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BIM AND GIS INTEGRATED UTILITY SUPPLY STATION LOCATION OPTIMIZATION AND POSSIBILITIES

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Optimal planning of utility supply station location is an integral part of infrastructural projects. In general, this is a multi-objective optimization process by considering engineering, financial and geographical constraints. A shift from conventional 2D-CAD, manual quantification and design application-based approach to Building Information Modelling (BIM)-Geographic Information System (GIS) integrated approach is found to be suitable for minimizing optimal planning time, cost and increasing automation. In this paper, an Autodesk Revit add-in tool is proposed aimed at integrating BIM and GIS for Genetic Algorithm (GA) based utility supply station location optimization and to assess the possibilities of this integration. From the case study it is observed that up to 90% of cost saving can be accomplished by this proposed approach. It is found that compared to the traditional multi-software approach with manual data transfer, this integration can be utilized for multi-stage optimization and is suitable for automating heterogenous data integration with increased accuracy. The platform in which the add-in tool is developed for the utility network can be at either BIM or GIS and this selection is influenced by the availability and ease of data retrieval from the respective semantic information system and the level of automation that is to be accomplished. Standardised BIM-based modelling combined with concepts like artificial intelligence and image processing techniques can be promising for attaining desired results in industrial applications.

Keywords: BIM, genetic algorithm, GIS, revit and utility network

1 INTRODUCTION

Our complex urban systems include utility networks as a core component, and the integration of digital representations of these networks at various spatial scales can be used to address optimal planning processes of supply station location [1]. Utility supply station location optimization according to project objectives, constraints and unknown variables is a complex process [2]. It is highly desirable to conduct optimal planning of utility supply station location(s) at the early project planning stage by considering geographical parameters and natural disasters to mitigate climate change effects and to increase reliability [3], [4]. Traditional multi-software-based manual data transfer optimal planning procedures can cause intense problems such as iterative reworks, errors while replicating data and information losses [5], [6]. Geometric information such as length of the network element, quantification of the demand that is to be met from the supply station and geographical constraints are to be gathered and possessed to generate optimal location. But in traditional approach data retrieval and query of geometric, spatial and parametric information is a slow process [7]. A new integrated network modelling approach with the below-described capabilities for utility supply station location optimization is needed to overcome the above-elucidated issues (i) Every artefact of the utility network model is to be organized in such a manner that modifications in the system information are to be transmitted to other linked elements of the project model (semantic information system modelling) (ii) A parametric digitized model is available before the actual construction (iii) A platform is required to process geographical data, project network data and optimization process simultaneously [5], [8]. To accomplish the above-said requirements, one of the suitable approach for utility supply station location optimization is BIM integrated with GIS.

1.1 BIM and GIS-based approach

BIM is a parametric n^{th} dimensional virtual modelling of construction projects capable of conducting realistic engineering studies, automated code checking, analysis and estimation well before construction begin. A single BIM file is enough for quantity estimation, analysis and management. Major benefits of BIM are automated calculation, quantity take-off, code checking and clash detection, digitization of construction modelling in a single platform, efficient planning and minimization of rework and a robust information-sharing platform. Recent developments in BIM technologies have appealed to an increasing requirement for automated and customized tools along with usual standard functions [9], [10]. BIM is an integrated way of working, supported by Information and Communication Technologies (ICT) which can provide more effective methods of designing, creating and maintaining the building assets. GIS is a powerful tool utilized for problem identification and problem-solving, decision making and visualization of data in a spatial environment by capturing, storing, manipulating, and analyzing all kinds of related geographical data [11]. BIM can automate code checking, calculation and analysis of construction modelling developments and the same capability can be combined with GIS for improving the process.

Significant research has been made in BIM and GIS integration focusing on various aspects of construction, operation, management and city modelling. Utilization of GIS and BIM pipe network information for facility operation and maintenance of MEP systems has been presented in [12]. Wang et al. [13] developed a decision support system for underground utility management by BIM-GIS integration. BIM and GIS-based multi-criteria topology development of water utility has been presented in [1] and the planning of the water distribution network in [14]. Jack and Deng developed a framework for utility information management and analyses [15]. A vulnerability assessment of urban infrastructure using BIM and GIS was presented in [16]. Amirebrahimi et al., [17] developed a framework for the assessment of flood damage to buildings by integrating BIM with GIS.

Even though BIM and GIS combined approach offers the potential to develop customized add-in tools, its leverage is less in utility supply station location optimization for multi-building projects. There are many publications related to BIM capabilities and their utilization for automated/semi-automated add-in development, such as wastage reduction and design validation [10], [18], and [19]. Most of the matured BIM software provides Application Program Interface (API) for developing customized tools. Autodesk's Revit API-based custom tools help engineers to save time by automating the calculation and estimation process, especially for repetitive tasks and achieve improvements in the quality of the design and conduct customized and quicker value engineering processes on a realistic BIM model [20]. It is understood that standardized modelling by an effective Work Breakdown Structure (WBS) is mandatory for BIM-based automated tools [21]. Integration of the semantic information system of BIM with GIS can be very useful for utility supply station location optimization. As most of the data related to utility networks are to be digitized in an easily sharable format for conducting optimization by BIM and GIS integrated approach, the same data can be utilized for many regional-level applications. As per the literature review [16], previous research is less on BIM and GIS-based utility supply station location optimization studies. This paper is an attempt to develop and utilize a BIM-GIS integrated platform for utility optimal planning by developing a basic add-in tool referred to as BIM_UNOPT and conducting a case study for evaluating the applications and potentials of this integration.

