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3D visualization of interpolating geotechnical strata in a BIM environment and estimating the volume

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Abstract: As a result of the development occurring recently in the construction industry and infrastructure development, with respect to the importance of the geotechnical aspect in this field, the two-dimensional representation unable to develop the complete picture of the soil characteristics. Therefore, the necessity to create a three-dimensional representation of the soil layers can be considered as crucial element. The 3D model will provide the required clarity among soil information in the process of integrating designs between different disciplines. Moreover, it will be facilitating the work environment and anticipating potential risks which caused previously by lack of information. This research investigates the process of integrating the information obtained by spatial interpolation techniques using “GIS” environment in order to divide areas according to construction safety zoning by transferring the obtained information to a “BIM” environment (Civil3d) and representing soil layers. The area of study in this research is located in the Tanuma area in Basra Governorate, which consists of 19 boreholes extending to a depth of 45 meters, including 332 SPT and 360 soil descriptions. The research relied specifically on SPT values in order to divide the areas according to OSHA regulations.

Keywords: geotechnical modeling, GIS, BIM, 3D modeling, volume of soil

1. Introduction

Visualizing soil in three dimensions is one of the vital techniques at present in the construction industry and infrastructure development. This importance is resulted from its ability to provide accurate information which can speed up decision making process. The 3D representation of soil properties facilitating the process of sharing data between decision-makers which may come from various industries with different backgrounds. This process contributes to reduce errors and improve efficiencies. However, providing such model is currently challenging in term of selecting the right technologies and to identify the required information for accurate soil representation. Need two tools to achieve this development. The first one helps to represent soil data and correlate it to the geographical location; the second one supports three-dimensional visualization and enables the user to review the data and layers.

One of the current powerful tools is the Geographic Information System, a computer system with a graphical interface that enables the user to store, display, and analyze geographically referenced data. Geospatial data describes characteristics associated with that geographic location, such as plants, houses, or streets. This system is distinguished by its ability to store data, analyze it, and visualizing it at the same time. “GIS” has proven its efficiency in using spatial interpolation techniques which will support the process of unknown predictions Previously “GIS” was used to evaluate the geotechnical properties of soil in Sulaymaniyah Governorate using various spatial interpolation methods, the research illustrated that the “OK” method is the most efficient [1]. In the same contest, “GIS” in Brazil also used to manage, store, and prepare a database related to geotechnical soil properties that have been designed to meets the needs of the federal authorities [2] .In Surfers Paradise, a study was conducted to represent and develop soil

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subdivision maps, and spatial interpolation methods were used, especially the "IDW" method based on SPT, considered more common than Kriging due to its simplicity in application and provide direct result in such short period. The peat area was also identified, showing its thickness between 10 - 19.6 m [3] and dividing the areas according to soil hardness, moisture content, and shear strength to analyze the stability of the foundation [4]. Furthermore, the digital maps of the regional soils of Abu Dhabi, Dubai, and the Northern Emirates were unified to create a unified national soil map of the United Arab Emirates through the use of spatial interpolation techniques [5]. Study [6] showed that among all the deterministic methods, "IDW" is the most important and optimal interpolation method. It should be noted that the most accurate method varies according to the characteristics and depth of the study [7].

There is a huge opportunity to improve "GIS" management features by integrate it with Building Information Modelling "BIM" philosophy. Visualizing, store data, mapping existing assets provide huge benefits to data management, however, decision making process demand more planning and management features that "BIM" can support. "BIM" can be considered a representation platform and data process management. 3D model includes graphic shapes and properties related to all components, such as type, quantities, and all related information can be attached. In addition, managing, exchanging and sharing data between different disciplines with different backgrounds considered as one of vital feature that support decision making process. Integrating "BIM" and "GIS" can provide all information related to the asset in one place and optimizing all the design alternatives

The need has emerged to integrate these two essential platforms because of their significant impact in the field of industry and construction. However, the integration of these two platforms is still in the initial stages, but it is witnessing rapid development. The integration process between them is difficult due to the lack of tools that enable data management Between the two systems. Three different approaches were used to integrate these two platforms: the first was the integration of "BIM" into "GIS", the second was the integration of "GIS" into "BIM", and the third was the integration of "BIM" and "GIS" into a new platform.

