A Multi-Criteria Optimization Study for Locating Industrial Warehouses with Integration of BIM and GIS Data

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Achieving a maximum production capacity in large manufacturing factories requires optimal design and implementation of development plans. One of the newest advancements in manufacturing and project management is Building Information Modeling (BIM) which uses creative processes for production, analysis, and management of building information. On the other hand, the output of the Geographic Information System (GIS) model includes one or more actual locations, which satisfy all needs. It provides points related to the BIM tool and it creates a 3D model for visualizing the optimum location. Integration of GIS and BIM can bring about several advantages including optimum locating. The aim of the current study is to propose a useful model for locating warehouses in large manufacturing factories using a BIM-GIS integrated model. To this end, BIM was used for simulation and locating of product warehouses in the casting unit of Esfahan's Mobarakeh Steel Company (EMSC) in Iran. In order to meet these aims, several locations were selected in the EMSC compound, and decision making regarding three superior alternatives which were carried out by creating a 3D model of the warehouse and fitting of the model in three suggested locations. Using the extant literature, interviews with experts and managers, and survey questionnaires, essential criteria affecting the optimum locating of industrial warehouses were extracted based on the Building information modeling data. Then, the Analytic Hierarchy Process (AHP) method was used for data analysis. The results indicated that among various criteria, economic–social and crisis management criteria had the highest weights. These results were then used for selecting the optimum locating for the construction of warehouses.

Keywords: Building Information Modeling (BIM); Geographic Information System (GIS); Industrial Warehouses; Analytic Hierarchy Process (AHP); Iran

Introduction

The construction industry has experienced rapid international growth in recent decades along with the development of human society. Large scale projects are currently being funded and constructed new materials and building methods are being used, and new project design and implementation methods are being introduced. However, each construction project has its unique characteristics, environment, and climate. Performing risk management is essential during the first stages of the project before incidents occur (Zou et al., 2017; Khosravi et al., 2020). However, traditional value engineering approaches are limited to static methods and can only play limited roles in real work locations (Ghaffarianhoseini et al., 2017). As risks exist on any project, the lack of risk management can result in unacceptable or disastrous results such as high cost and long delays, damages, injuries, and even death or collapse of the project. Modeling technologies such as Building Information Modeling (BIM) are perceived as an effective solution in the construction industry to mitigate these potential challenges (Muriana, and Vizzini, 2017). Leveraging building information through modeling can result in significant headways in reducing risks and dangers on construction projects (Ghaffarianhoseini et al., 2017).

BIM is a process used by construction engineers and stakeholders where a construction project is simulated in a multi-dimensional digital model and determines many of the advantages of the project from start to finish (Fountain and Langar, 2018). Therefore, the concept of BIM can create quick 3D information models of a project and predict and illustrate the structure, management, maintenance, and repairs in a digital computer-based environment to facilitate the identification of initial risks (Khoshfetrat et al., 2020). BIM also supports better communication and improved coordination and cooperation among project team members, which are highly essential to project success (Schueter et. al., 2012). BIM can also be described as a novel method for design and documentation in the construction industry that provides stakeholders with complete and integrated documentation of the project stored in a database (Ghaffarianhoseini et al., 2017). Studies have indicated that using BIM has also significantly reduced errors stemming from various design software applications that occur due to a lack of intelligent and integrated information (GhaffarianHoseini et al., 2017; Sacks et al., 2018). Recent research endeavors have shown that using BIM can reduce project costs in all stages, namely, before, during, and after construction (Saka and Chan 2020; Sarvari et al., 2020). However, in many developing countries such as Iran, cost and energy management are often ignored in projects and are limited to small parts of the private sector (Eberhard et al., 2017; Saka and Chan 2020).

Geographic Information System (GIS) is another technology that integrates locating information and related data in a single environment. This technology can provide transparency in all stages of construction, including data creation and management, data integration, cost evaluation, among other areas. A sheer volume of information in the construction industry is related to location and geographical position. Today, geographic information is among the most crucial vital data for management, planning, and decision-making. This type of information is essential that it is now being referred to as the fourth basis of decision-making (Lü et al., 2019).

GIS provides a viable approach for the storage, management, and analysis of geographical informing, and is designed for use with information associated with simultaneous geographical and descriptive dependencies. A scan of existing studies indicated that, while the integration of BIM and GIS have been highlighted, there is still a need to investigate essential criteria such as geotechnical studies of building location, topological characteristics of the region, green space, spaces needed for future developments, access to road and railway transportation networks, and attention to crisis management and passive defense (Liu et al., 2017; Oldfield et al., 2017).

Attention to various essential criteria and optimum locating of construction sites determined by criteria such as distance, geographical characteristics (i.e. temperature and topography), and access to road and railway transportation networks is essential to reduce the risks associated with a project (Zgonc et al., 2019). In particular, storage warehouses for large manufacturing factories are a significant part of their supply chain. Therefore, supply chain management is required for evaluating the location of these warehouses as part of a logistic network (Agyabeng-Mensah et al., 2019).

The optimum locating or placement of warehouses to support a dependable logistic network is a critical supply chain management decision. This decision impacts the ability of a company to increase sales, reduce transportation time and costs, and improve competitiveness. Furthermore, the location of manufacturing warehouses affects the cost of transportation between various units, and it can also influence demand in the service industries. Therefore, given the importance of locating warehouses and the need to optimize the supply network to reduce costs and maximize the use of resources, researchers noted that it is necessary to use novel methods to incorporate natural criteria in location selection and solve this multi-criteria decision-making problem (Chen et al., 2008). In addition, digital solutions such as BIM for warehouse design, construction, and operation and GIS for location mapping can be leveraged to assist in locating industrial warehouses.