2 METHODOLOGY

A methodology to process a basic utility supply station location optimization problem by integrating BIM, GIS and Genetic Algorithm is presented in this section. By utilizing this methodology, a C# based add-in tool is developed in BIM platform to conduct optimal planning study. The methodology is divided into two sections. The first section is the integration of GIS data into the BIM platform. Only flood hazard GIS data is integrated with BIM platform and section 2.1 details the conversion process. The second section discusses the proposed approach for the determination of the optimal location of a centralised supply station for a radial distribution network and section 2.2 describes the procedure. Even though the proposed methodology in section 2.2 is suitable for different kinds of utility networks, this work considers only plumbing distribution network. Tool development is detailed in section 2.3.

2.1 Converting GIS data and linking with BIM

The flood inundation model is created by following the hydrological, climatic and geographical parameters for the selected region. In this research, it is done by a 1D-2D coupled hydrodynamic modelling approach using the MIKE FLOOD application. As detailed in Fig. 1, using the GIS Conversion tool, 'Raster to Point features' the flood raster is converted to point features. By using the "Features toolset of Data Management tools", XY coordinates are added to point features. The resultant point feature's attribute table is exported to database format and stored at a specific computer file location for automated reading by the BIM _UNOPT add-in tool. By coding using C# language, the database is integrated into BIM _UNOPT tool and reads the database file when this tool is invoked by the user. SQL database method is utilized in this work.

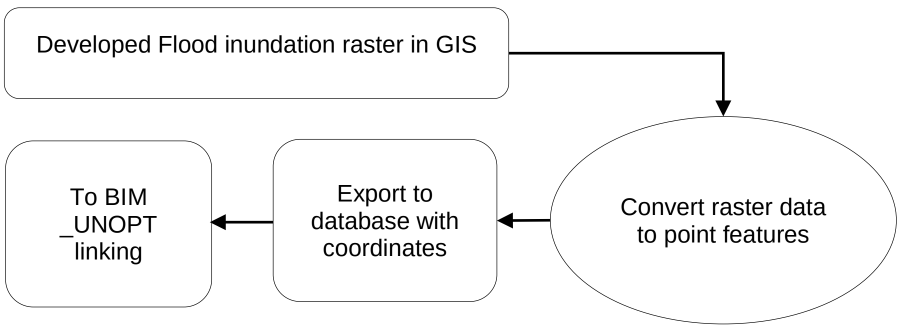

Fig.1. Flow chart of flood GIS data conversion to BIM

2.2 Optimal location of the supply station

BIM_UNOPT tool is coded to extract the required project-level utility network data from the BIM model and is capable to conduct Genetic Algorithm (GA) based optimization by combining GIS flood data linked with this tool as described in section 2.1. Section 2.2.1 describes the objectives and constraints for a basic-level utility supply station optimization problem and section 2.2.2 describes the information flow in the GA process. The following objective and constraints are to optimize the location of a central supply station with a radial network by avoiding locations with a high level of flooding. Cost optimization for a centralized supply station according to the carrying capacity of the utility network by excluding the highly flooded region for a utility network is the problem.

2.2.1 Objective and Constraints

Objective

Minimize utility network cost (S_{CU}) = S_{CR} + C_{SS} (1)

S_{CU}: Sum of cost for utility network

S_{CR}: Sum of cost for all utility radial connections originating from the supply point

C_{SS}: Cost for a supply station

$$S_{CR}=\sum_{R=1}^{N}(C_R * D_R) * C_n \quad (2)$$

C_R : Cost of utility radial connections supply and installation per meter length

D_R : Total straight distance of the utility radial connections per meter between the supply station and building utility receiving point.

N: number of utility radial connections originating from the supply station

C_n: A constant for converting the straight distance to the actual site routing distance

Constraints

Utility network element's carrying capacity constraints

$$Q_R^C \leq Q_{Rmax}^C \quad (3)$$

Q_R^C : Maximum demand served by the radial utility element

Q_{Rmax}^C: Rated maximum carrying capacity of the radial utility element

Site flood constraints: The supply station location's flood inundation height

$$h_f^{SS} \leq h_{fmax}^{SS} \quad (4)$$

h_f^{SS}: Effective flood height at the supply station as per the flood inundation GIS data

h_{fmax}^{SS} : Maximum allowable effective flood height at the supply station predefined by the user

The equation for effective flood height is given below

$$h_f^{SS} = h_f^{GIS} - H_{bf} \quad (5)$$

h_f^{GIS} : Flood inundation height obtained from GIS flood map as obtained from section 2.1

H_{bf} : Foundation height of the supply station building

2.2.2 Information flow diagram

As shown in Fig.2, the proposed tool will filter each building's utility water demand and building location details from the BIM information model for the entire project. This collected data form a list and its serial numbering constitutes the domain of the GA population. According to the size of the extracted list, the chromosome size is determined by the proposed tool. The GA optimization process of Fig.2 is detailed in Fig.3. Each generation's chromosome's fitness function is estimated as described in Fig.4. Fitness function is given in eq.6. The GA process final result is a building number and the user can locate the supply station either at that building or its nearby.

Fitness Function =1- S_{CU} / S_{CUmax} (6)

S_{CUmax} : Maximum possible total cost for the utility network

The Genetic Algorithm Framework (GAF) [22] is used to develop GA optimization steps in the BIM_UNOPT tool. In the beginning, the first population will be generated by GAF by a random selection method according to the GA parameters specified by the user.

2.3 Tool development

An add-in tool in the Revit platform is developed by following the steps described in Revit Software Development Kit [20]. Using C# language necessary coding is done for the main program according to the proposed methodology and the required steps to link this program with Revit and button creation for the add-in tool. In main program coding, plumbing network-related equations are used to size the interconnecting PVC conduit. Using SQL database, price data of conduits is stored.