One of the studies that dealt with the integration of these two platforms is their use to improve and manage bridges in geographic information systems on the web [8] . Geographic information systems were used with the Analytic Hierarchy Process (AHP) in order to evaluate the suitability of agricultural lands in Erbil Governorate [9] . Study [10] showed that Iraq needs more "BIM" technology, as the rate of non-use reached 75%, and that failure to use it leads to a waste of cost and time. HBIM was integrated with "GIS" in order to create a three-dimensional representation of the city [11] . It has been proven that the process of integration between these two technologies facilitates the process of three-dimensional representation of buildings and infrastructure [12] . Study [13] dealt with recycling excavated soil based on integrating building information modelling techniques and the Internet of Things (IoT) into geographic information systems. Where they integrated design information from the "BIM" platform to the "GIS" platform, relying only on the information in the soil report without using spatial interpolation operations and using REVIT as a "BIM" platform. The integration of these two platforms was also used to develop the vision of modern cities on an ongoing basis for asset management [14] . Among the studies that dealt with the process of integrating these two platforms in order to represent the ground structure in three dimensions and its impact on improving the construction process [15]and also in [16] took the Nola logistics factory in southern Italy as a study area. In addition to the advantages, 3D geotechnical structure representation reduces risks that may occur during work [17] due to providing a comprehensive view of the site.

The studies that were reviewed showed many applications that can be obtained as a result of the integration of geographic information systems with Building Information Modelling. This methodology is still at the initial stage in some cities. For the three-dimensional representation of soil layers, methods other than the integration of these two platforms were used. The first method was developed using the three-dimensional particle finite element method (PFEM) in order to simulate soil erosion processes and evaluate the failure of soil slopes, which means a representation of a specific problem and not the entire soil layers. This method is relatively challenging because it requires knowledge of finite element systems, which may represent a problem for some users [18] .Finally, study [19] dealt with the representation of fine granular soil layers in Sulaymaniyah Governorate using the Plaxis program.

As a result of previous studies, the following points were concluded: (1) Three-dimensional representations of soil may be done using engineering programs such as Plaxis and others. These programs could be less accurate as a result of relying only on soil report information without using spatial interpolation techniques that help to know the characteristics of unexamined sites. Or using the particle finite element method. That may constitute a problem for some users as a result of it requiring previous knowledge of the finite element method. (2) The limited use of "BIM" technologies in Iraq and the waste of the advantages of this technology. That leads to a waste of cost and time. (3) The use of "BIM" integration technologies with "GIS" in Iraq is limited to other applications more than the geotechnical aspect or the three-dimensional representation of soil layers. (4) The integration of these two platforms is applied In a few regions of the world and expanding to include more regions.

As a result of the reasons mentioned above, this research paper presents a proposal for a three-dimensional representation of soil layers in Basra Governorate. By using spatial interpolation techniques in order to predict unexamined sites. It presents a new approach for transferring spatial interpolation data from a geographical information system as an integration platform to building information modeling as a modelling platform through Shapefile containing contour lines that represent the change in soil properties. Providing technique allows users to deal with this study quickly. Seeking in the future to provide tools for transferring and managing data directly between the two platforms. The research paper contributes to the division of land areas according to what was presented in (OSHA) Occupational Health and Safety Organization. And calculating the volume of layers. Which makes their use an essential and decisive element in making geotechnical decisions.