Therefore, the current study investigates the integration of BIM and GIS data to determine the best candidate for locating industrial warehouses. This study focuses on the slab warehouse of the casting unit of Esfahan’s Mobarakeh Steel Company (EMSC) in Iran, and develops a mature multi-criteria decision-making technique based on the Analytic Hierarchy Process (AHP) method. Essential criteria affecting the location of industrial warehouses were first determined through interviews with those professional experts involved in this study. Then, using a combination of BIM and GIS models, a suggested candidate for locating industrial warehouses was investigated and identified using AHP. While the use of AHP method to drive the decision of selecting and locating an industrial warehouse is a critical component to this research, the study further contributes to the existing body of knowledge of locating warehouses by simultaneously considering the integration of both BIM and GIS data to determine essential criteria for locating industrial warehouses. The application of AHP method to both BIM and GIS data has been very rarely investigated in the extant literature. The framework proposed in this study to optimize locating industrial warehouses with the integration of BIM and GIS data does not seem to be adopted so far altogether in a single research study. The findings of this study serve as a guide and practical toolkit for relevant stakeholders.

Literature Review

BIM

With several perceived benefits of BIM in practice, a surge of BIM adoption by various project stakeholders throughout the whole project life cycle has been observed worldwide in recent years (Lu et al., 2017; Sacks et al., 2020). Eastman et.al. (2011) defined BIM as “a novel modeling technology and an integrated set of processes for creating, connecting, and analysis of building models”. The concept of BIM includes infrastructures of information technology tools that integrates design steps while also supporting the construction and commissioning of buildings. The reason for the development of BIM technology was the existence of problems in the traditional system of building planning and construction (Easman et al., 2011).

Various researchers have investigated the advantages of BIM from different points of view. These advantages include suitable communication with the design team (Chen et al., 2018; Chan et al., 2019), creation of time schedule and budgeting (Chen and Tang, 2019), employer satisfaction (Charehzehi et al., 2017), reduction in the cost of changes (Wang et al., 2016), increase in precision of final cost predictions (Lawrence et al., 2014; Lu et al., 2016), reduction in the project implementation time (Saieg et al., 2018; Chan et al., 2019) and improvement of integrated design (Alison, 2010; Chan et al., 2019). One of the basic goals of BIM database is to help in the management and synchronization of multiple models that exist for a single project (Eastman et.al. 2011). Furthermore, a thorough review of previous studies shows that there are several instances of using BIM for the determination of exact building location (Liu et al., 2017; Khoshfetrat et al., 2020). Managing the construction of industrial units includes various activities that require accurate and accessible information. BIM can satisfy a wide range of information and performance needs in these projects (Pärn et al., 2017; Pearlson et al., 2019).

Integration of BIM and GIS

BIM is used to create a rich and powerful database for a facility and its parts. It provides the ability to make optimum decisions in any stage of the project lifecycle and helps in significantly reducting the time and cost of implementation (Sarvari et al., 2020).

Studies have revealed that the main nature of information in construction projects is location information, suggesting that in order to create an intelligent BIM process, it is necessary to use the novel GIS technology (Liu et al., 2017). While many decisions are dependent on data, locational analysis, and position of geographical characteristics, environmental conditions can change over time and create challenges for process management. GIS provides powerful and important tools for managing these criteria, and their integration with other systems can lead to significantly improved results (Nwachukwu, 2018).

GIS technology has the ability to provide comprehensive analyses.This capability enables project designers and managers to analyze the effect of their designs in a conceptual stage called Geodesign (Dou et al., 2020). Yang et al. (2018) discussed how a geodesign method facilitates a process of managing a closed-loop urban system through algae cultivation by turning urban waste streams into renewable energy. Three sites in Atlanta were tested to explore to what extent the system performance can move toward a “net-zero” urban environment. The results showed that the three neighborhoods have the highest potential to reach 12–18% of the total building energy demand met by the energy production in the algae system in the extreme scenario (Yang et al., 2018). GIS technology can depict natural and man-made environments and analyze their effects on infrastructural systems such as transportation, land usage, geographical conditions, water resources, human lives, etc. (Madhu et al., 2017). GIS technology can also predict and model actual construction and special examples of passive defense and crisis management (Zhou et al., 2018).

BIM and GIS technologies are two complementing tools and one cannot replace the other. BIM includes integration and gathering of building information. GIS is a specific technology that integrates information related to location and details related to the environment and can be used for more effective decision-making (Dallasega et al., 2018). GIS information can, thus, interact with specific parts of the BIM dataset. The design and planning stages of the construction project require access to a wide range of data. Therefore, GIS can help the construction industry by providing correct categorization of all the required information. The final aim of using these systems is to make proper decisions during the implementation of construction projects (Liu et al. 2017; Sacks et al., 2018). GIS technology can facilitate the storage of data in a central location and can create geographical connections between information. Furthermore, GIS technology creates the possibility of evaluation of projects with any scale which can further highlight the importance of GIS technology and its integration with BIM (Zhu et al., 2018; Ashkezari et al., 2018).

Industrial Warehouses

Industrial warehouses are constructed for various activities requiring an expansive and roofed area. Various types of industrial warehouses exist, each of which has its own characteristics (Meera, 2013). In general, industrial warehouses can be divided into three categories of truss, Ultimate Building Machine (UBM), andSheet beam constructs, where steel is the main main material used. The weight, stability, and construction cost are among the important criteria for selecting the type of industrial warehouse (Saleem and Qureshi, 2018). In warehouse construction, the size of the entrance is also extremely important and can be one of the identifying characteristics of each construct (Piroglu et al., 2017).

Industrial warehouses differ from other types of warehouses. Compared to other types of warehouses, the industrial variant is often wider, with larger dimensions for their columns and beams. These characteristics of industrial warehouses are mostly determined based on their application, construction location, among other essential criteria (Cacho-Pérez, 2017). Due to their unique applications, high strength, large size, and the difference in the construction process, industrial warehouses can have usages other than their initial intended application (Lee et al., 2016). The cost of construction of these warehouses is high due to their highy height and heavy weight when compared to other warehouses. The design of industrial warehouses is also different from normal constructs, specifically in regards to frame shapes, presence of slopes, and significantly larger entrances compared to other constructs (Vayas et al., 2019).