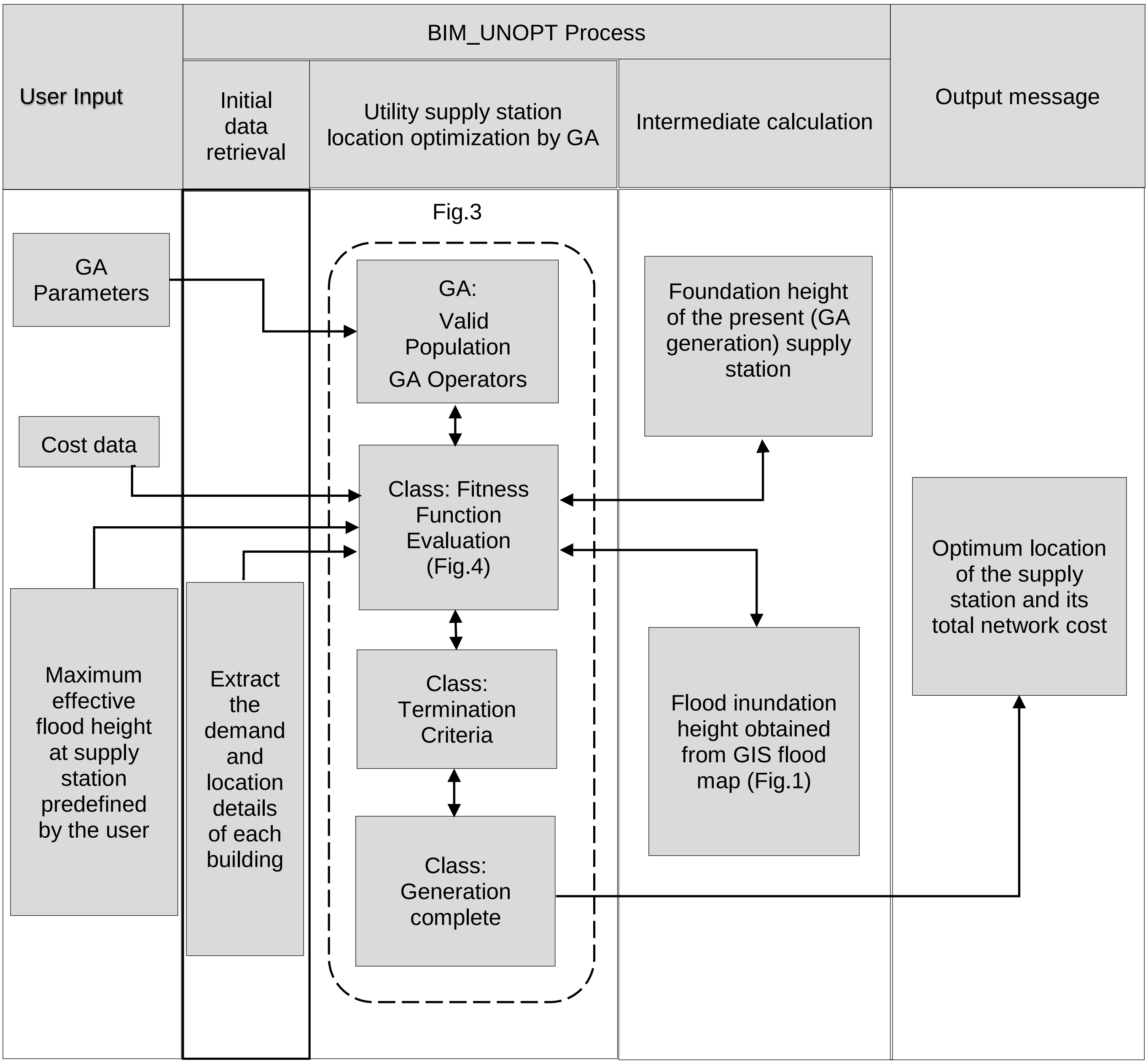

Fig. 2. Information flow diagram for utility supply station location optimization

3 CASE STUDY

A design project study is considered at Sreemoolanagaram, Ernakulam district of Kerala State, India. Based on the methodology explained in section 2.1, GIS data (of the corresponding region- Sreemoolanagaram) for flood inundation height is linked with BIM. The flood inundation raster for the project site is given in Fig.5 with a Google map background. This project site contains 30 typical buildings as shown in Fig.6. Each building requires a radial feeder from the central supply station for distributing water. The water distribution network is modelled for every building in Revit and is found that each building's demand is 2350 liters per day To optimize the location of the central supply station the developed tool is utilized and the results are shown in Fig.7 along with input data. The developed tool extracts the demand data and location details to prepare a list to act as a population database. This tool will estimate the fitness for the total cost of the network by following equation 6 by considering the total water storage requirement for a day and filling time as one hour for every building. A central location as encircled in Fig.6, is the optimal location estimated by this tool for the water supply station for this case study. By manual calculations using AutoCAD and Excel-based spreadsheets, results are validated. By the BIM_UNOPT method, the total cost of the network is 10,196 USD and by the conventional approach, the cost is 11,146 USD. An error percentage of 8.5 is obtained when comparing both methods. When different projects are done using this concept, an error of up to 15% is present between the proposed tool and the conventional approach. A factor S_c (here 1.3) is used in this proposed approach to convert the straight line distance to the actual routing distance. This is the reason behind this error and according to the project site, this factor will vary. Despite all this, the proposed approach is attractive due to automated results and this tool can be extended using artificial intelligence and image processing technologies to generate realistic routing.

