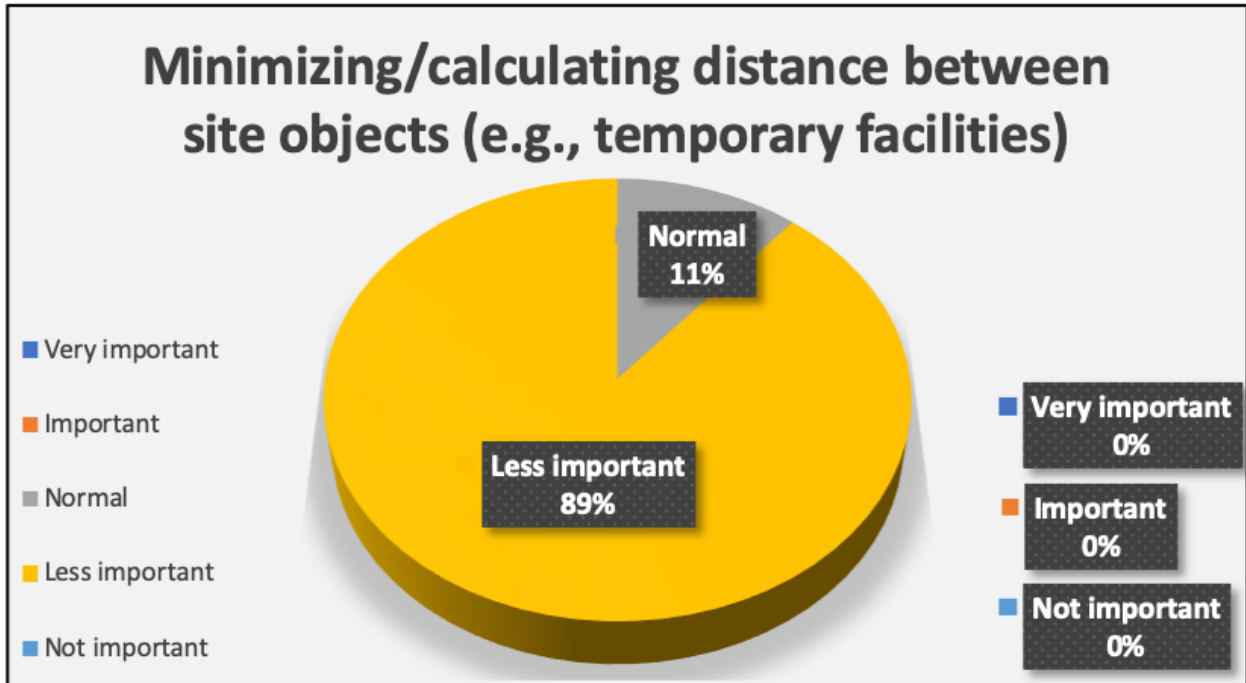


Results for question 11 - Chart 7 (function/feature 7)

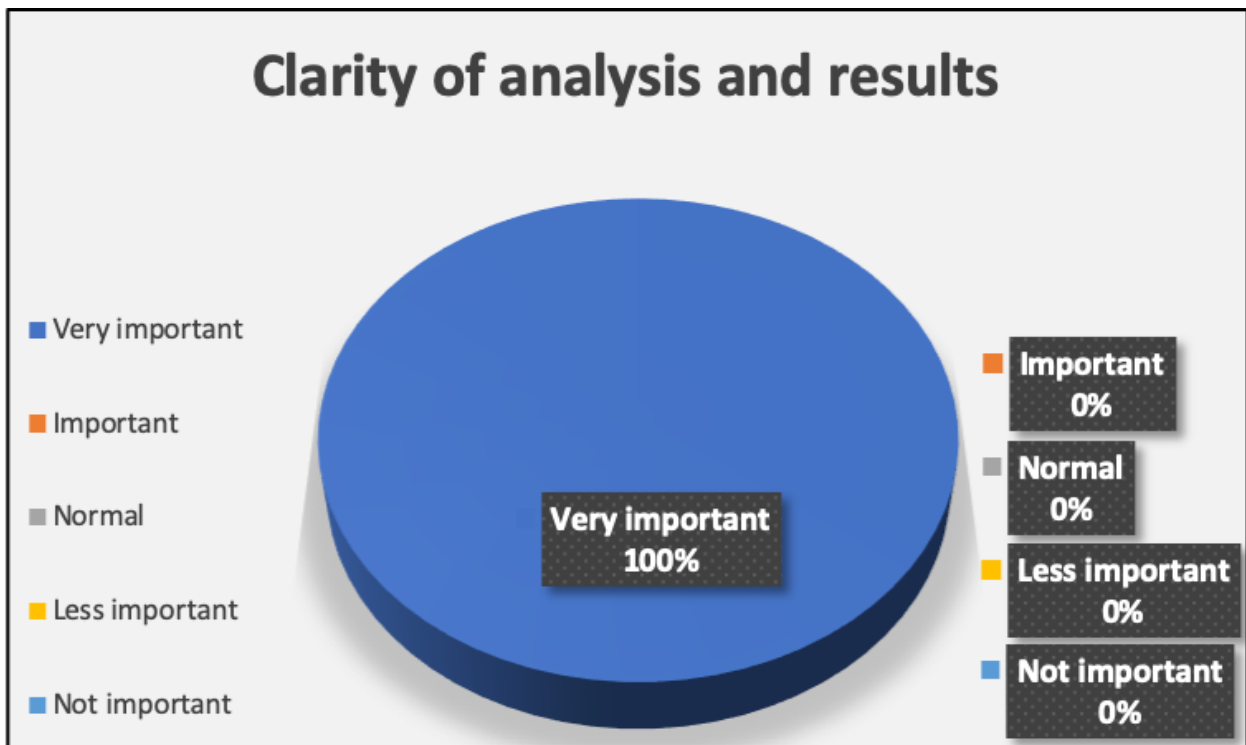
Provide various feedback output including graphical (e.g., drawings), textual (e.g., messages), and tabular (e.g., reports).