Finally, the tool (IFC (industrial foundation classes) open viewer (Explained in Section 3.4)), is used to display data extracted from integration process, which represents the depths, thickness, and type of soil layers. Using this tool leads to improving and facilitating the decision-making process. as well as enhancing control during the construction phase and ensuring that the construction process proceeds in a manner consistent with reducing potential risks. The model is extracted in IFC (Industry Foundation Classes) format [20]and shared by specialists in different project areas to integrate them into a single platform. It facilitates the process of editing, taking notes, and measuring lengths, as these files can be viewed in (IFC Open Viewer)

2.GIS & BIM integration and scope of work

The integration process between geographic information systems and building information modeling is considered one of the most important developments occurring in the construction and geotechnical engineering industry. The integration process between them provides a useful relationship and a comprehensive understanding to make decisions in the early design stages. Geographic information systems are used to organize a geographical context while providing modeling. Building information modeling is a spatial visualization of the characteristics associated with the geographical location in question, which means that both tools play an effective role during the project's construction stage. However, integrating them is necessary to increase the benefits provided during the project life cycle. Geographic information systems allow the representation of many different data, such as raster data. Or vectors such as points, lines, and polygons. As for representing this data in three dimensions, it is done through building information modeling. This research paper aims to clarify the method of representing soil layer data in three dimensions according to the safety zones specified by OSHA [21] and calculating the volume of each layer.

3.Tanomah, Basra, Iraq ,19 borehole Example of integration the Geotechnical interpolating layers generate by GIS with civil3d:

The results of the standard penetration test were used to create soil classification maps due to the ease and abundance of empirical relationships with other important geotechnical parameters such as the modulus of elasticity, moisture content, and unconfined compressive strength. It is an on-site test performed during the process of drilling test wells. A thick-walled pipe is pushed with a hammer weighing 63.5 kg from a height of 76 cm. The pipe penetrates the soil, and the number of blows required to penetrate three consecutive distances is calculated, each distance being 150 mm. The number of blows for the first distance is neglected and the sum of the number of blows for the second and third distances is relied upon to be SPT-N value for that location.

Table 1 Statistical summary of Standard penetration test result.

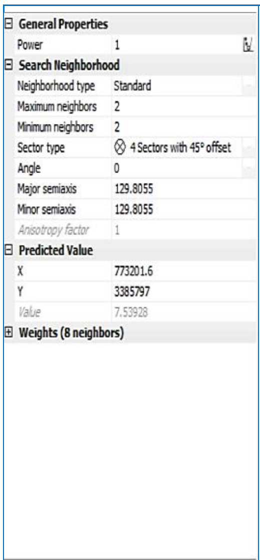
Depth:	D0.5	D9.5	D12	D17	D27
Count:	19	19	19	19	19
Minimum:	3	4	4	5	13
Maximum:	13	16	31	30	62
Sum:	142	180	273	351	694
Mean:	7.473684	9.47368	14.3684	18.4737	36.5263
St. Deviation:	2.414178	3.45449	6.9222	7.42945	12.963

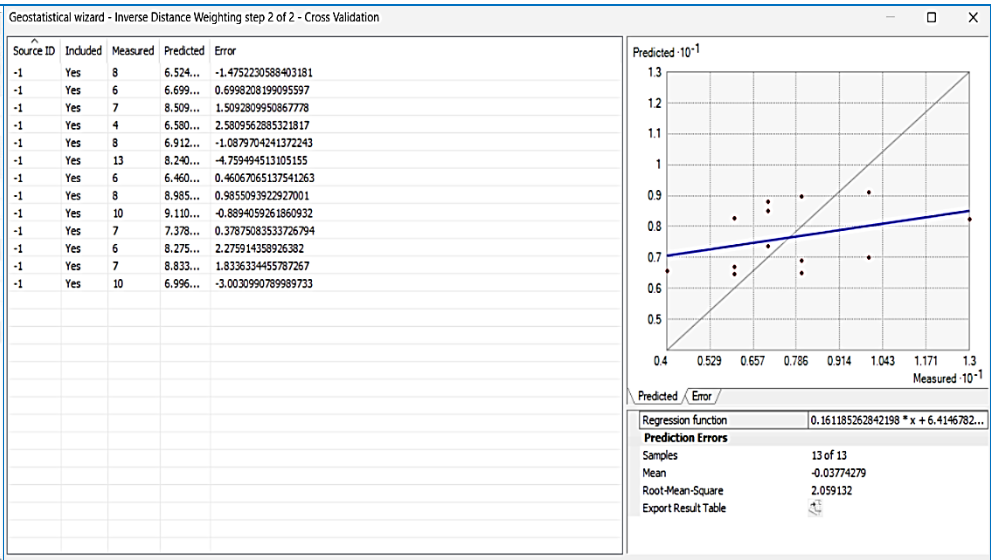
Table 2 Standard penetration test result for different depth and classification of soil according OSHA.