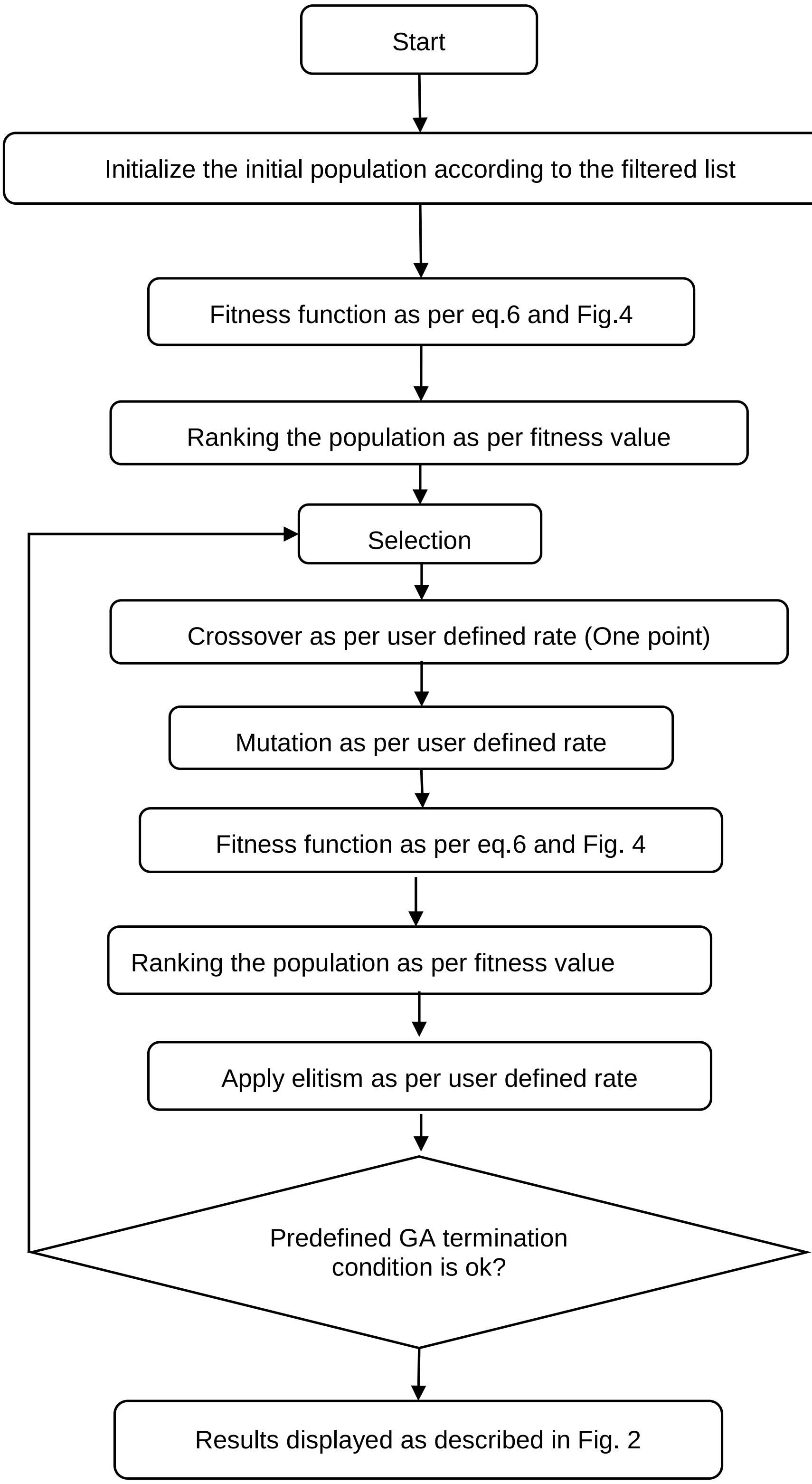

Fig. 3. Flowchart for GA process

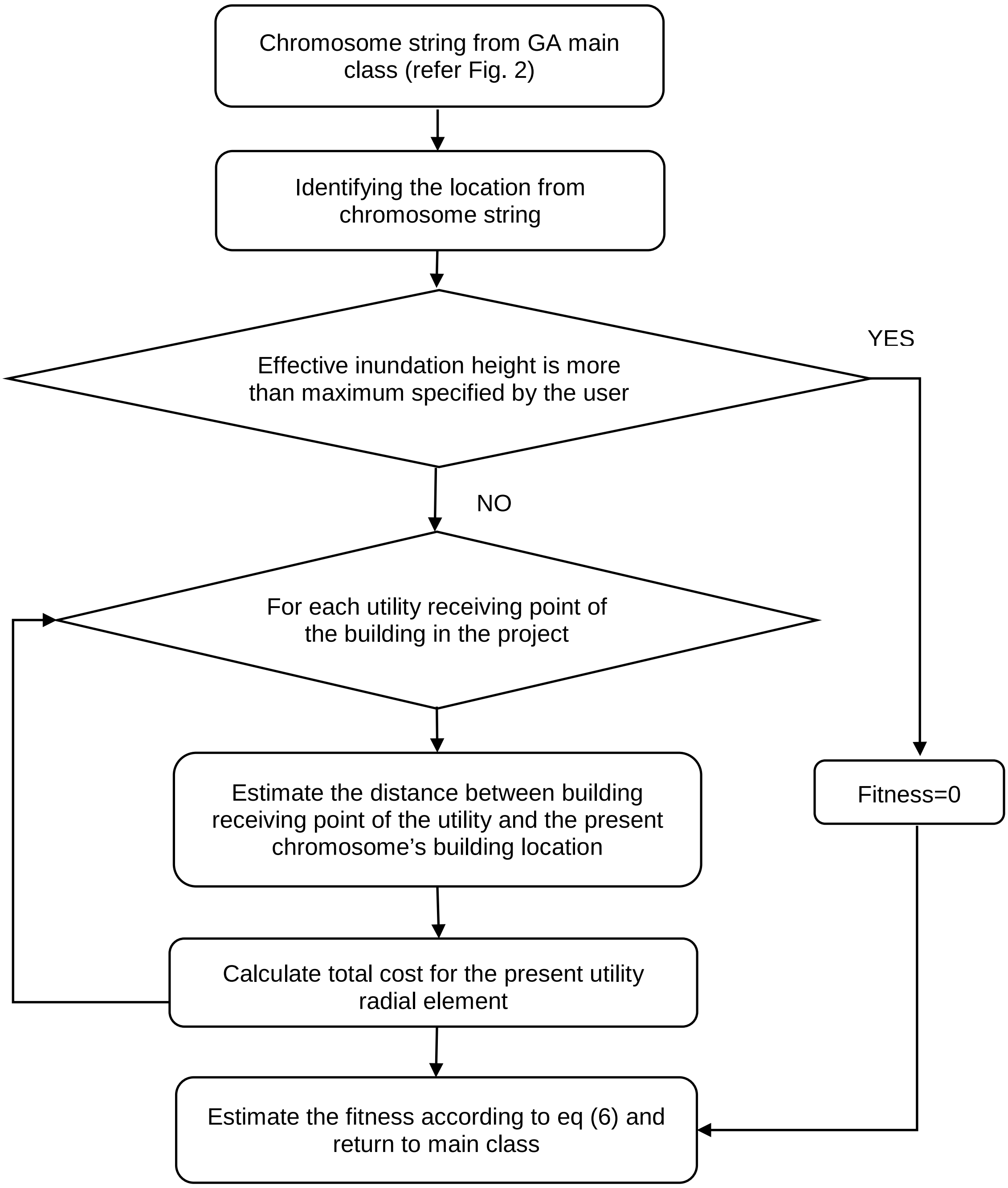

Fig. 4. Fitness value calculation

As depicted in Fig.5, flooding is present only on the northwest side of the boundary of the building project considered and 0.6m is the allowable maximum effective flood height specified by the user. Tool skipped the buildings that have an effective flood height of more than 0.6m by referring the linked flood database according to the extracted coordinates and assigning fitness zero for those buildings.

Results from a case study using the BIM_UNOPT tool show that compared to conventional design, this tool can save up to 90% design time and related saving in labor costs. This increase in savings is due to automation as described in Fig. 8. In conventional approaches multiple applications are utilized by a designer and manually he/she collects and processes the desired data between applications for conducting optimization. But in BIM-GIS integrated approach