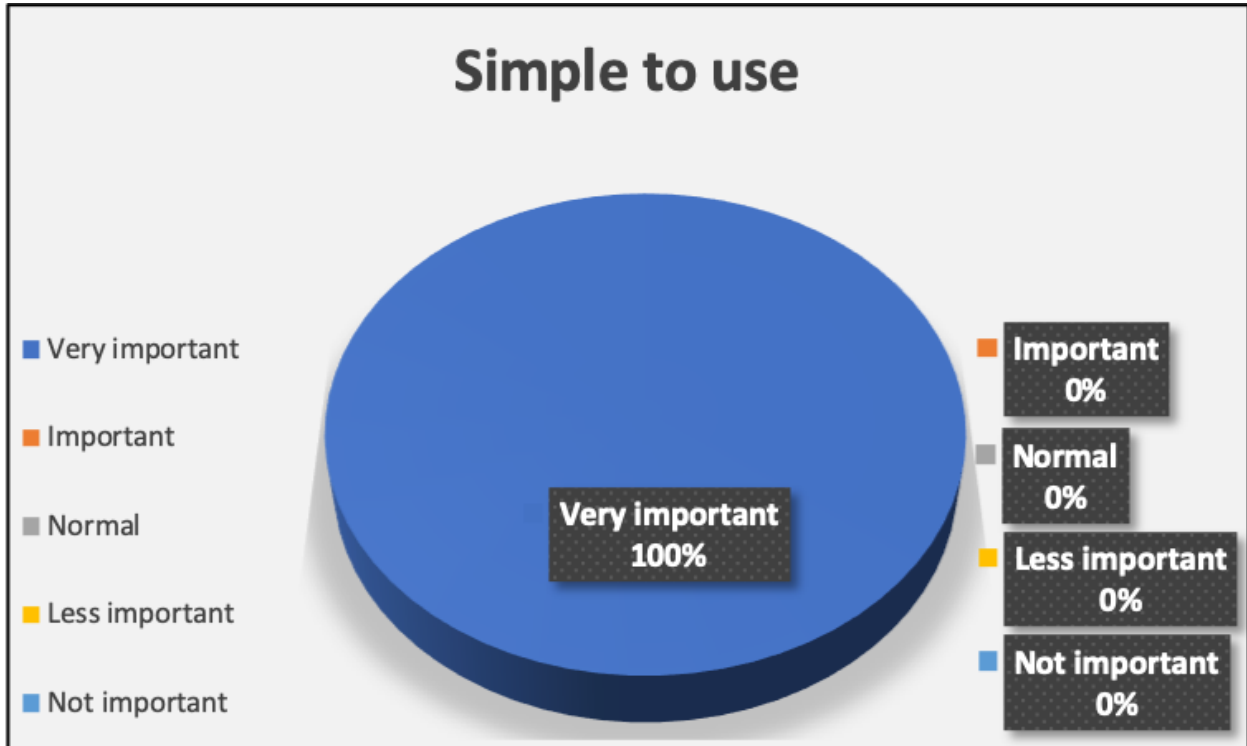
Results for question 11 - Chart 8 (function/feature 8)