There are important criteria that must be considered during the construction of industrial warehouses. The cross-section, the location, and placement on the cross-section, the distances between supports, type of bracings, type of strengthening systems, the size of roof openings, and the placement of strengthening systems (internal locating) are among these important criteria (Singh et al., 2017). Furthermore, other information such as roof cover, roof slope, wind and earthquake load, and auxiliary load allowed stress for local soil and type of soil at construction sites are also important in the design and construction of industrial warehouses

(Meera, 2013). Important criteria for optimum locating of industrial storage warehouses are presented in Table 1.

Please insert Table 1 about here

EMSC is the largest private industrial complex and the largest Iranian steel company, located at 65 km southwest of Esfahan (Tavassolirizi et al., 2020), near the city of Mobarakeh, Isfahan Province, Iran (Figure 1). The design of EMSC is based on importing raw materials from the east and exporting products from the west and, therefore, storage warehouses, which are an important part of supply chain and product sale must be placed on the west side of the EMSC. As shown in Figure 1, three suitable alternatives have been determined for the construction of the slab warehouse of the casting unit of EMSC. The features of alternative 1 include easy access to railways, easy access to road transport, existing appropriate space for future development, low volume of excavation, no need to demolish green space and buildings. The features that have made alternative 2 a possible option for constructing a slab warehouse include eliminating required costs for railway development, no need for high volume excavation, and no need to develop access routes and roads. Alternative 3 was also considered as a possible option because of the existence of sufficient space and its close location to the production sector.

Please insert Figure 1 about here

Research Methodology

The current study aims to present a model for locating storage warehouses in large manufacturing factories using a BIM-GIS integrated model. To achieve this overarching objective, previous research studies and annual reports of credible industrial and civil companies were first reviwed to to identify locating criteria. Then, self-administered survey questionnaires were distributed to experts and managers directly involved in development projects to further determine essential criteria affecting locating and the importance of each criterion.

The 20 survey participants included experts, chief executive officers (CEOs), and managers of manufacturing and management units of EMSC and road and building engineering experts with at least 20 years of hands-on solid experience in the field of civil engineering. Another criterion for the selection of experts is their own familiarity with both BIM and GIS technologies.

The culminating effort of the literature review and survey was the development of a BIM-GIS integrated model to identify the location of the workshop. The solution method was selected based on previous works, using geographical distance and covering of all needs to select candidate locations for locating the warehouse. the, The proposed model can identify suitable alternatives for the optimum location of the warehouse if the geometry of the construction site of the warehouse is created in BIM. The output of the GIS model included one or more actual locations, which satisfy all needs. Then, the integration of this model with BIM created a 3D model for visualizing the optimum location of the warehouse.

Next, selected candidate locations for locating of slab warehouse of the casting unit of EMSC were selected based on the important criteria and pairwise comparisons were performed using AHP. Finally, candidate locations were ranked according to the weighting values. Figure 2 shows the conceptual model of this study.

Please insert Figure 2 about here

Analytic Hierarchy Process (AHP) Method

Selecting a decision-making process that take into consideration financial and time constraints is critical . The AHP method is an inclusive decision-making process for identifying and ranking the priorities of criteria thatuse the pairwise comparison of various alternatives to prioritize each alternative (Saaty, 2001).

This process involves various alternatives in the decision-making process and it has the possibility of performing sensitivity analyses for criteria and sub-criteria. AHP is also based on pairwise comparison which facilitates calculations and judgments. AHP transforms a complex decision problem into elemental issues related to each other through a hierarchy and determines the main goal with the lowest level of the hierarchy in the simplest possible way (Wang, 2015; Marttunen et al., 2019). The results obtained in previous studies have shown that AHP can be adopted in various applications due to its simplicity, flexibility, simultaneous use of qualitative and quantitative criteria, and its ability to evaluate compatibility during judgments (Darko et al., 2019; Dabiri et al., 2019). AHP is carried out using six steps (Bertolini et al., 2006):

Step 1: Creation of hierarchy structure: This structure consists of a four-stage hierarchy including the overall goal (usually the selection of the best alternatives), criteria, sub-criteria, and alternatives (Mu and Pereyra-Rojas, 2018). Converting the problem under evaluation into a hierarchy structure is the most important step in the AHP process because it breaks down complex problems into less complex ones which can be compatible with human nature and cognition. So, the human is better able to analyze and decide upon them (Ivanco, and Michaeli, 2017; Matos et al., 2018). Furthermore, each criterion is divided into several sub-criteria which are compared to each other and weighted.

Step 2: Determination and calculation of importance coefficients (weights) of criteria and sub-criteria: Pairwise comparisons are used to determine the weights of criteria and sub-criteria which determine the relative importance of each criterion compared to others. In this study, the method proposed by Bertolini et al. (2006) was used. In this approach, each pairwise comparison is assigned a number between 1 to 9, the meaning of which is presented in Table 2. Then, the assigned weights are normalized.

<u>Please insert Table 2 about here</u>

Step 3: Determination and calculation of importance coefficients of alternatives: After determining the importance coefficient of the criteria and sub-criteria, it is necessary to determine the importance coefficient of alternatives. In this step, the priority of each alternative is evaluated based on its relevant sub-criteria (or in case of no sub-criteria, directly based on the main criteria). Evaluations are done based on pairwise comparison of alternatives and the results are recorded in the pairwise comparison matrix of alternatives. The importance coefficients are then calculated by normalization of the rows in this matrix. There is an important distinction between the pairwise comparison of criteria and alternatives. The pairwise comparison of alternatives is carried out based on relevant sub-criteria or, in case of no sub-criteria, directly based on the main criteria while criteria are compared based on the aims of the study. Therefore, instead of asking how important criterion i is compared to criterion j for achieving the goals, in comparing the alternatives, the question is posed as how much is alternative i more important than alternative j in relation to the x sub-criterion? (Bertolini et al, 2006).