an add-in tool automates most of the traditional process such that with minimal inputs results are obtainable within a few minutes. Generally, the design is an iterative process, it makes sense to believe that for multifaceted projects, much productivity can be attained by automatic design tools. Compared to the traditional 2D CAD method, the new approach has fewer software requirements, more automated procedures and a lesser probability of errors. All-in-all, this approach to the optimal planning process can be generalized to conduct different types of utility networks such as ring or tree networks under different kinds of hazard scenarios and is extendable to utilize more potential technologies such as artificial intelligence. A comparison between the traditional and proposed approach is given in table1.

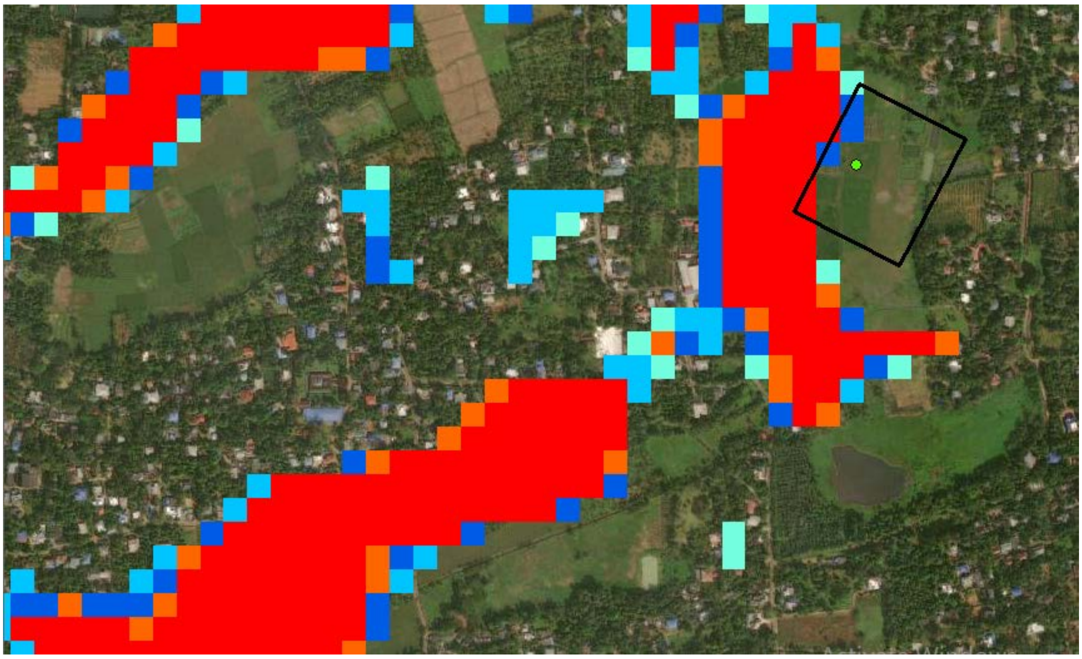

Fig. 5. The flood inundation height raster data with google map background for the location of the case study. The black hollow rectangle area is the project site