Results for question 11 - Chart 9 (function/feature 9)



Results for question 11 - Chart 10 (function/feature 10)



Results for question 11 - Chart 11 (function/feature 11)



Results for question 11 - Chart 12 (function/feature 12)

Discussion of the results for the interviews

Based on the results of the interviews, this study provides the following findings:

- 1- The very important factors selected by interviewees to be considered when planning a site layout are safety and identify and avoid conflicts onsite with a percentage of 100% and 98%, respectively (results for question 4 charts 2 and 3). 74%, 46%, and 48% of interviewed professional selected visibility, the construction site and its surrounding environment, and accessibility and route planning respectively as important factors in planning the site layout (results question 4 charts 4, 6, and 7). Reducing travel distance between site objects and environment protection were deemed of normal priority by 63% and 52% of the interviewees respectively (Question 4 charts 1 and 5).
- 2- CAD and primavera were the choice of all interviewed professionals for planning/drafting the construction site layout and scheduling the construction activities respectively (Questions 6 and 7). It is worth mentioning that during interviews most professionals noted that they also manually sketch on paper when applying or explaining quick changes to the site layout plan then, if necessary, they use CAD to apply those changes in their plans.
- 3- Practitioners prefer a tool that supports their decisions rather than making the decisions for them when designing or planning the construction site layout. We can see this based on the answers for question number 9 were the highest percentage of professionals (93%) favored a tool that supports their decisions. This finding is also in line and with agreement with the findings in the literature on site layout planning that shows that professionals prefer to apply their own experience when planning the construction site layout and tend to change computer output according to their preference.

- 4- Identifying the number of required temporary facilities, materials, etc., minimizing/calculating travel distance, and nature of the construction site were the least selected challenges for practitioners when planning the site layout with percentage of 7.4%, 14.8%, and 14.8% respectively. All interviewees selected Changing the project's requirements/design and foreseeing the consequences of the decisions made as challenges when planning the site layout while 37% of them selected congested sites with limited space to be a challenge as well (results for question 10).
- 5- It was clear that practitioners do not have a problem with locating temporary facilities, materials, equipment, etc. on the construction site. What practitioners need assistant with is knowing the consequences or impact of their decisions about locating temporary facilities, materials, equipment, etc. on the construction site. We can see that based on the answers for questions 10 and 11 (chart 2 and chart 3). A 0% of the 27 interviewees selected placement of temporary, etc. on site as a challenge. A 100% saw that including the function/feature of placing temporary facilities, etc. onsite is less important. However, one of the most challenges selected by professionals was foreseeing the impact of their decisions in the future. This can be especially challenging in the long term. Also, all 27 interviewees selected the function/feature of identifying potential conflicts in their plan as very important to be included in an SLP tool.
- 6- The provision for a temporary facilities library that holds geometric and functional information about temporary facilities is very important and will facilitate the selection temporary facilities required to support the construction process and will facilitate planning of the construction site layout. Based on the answers for question number 11 chart 5 we can see that most of the interviewed professionals agreed to this with a percentage of 100%.

This can be in part due to the fact that practitioners are used to use such libraries in the AEC (architectural engineering construction industry) when drafting design drawings for buildings and floor plans using CAD tools (e.g., AutoCAD) where they have libraries for different building components including doors, furniture, etc.

- 7- Providing professional with feedback output in multiple forms including graphical (e.g., drawings), textual (e.g., messages), and tabular (e.g., reports) will strongly assist users in efficiently planning the site layout and will help them document their project. All interviewees selected this function as very important to be included in a site layout planning tool (results of question 11 chart 8).
- 8- All interviewed professionals agreed that it is very important for an SLP tool to be simple to use, provide users with clear analysis and results, and easy to learn (results for question 11 charts 10, 11, 12) while 70% and 78% of them selected 4D simulation and route planning while considering safety to be included in an SLP tool as very important respectively (results for question 11 charts 6 and 7). Minimizing/ calculating travel distance between site objects and identifying required number of temporary facilities were deemed as less important by 89% of the interviewees (results for question 11 charts 1 and 9). This is mainly due to the fact that professionals tend to do this task by themselves and they do not see the importance or the need for a tool to do it for them.
- 9- Finally, based on the interviews the highest percentage of professionals agrees that there is a need for a tool dedicated to site layout planning to assist them and support their decisions while planning the construction site layout (results for question 8).