Step 4: Final calculation of alternatives' scores in relation to criteria and sub-criteria: In this step, after integrating the calculated importance coefficients, the "final score" of each alternative is determined. To this end, the Saaty's principle of hierarchical composition (Bertolini et al, 2006) is used which results in a "priority vector" by considering all judgments at all levels of the hierarchy (equation 1):

$$\text{Final score (priority) of alternative } j = \sum_{k=1}^{n} \sum_{i=1}^{m} Wk\ Wi\ (a_{ij}) \tag{1}$$

Where:

W_k= factor's importance coefficient

W_i= importance coefficient of sub-criteria i

a_{ij}= the score of alternative j compared to sub-criteria j

Step 5: Comparison of the criteria weights: In this step, the weights of criteria are compared to each other. The relative importance of the criteria is determined based on the main goal of the study.

Step 6: Evaluation of logical compatibility in judgments: One of the advantages of the AHP method is the possibility of evaluating the compatibility of judgments used to determine the importance coefficients of criteria and sub-criteria. According to Bertolini et al (2006), the Incompatibility coefficient (I.R) is calculated by dividing the incompatibly index (I.I) by the randomness index (R.I) (equation 2). If this index is equal or smaller than 0.1, then the judgments are acceptable; otherwise, judgments must be revised.

$$\text{Incompatibility Index (I.I)} = \frac{\lambda max - n}{n-1} \tag{2}$$

where; λmax is the greatest eigenvalue, and n is matrix dimension.

Results and Analysis

Selection of Construction Location for Slab Warehouse Using BIM-GIS Data

In this study, three places located on the western side of the EMSC complex were selected for the construction of the slab warehouse of the casting unit of EMSC as indicated in Figure 3. First, these three locations were evaluated by experts according to initial criteria including the implementation cost and locating criteria (Tables 3 and 4), and the final suitable alternative was selected. Based on the results presented in Tables 3 and 4, alternative 2 was selected as the optimum location.

Please insert Figure 3 about here

Please insert Table 3 about here

Please insert Table 4 about here

To provide the importance of the subject and in order to conduct a more accurate evaluation of alternatives, a 3D model of the warehouse (Figure 4) was created in the Autodesk software environment. The placement of this 3D model in candidate locations (Figure 5) was designed and implemented using a detailed evaluation of optimum location and evaluation of all possible details. In this step, by locating the 3D model of the warehouse created through the integration of BIM-GIS data in the three possible locations, experts managed to evaluate possible problems caused by the construction of the warehouse in each location before actual construction. In recent years, Autodesk Civil 3D has been used as a GIS system (Szewioła and Poniewiera, 2017). According to the experts' observations, including the members from the commissioning team, project owner, designers, and implementing organizations, new essential criteria were used for the evaluation of three candidate locations in order to cover all possible details and select the best final answer. The descriptive statistical data related to these criteria and sub-criteria acquired using a 3D model of the warehouse created using BIM-GIS integrated model is provided in Table 5.

Please insert Figure 4 about here

Please insert Figure 5 about here

Please insert Table 5 about here

Selecting Superior Alternative Using AHP Technique

In this step, pairwise comparison matrices for parameters were filled and reviewed by experts before entering the Expert Choice software for calculation of importance coefficients and priorities. The basis of this decision-making method is pairwise comparisons. After the creation of the hierarchy tree (Figure 6), a set of pairwise comparisons were carried out. These comparisons will determine the weight of each criterion compared to the rival alternatives. Finally, AHP integrates the pairwise comparison matrices to make the optimal decision.

Please insert Figure 6 about here

Prioritization of main evaluation criteria and their related sub-criteria

To this end, first of all, the main evaluation criteria of the study were identified and the relative importance of main evaluation criteria was determined using Saaty's 9-point scale for pairwise comparison in AHP (Saaty, 1980) and the pairwise comparison matrices were created based on the opinions of experts. Then the final weight and prioritization of each evaluation criterion were obtained. The weight and priorities of criteria and their related sub-criteria along with their incompatibility index are presented in Table 6. According to these results, economic–social criteria and crisis management criteria with weights of 0.431 and 0.334, respectively, had the highest weights. Furthermore, natural criteria were in third place with a weight of 0.166.

The results also indicate that sub-criteria of construction location including soil conditions with a weight of 0.470 and topography with a weight of 0.238 has the first and second priority among the natural criteria. Sub-criteria of the slope with a weight of 0.062 and reduction of environmental risks with a weight of 0.021 had the next priorities. The incompatibility value for this group was lower than 0.1 (0.07) and therefore the comparison was accepted.

According to the results, in the passive defense group, the sub-criteria of terrorist attacks with a weight of 0.280 has the highest priority, and placement in the storm’s path with a weight of 0.020 had the lowest priority. Placement in the flood path with the weight of 0.123 had the second priority. The incompatibility index for this group was 0.06 which indicates a valid comparison.

The results for economic–social criteria indicated that space for future expansions with a weight of 0.407 has the first priority and reduced project delays had the second priority with a weigh of 0.329. Sub-criteria of access to transportation networks, reduction of construction and maintenance costs, and reduction of transportation costs had the next priorities with weights of 0.178, 0.109, and 0.034, respectively. The incompatibly index for this group was calculated to be 0.06 which is acceptable as well.

Please insert Table 6 about here

Prioritization of final candidates for construction location of slab warehouse

Table 7 shows the partial weights of each alternative with the related sub-criteria. Using the final weight of each alternative in relation to the sub-criteria, the final weights of all alternatives were determined. To this end, the comparison moved from the lowest level of the hierarchy to its highest level, and priorities were determined. The final weight of each alternative is calculated by multiplying the partial weight of each criterion with the related sub-criteria. According to the results presented in Table 8, alternative 1 with a weight of 0.216 has the highest weight and the first priority. After that comes alternative 2 with a weight of 0.198 and alternative 3 with a weight of 0.101 in second and third priorities, respectively. Therefore, alternative 1 has the highest priority for the construction of the slab storage warehouse of the casting unit of EMSC. The results indicate that although alternative 2 was selected in initial evaluations by experts, using a 3D model optioned from integrated BIM-GIS data changed the optimum alternative to alternative 1. Finally, by considering all consequences of wrong locating, the optimum alternative (alternative 1) was selected for the construction of the slab warehouse. In fact, the professional experts involved in this study were invited to review their decisions for selection of location of the warehouse based on the results derived from this study, again. They unanimously concluded that alternative 1 (eventually chosen by the proposed method) is really better than alternative 2 (initially chosen by the experts).