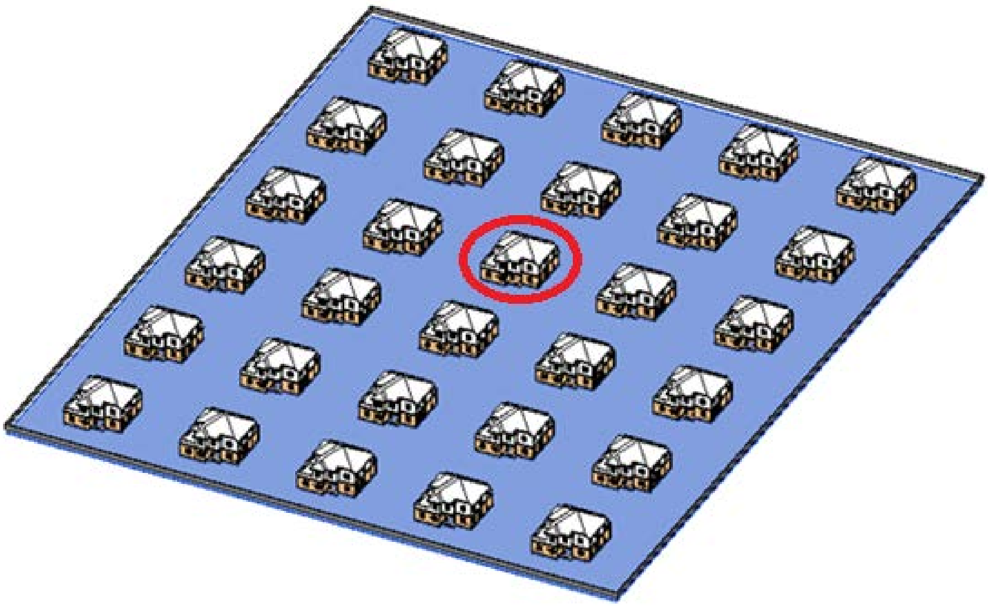

Fig. 6. Case study project developed in Revit

The downside of the developed tool BIM_UNOPT is that it's limited to a basic optimization problem for a radial utility network. Civil and transportation network systems of the project site are to be considered for integrated optimization, and this study lacks the same. The extraction process is the key function that will determine the degree of accuracy and capability of add-in tools. There must be uniformity in BIM modelling to develop an automated tool to extract the necessary data without errors, otherwise leading to undesirable results. So a permanent quality checking team and auto-detecting ontologies for warnings are required to enhance the add-in tool. Modelling is required to be done in accordance with the developed tool's data retrieval algorithms which necessitate standardized modelling regulations implemented by authorities. In general, utility network design and implementation have lengthy installation, testing and commissioning requirements according to the building codes. This may complicate automated BIM tool developments as developers are required to convert complicated rules and regulations to an automated platform.

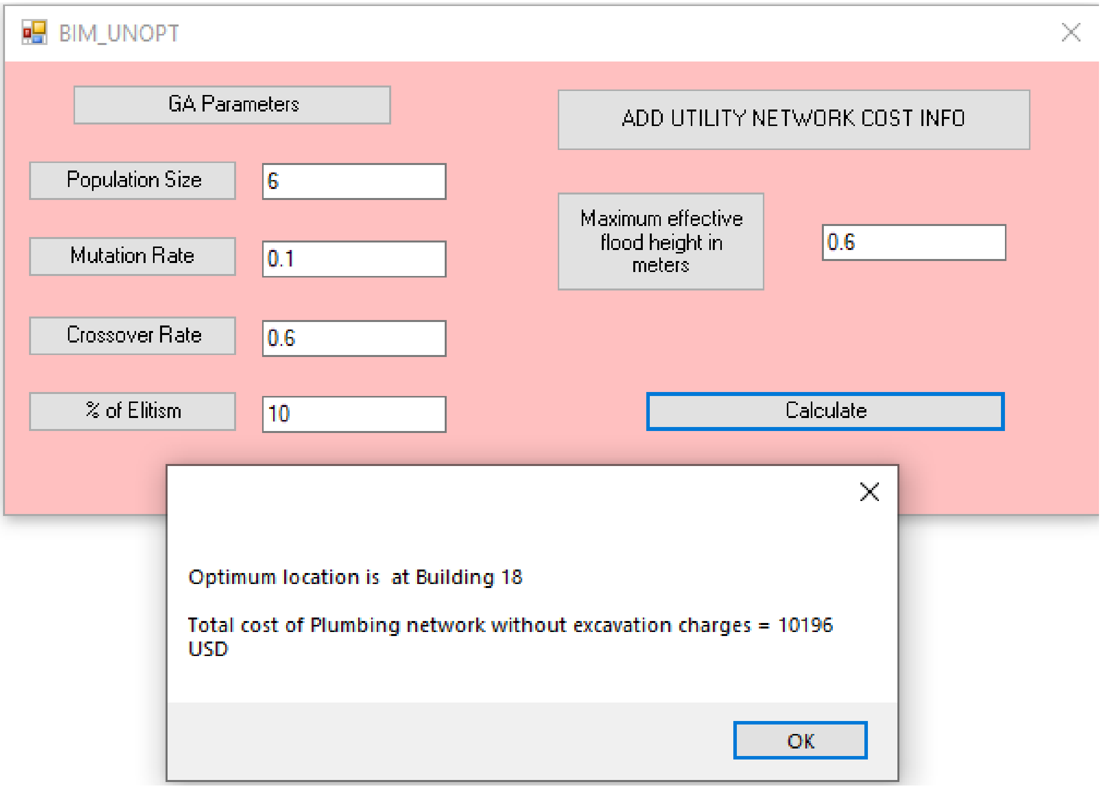

Fig.7. BIM_UNOPT user interface and results obtained as a message box

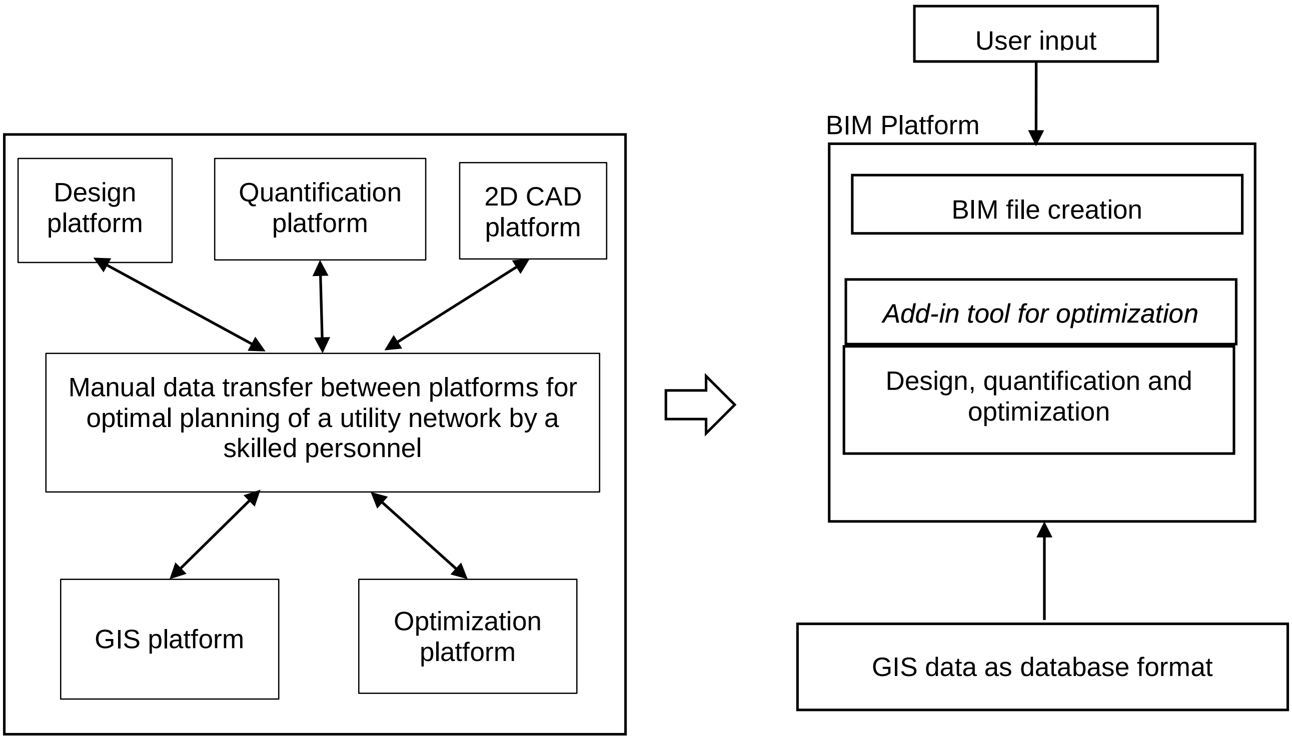

Fig. 8. The conventional and the proposed process of utility supply station location optimization

Table 1. Comparing the conventional approach with the proposed approach

Description of the requirements	Conventional approach	BIM and GIS-based approach
Software	Applications for 2D-CAD, quantification and design	BIM_UNOPT
Labor hour	Due to manual skilled work, more time is required	Due to the increase in automated data retrieval and process in a unified environment, lesser labor hours are required.

Description of the requirements	Conventional approach	BIM and GIS-based approach
Ease of sharing the information of the optimal planning process	Since data and results are stored in multiple files, sharing is time-consuming work.	Entire data is available in digitized format in a single window, so sharing is easier
Ease of integrating the latest technologies	Possible, but it may result in low performance	Easy and recommended for accurate results
Error detection and minimizing the error propagation	Based on the skill of the designer it varies	Automatic error detection and mitigation tools can be developed(but if not properly modelled for data retrieval, it results in huge error)
Issues related to interoperability between application platforms	More	Less

4 POSSIBLE EXTENSIONS

Optimization for multiple supply stations: This work is done for a single supply station. The same approach can be extended to multiple supply station optimization problem. If “n” number of supply stations are considered for the utility network, then an algorithm is required to find out the subset of buildings belonging to respective stations among available choices from the ‘n’ number of supply stations for estimating the fitness function.

Vertical distance: In this work, distance is estimated by 2D equations and this can be extended to a 3D level where vertical riser distance is also considered for increasing the accuracy of calculating the length of the utility element. The regional code of installation height can be added to BIM_UNOPT for the same.

Multiple GIS data as variables: Flood velocity and inundation height can be linked to the BIM platform from GIS data for conducting optimization as variables. A tool can be developed by considering velocity, inundation height and building level utility demand as a constituent of chromosome to conduct optimal planning processes according to these three variables.

Double optimization in the BIM platform: Two-stage optimization process can be developed using the method explained in this research. The first stage solves the project-site level supply station optimization and the second stage considers the building level optimum location for the main utility distribution center for that building. In Autodesk Revit, “Spaces” assigned to rooms contain utility demand data. Using this data as serving points from the main distribution station of a building, the optimization study can be conducted by developing an add-in tool. By exporting all this BIM-based utility network data to GIS platform, a city-level optimal planning study is possible.