Please insert Table 7 about here

Please insert Table 8 about here

Discussion and Conclusion

In recent years, locating and placement studies for the industrial sector has become one of the key elements for project success and sustainability of industrial units. Optimization of industrial facilities positioning can lead to reduced costs, improved project productivity, and yield the ultimate success of industrial units. Conducting proper industrial locating studies will not only influence the economic activities and productivity of industrial units but can also have social, environmental, cultural, and economic impacts in the construction industry. All traditional approaches to the issue of choosing the location of industrial halls such as warehouses are less effective in the face of ambiguity in language assessments.

In order to overcome these challenges, the current study proposed a multivariate decision-making approach that integrated BIM and GIS data to select the optimum location of an industrial warehouse. The outlined model was tested and validated for location the construction of a slab storage warehouse in Iran. The essential criteria influencing the selection of optimum locations for warehouse construction in the casting unit of Esfahan’s Mobarakeh Steel Company (EMSC) in Iran, were identified based on BIM-GIS integrated model. The integration of BIM and GIS models resulted in various advantages in optimum location of human facilities, industrial activities, and environmental assessments. Also, it can be successfully used for the determination of suitable and unsuitable locations for each activity.

Then, the input of experts was used to determine the weights of the decision criteria through pairwise comparisons. Next, the possible alternatives for the construction of the warehouse were determined and ranked according to the experts, and an integrated ranking of alternatives was used to determine the most optimum location. The results indicated that among the essential criteria influencing the location of industrial warehouses, economic–social and crisis management criteria are the most important. Finally, the results of this study were used to select the best alternative for locating the warehouse, and the best model for locating of slab warehouse of the casting unit of EMSC was created. The results of the current study show that using 3D models can help urban planners in making better-informed decisions based on location data. Furthermore, the use of high quantity and quality of key criteria can generate better and more reliable decision-making results. The outcomes of the current study advocated that candidate location 1 had the highest priority for the construction of the slab warehouse of the casting unit of EMSC. The evidence shows that alternative 1 (the final selected option) is a better option than alternative 2 (the option selected with the initial criteria). In fact, despite the most significant cost reduction in the construction of the warehouse and most access roads to the railway advantages associated with alternative 2, this alternative has some disadvantages. These shortcomings were identified by integrating BIM-GIS data and include reduced road width, demolition of green space (cutting down trees at the construction site of the warehouse), creating problems in adjacent warehouses (such as removing entrance doors along with the warehouse), increased road arch correction due to reduced boulevard width, increased road traffic load beside the passage, the impossibility of developing the second opening of the warehouse, and not achieving the optimal length of the hall. In addition, these results reveal that despite criticisms aimed at this approach due to higher initial design time and costs, this method has reaped many advantages for an optimal location as well as locating for the establishment of human facilities, types of activities, and environmental assessments.

The need for integration and transfer of data between the BIM design process and GIS technology has become more apparent in order to combat the macroeconomic challenges of today and create more sustainable and flexible infrastructures. Using BIM-GIS integrated model in locating can help in planning and decision-making of industrial managers and reducing negative economic, environmental, and social effects of projects. The results obtained from this study can vary depending on the type and size of the project. Therefore, future studies can apply the same approach in other industries by using suitable evaluation criteria. It is also possible to investigate the application of the proposed approach for various types of projects with different sizes. The limitations of the current study include the limited statistical population and time constraints of the study which was mostly due to the special economic and political climate affecting this project. Considering that the statistical population of the research is limited to the time period of this research and the specific economic and political conditions of Iran. Also, because the study area in the present study is EMSC, the derived results cannot be generalized to other industries. To apply the results of this research to other industries, caution should be properly exercised. Therefore, it is suggested that this test be evaluated in other spatial areas for cross-comparisons.

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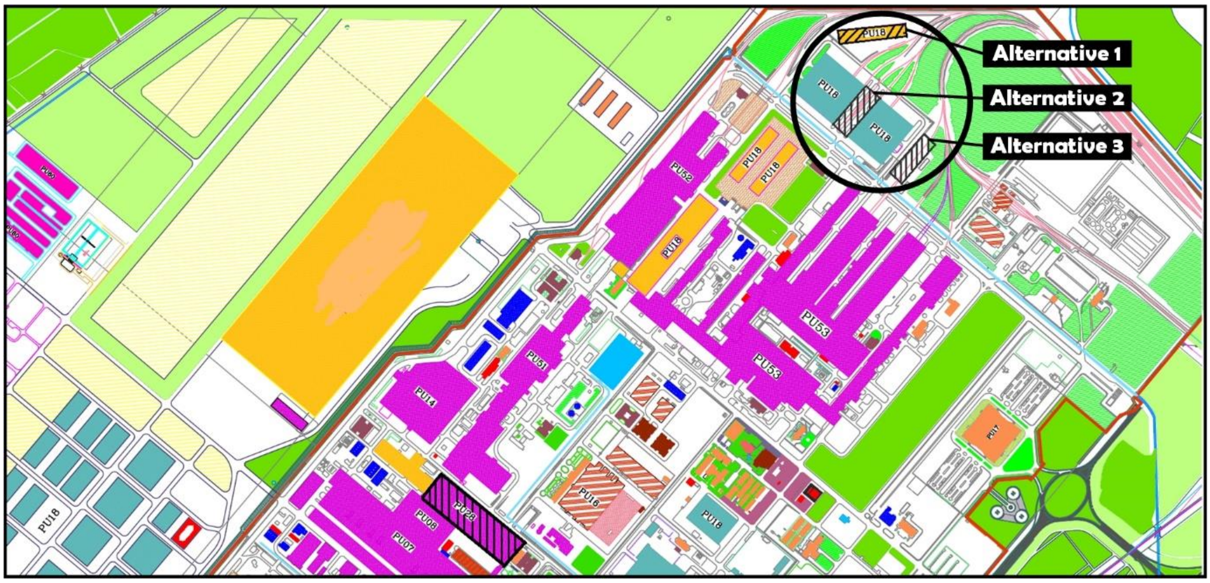