Multi-level integration: Two kinds of BIM and GIS integration is described in Fig. 9 and this research is as per Mode 1 integration. After conducting the BIM-based optimization in a multi-building level utility network, the required data is exported to GIS for city-level optimal planning studies. Multiple project-based studies in the GIS platform using big data analytics can generate standardized data such as unit cost. In Mode 2 type integration, project level and city level integration is done in the GIS platform and only building level distribution center optimization is done in the BIM platform. According to the requirements, the developer should select the level of integration for the desired results. BIM platform is suitable for small-scale projects with detailed bottom-up optimization where every network element level information is required.

Automated code checking: If any data is missing or there is an error in the retrieval process they can be detected and mitigated by developing algorithms. For this case study if the demand of a particular building is missing, then an error warning or developing an additional function for BIM_UNOPT that is capable to estimate the demand according to the built-up area and type of the building can be considered.

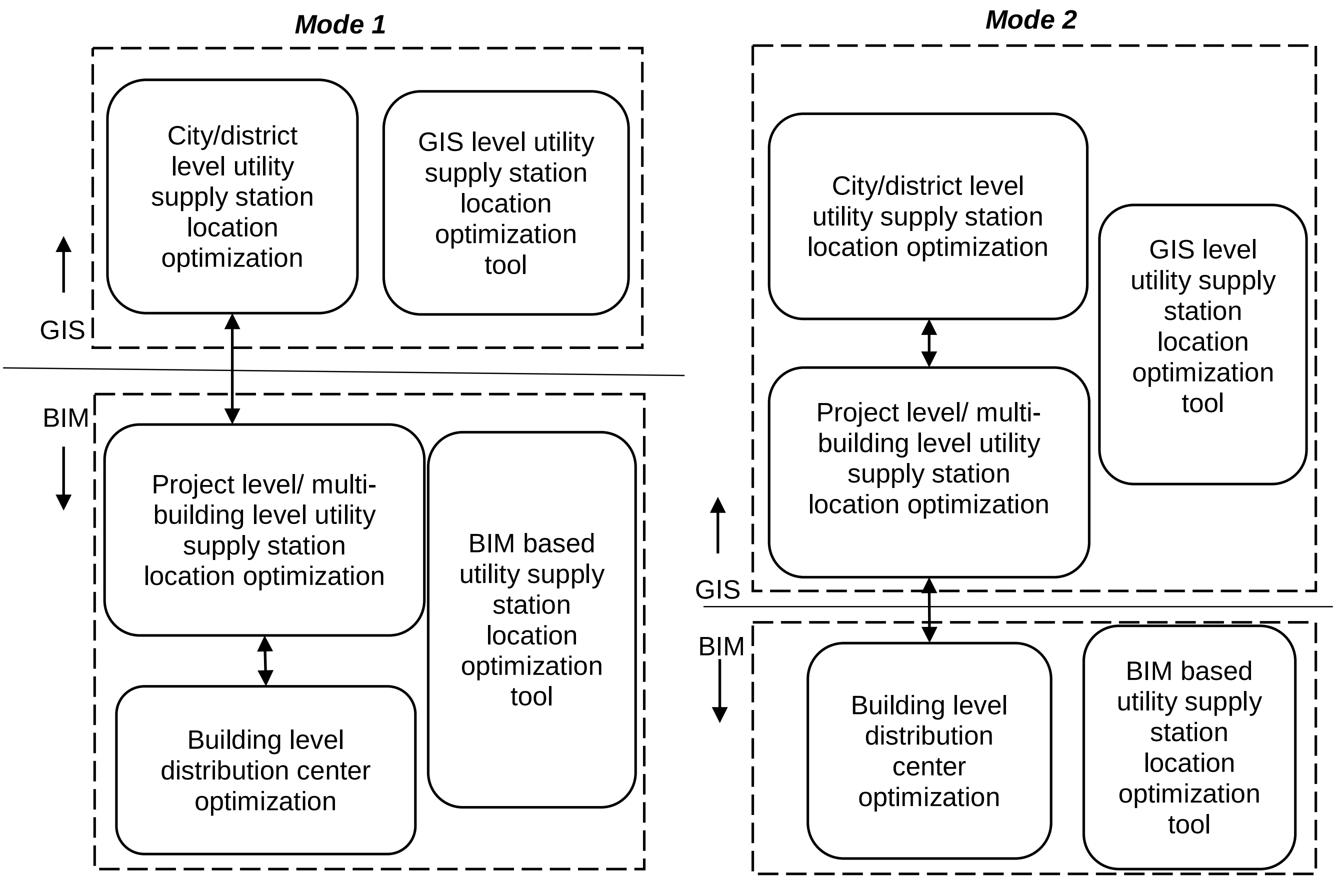

Fig. 9. Two mode of BIM-GIS integration for multi-stage utility supply station location optimization

5 CONCLUSION

Automated BIM and GA-based utility supply station location optimization by linking the GIS flood data is presented in this paper and this approach has improvements over conventional planning. From the case study, it is affirmed that the BIM add-in tool approach can considerably minimize cost, labor hours and software requirements compared to 2D-CAD and Excel-based optimal planning processes. There is an error value of 8 to 15% between two approaches. This error can be justified due to the faster results with least effort in the proposed approach and future possibilities to improve the tool to generate realistic results. The research identified that BIM and GIS integrated approach is capable to process both network infrastructural data and optimization processes simultaneously in a collaborative platform and in an efficient manner. In general, the integration of GIS data in the BIM platform for the optimal planning process of utility networks is expected to provide a digitized sharable model for all stakeholders. The study emphasizes that BIM and GIS integrated approaches for utility supply station location optimization and possibilities have significant potential for future research. In spite of many good research-related positive recommendations for BIM and GIS-based network modelling, its industrial-level application is still in its infancy. To prepare some industrial-level tool technologies such as artificial intelligence and image processing, BIM-based smart objects and suitable algorithms are to be utilized.

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