Figure 1. The Investigated Site Plan Casting Unit of Esfahan's Mobarakeh Steel Company (EMSC)

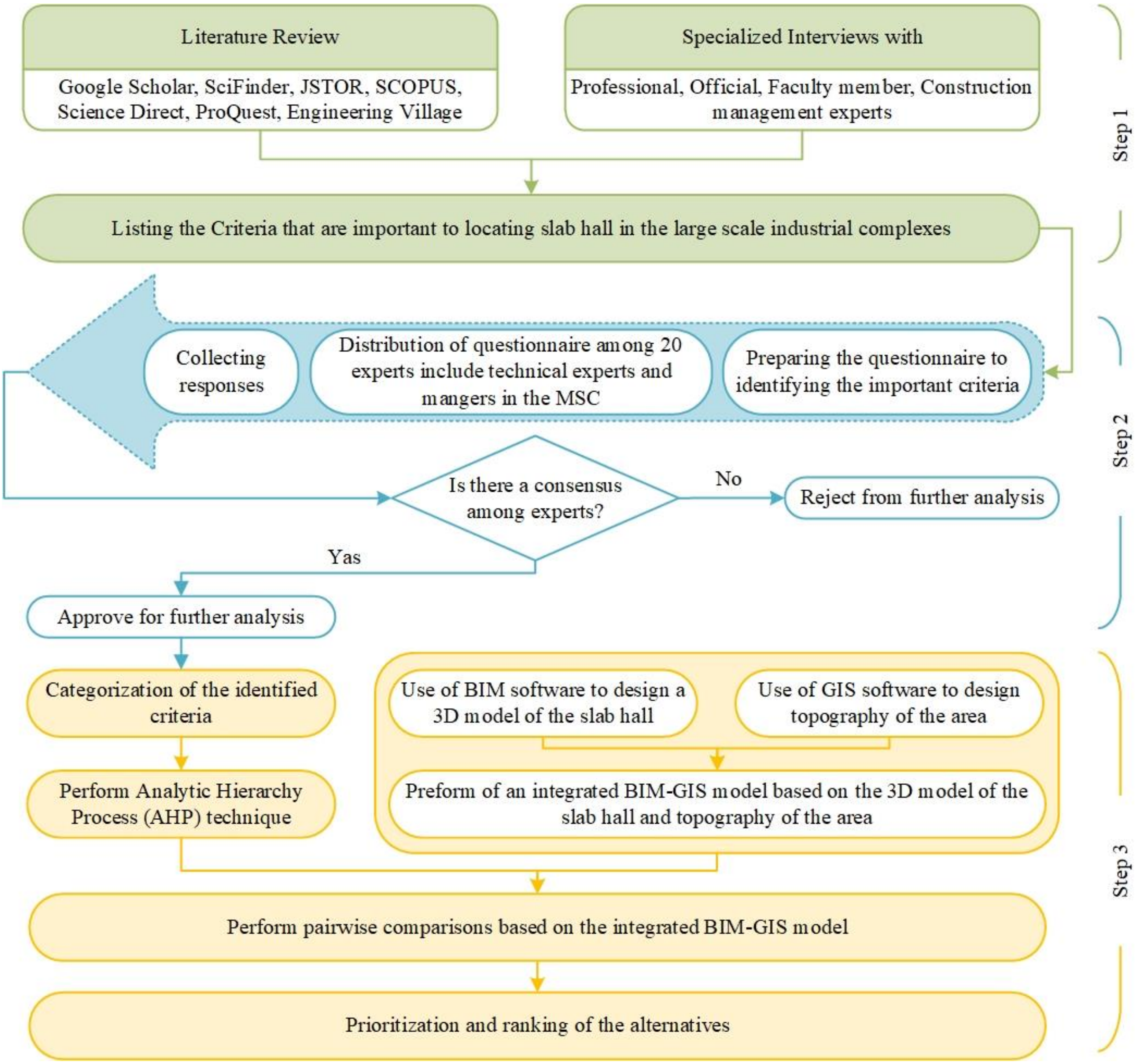


Figure 2. Overall Research Framework for the Study

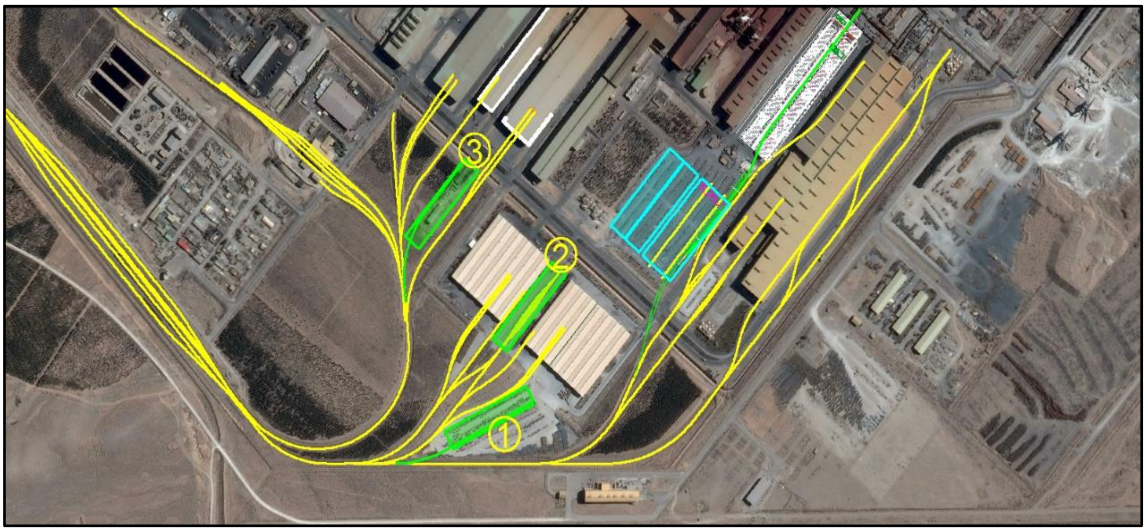


Figure 3. The Alternatives for Construction of Slab Warehouse

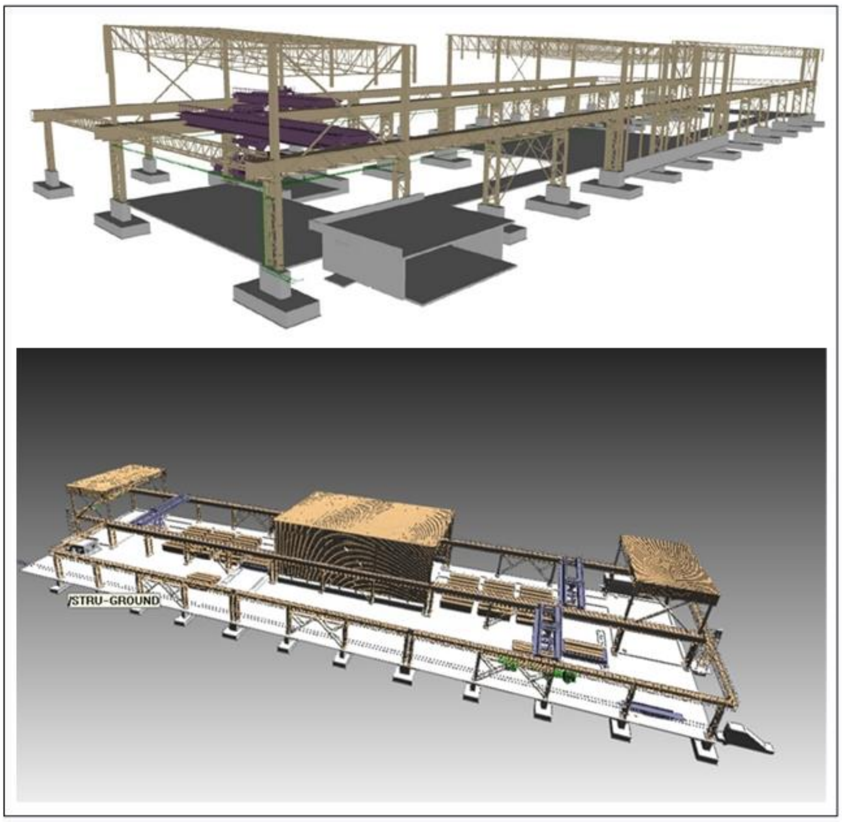
a) Locating the 3D model of the slab hall in the alternative place 1

b) Locating the 3D model of the slab hall in the alternative place 2

c) Locating the 3D model of the slab hall in the alternative place 3

Figure 4. Use of BIM and GIS Software to Design a Three-Dimensional Model of the Slab Warehouse and Topography of the Area

a) Three-dimensional model designed of slab hall using Revit software (BIM)



b) Designing the topography of the area and the ways to access the slab hall using CIVIL3D software (GIS)

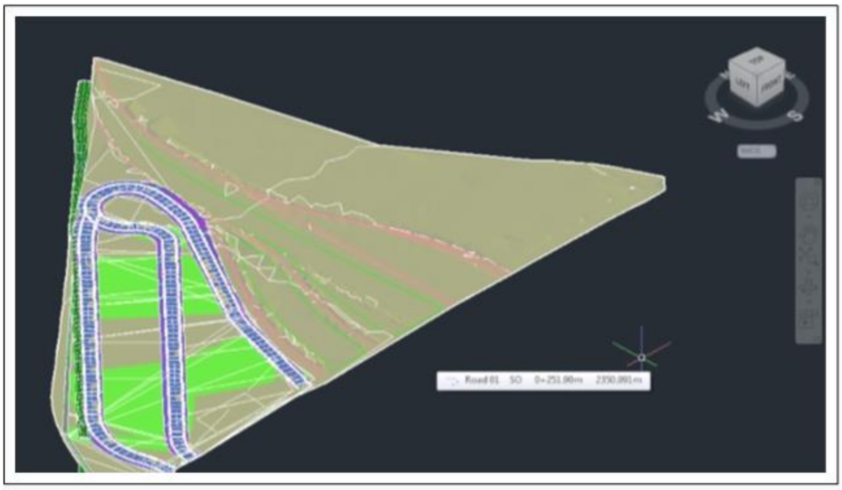


Figure 5. Locating the Drawn Model of the Slab Warehouse Using Revit Software in the Selected Place Alternatives Using Google Earth Photos (BIM-GIS)

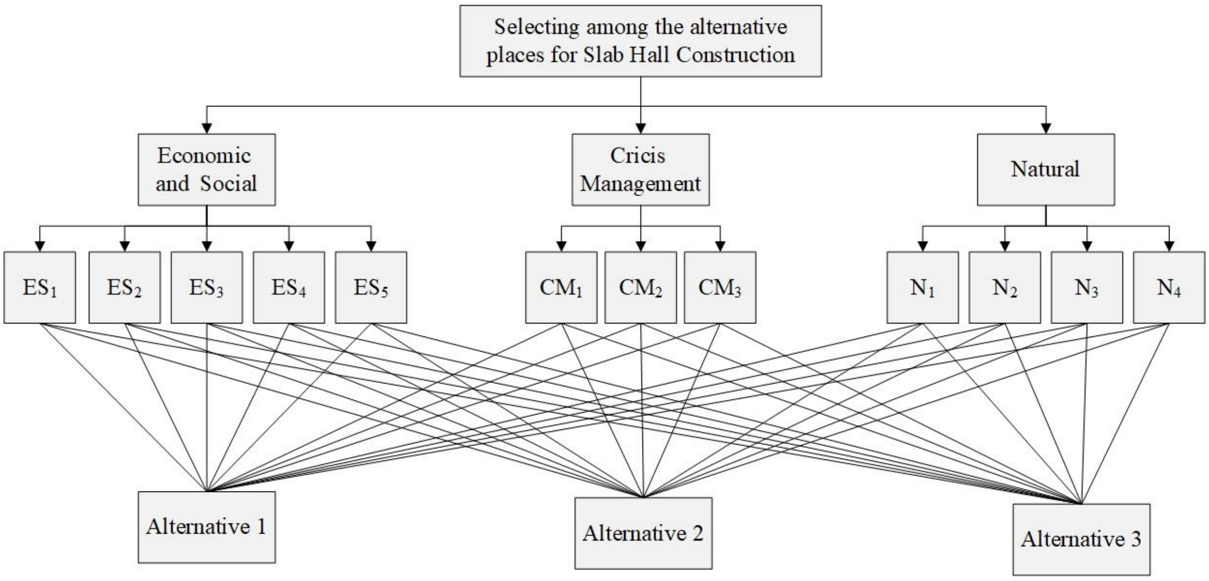


Figure 6: Hierarchical structures of the Analytic Hierarchy Process (AHP) model

Table 1. Important evaluation criteria for optimum locating of industrial storage warehouses based on available literature review

No.	Criteria	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	Frequenc
1	Natural criteria			*		*	*		*		*	5
2	Passive defense				*	*						2
3	Socio-econonomic facors				*	*	*	*	*		*	6
4	Construction site conditions such as soil, structure, etc.					*	*		*		*	4
5	Topography					*	*		*			3
6	Slope					*	*		*			3
7	Reduction of environmental risks					*			*			2
8	Terrorist attacks (stealth capabilities)				*	*						2
9	Placement in flood path					*			*			2
10	Placement in storm path					*			*			2
11	Access to transportation network					*				*	*	3
12	Reduction of construction and maintenance costs		*								*	2
13	Reduction of transportation costs	*	*	*							*	4
14	Reduction of project delays										*	1
15	Space required for future expansion										*	1

Notes:

[1] Tao, et al. (2012); [2] Revelle et al. (2008); [3] Asadi and Karami (2016); [4] Özcan et al. (2011); [5] Ghalandarian-Golkhatmi (2014); [6] Borna (2017); [7] Puente et al, (2007); [8] Freeman and Chen (2015); [9] Habibi et al. (2018); [10] Asgari Siahboumi (2017).

Table 2. Nine-degree spectrum for pairwise comparison of evaluation criteria and sub-criteria (Saaty, 2016)

Score (importance)	Definition	Description
1	Equal importance	Both criteria have equal importance in the study
3	Slightly more important	Results show that criterion i is slightly more important than criterion j
5	More important	Results show that criterion i is more important than criterion j
7	Significantly more important	Results show that criterion i is significantly more important than criterion j
9	Absolute priority	Results show that criterion i is absolutely prioritized over criterion j
2, 4, 6, 8	Middle values	When the weight is between two of the above

Table 3. Initial evaluation of alternatives based on implementation cost (in million US$)

Row	Section	Alternative 1	Alternative 2	Alternative 3
1	Excavation and demolition	0.2	0.2	0.3
2	Construction	10	10	10
3	Crane	8	8	8
4	Railway and switches	1	0	1
5	Electrical supply	2	2	2
6	Water supply	2	2	2
	Total	23.2	22.2	23.3

Table 4. Evaluation of initial alternatives based on locating parameters

	Parameter	Weight	Alternative 1	Alternative 2	Alternative 3
1	Construction cost	30	25	30	25
2	Railway access	20	15	20	15
3	Space limitations	10	10	5	5
4	Destruction of green space	10	10	5	5
5	Demolition of existing facilities	10	10	0	5
6	Easy access to production line	20	15	10	10
	Total	100	85	70	65

Table 5. Descriptive statistical data for identified evaluation criteria and sub-criteria

Evaluation criteria	No.	Sub-criteria	Code	Average
Natural Criteria	1	The conditions of construction location such as soil conditions,	N_1	4.17
	2	Topography	N_2	4.08
	3	Slope	N_3	4.16
	4	Reduction of environmental risks	N_4	3.83
Crisis Management Criteria	1	Terrorist attacks	CM_1	4.28
	2	Placement on flood path	CM_2	4.16
	3	Placement in storm path	CM_3	4.08
Economic-Social Criteria	1	Access to transportation and railway networks	ES_1	4.16
	2	Reduced construction and maintenance costs	ES_2	4.12
	3	Reduced transportation costs	ES_3	4.50
	4	Reduced project delays	ES_4	4.34
	5	Space for future expansions	ES_5	4.07

Table 6. Determination of the Final Priority of the Indicators with the AHP Technique

Criteria	Weight	Sub-criteria	Basic weight	Ranking within category	Overall rating
Natural Criteria	0.166	N_1	0.470	1	1
		N_2	0.238	2	5
		N_3	0.062	3	9
		N_4	0.021	4	11
Crisis Management Criteria	0.334	CM_1	0.280	1	4
		CM_2	0.123	2	7
		CM_3	0.020	3	12
Economic and Social Criteria	0.431	ES_1	0.178	3	6
		ES_2	0.109	4	8
		ES_3	0.034	5	10
		ES_4	0.329	2	3
		ES_5	0.407	1	2

Table 7. Partial weight of each alternative compared to each sub-criteria

Location	**Natural Criteria**				**Crisis Management Criteria**			**Economic and Social Criteria**				
	N_1	N_2	N_3	N_4	CM_1	CM_2	CM_3	ES_1	ES_2	ES_3	ES_4	ES_5
Alternative 1	0.283	0.211	0.101	0.134	0.201	0.11	0.001	0.056	0.03	0.02	0.073	0.004
Alternative 2	0.17	0.064	0.091	0.09	0.133	0.083	0.144	0.01	0.281	0.227	0.153	0.313
Alternative 3	0.002	0.14	0.016	0.138	0.02	0.03	0.199	0.112	0.045	0.01	0.00	0.1

Table 8. Final weights and priorities of each alternative for construction of slab storage warehouse

Location	Final weight	Priority
Alternative 1	0.216	1st
Alternative 2	0.198	2nd
Alternative 3	0.101	3rd