BH	X	Y	D0.5	Soil Type	D9.5	Soil Type	D12	Soil Type	D27	Soil Type
bh1	773205.56	3385996.04	10	Type A	15	Type A	18	Type A	40	Type A
bh2	773272.48	3385974.45	13	Type A	11	Type A	31	Type A	56	Type A
bh3	773197.58	3385930.48	10	Type A	8	Type B	16	Type A	31	Type A
bh4	773263.21	3385904.96	8	Type B	10	Type A	16	Type A	33	Type A
bh5	773255.90	3385835.43	5	Type B	8	Type B	11	Type A	27	Type A
bh6	773330.99	3385884.45	7	Type B	8	Type B	10	Type A	32	Type A
bh7	773322.12	3385812.73	6	Type B	10	Type A	22	Type A	54	Type A
bh8	773314.07	3385742.05	7	Type B	9	Type B	10	Type A	25	Type A
bh9	773390.96	3385792.14	10	Type A	14	Type A	13	Type A	43	Type A
bh10	773382.45	3385723.20	11	Type A	15	Type A	15	Type A	43	Type A
bh11	773013.90	3385871.54	7	Type B	10	Type A	22	Type A	62	Type A
bh12	773012.16	3385805.25	8	Type B	16	Type A	20	Type A	31	Type A
bh13	773081.46	3385850.91	7	Type B	9	Type B	11	Type A	35	Type A
bh14	773075.71	3385784.76	6	Type B	10	Type A	21	Type A	50	Type A
bh15	773067.41	3385714.66	6	Type B	8	Type B	17	Type A	46	Type A
bh16	773141.20	3385762.18	8	Type B	5	Type B	5	Type B	27	Type A
bh17	773128.65	3385692.93	3	Type C	5	Type B	6	Type B	14	Type A
bh18	773124.48	3385619.35	4	Type B	4	Type B	5	Type B	13	Type A
bh19	773200.30	3385666.84	6	Type B	5	Type B	4	Type B	32	Type A

3.1 classification map generate by GIS

After collecting the results of laboratory and on-site tests via SPT from a total of 19 wells, test wells include a description of the soil as well as its classification based on penetration resistance or unconfined compressive strength. Soil is classified and divided according to standards and principles provided by the Occupational Safety and Health Administration. The process of verifying the spatial interpolation method begins through the following steps: 1) Inserting the data into geographical information systems by dividing the data into two groups; the first group performs the interpolation process. In return, the remaining group used to validation process of this method. (2) Implementing the spatial interpolation process by controlling a number of parameters, including (power-neighborhood type-neighborhood max- neighborhood min- sector type) and through it, the smallest RMSE and its parameters are adopted. Process shown in Figure (1) and Figure (2). After finding the appropriate parameters that give the least RMSE, they are used to create the classification maps, but this time, all test wells are used to generate these maps, Figure (3). Studies have proven the accuracy of the "IDW" method compared to other interpolation methods, as well as its ease. A historical overview and some examples are given in the introduction section of this paper, in which the above method was used to perform interpolation. This research is a continuation of the two-dimensional interpolation process to display it in a building information modeling environment and obtain a three-dimensional representation, and this is what will be focused on in this proposal.





(a) parameters of spatial interpolation	(b) Cross-validation of selection of interpolation parameters

Fig. 1 process of validation to verifying the spatial interpolation.

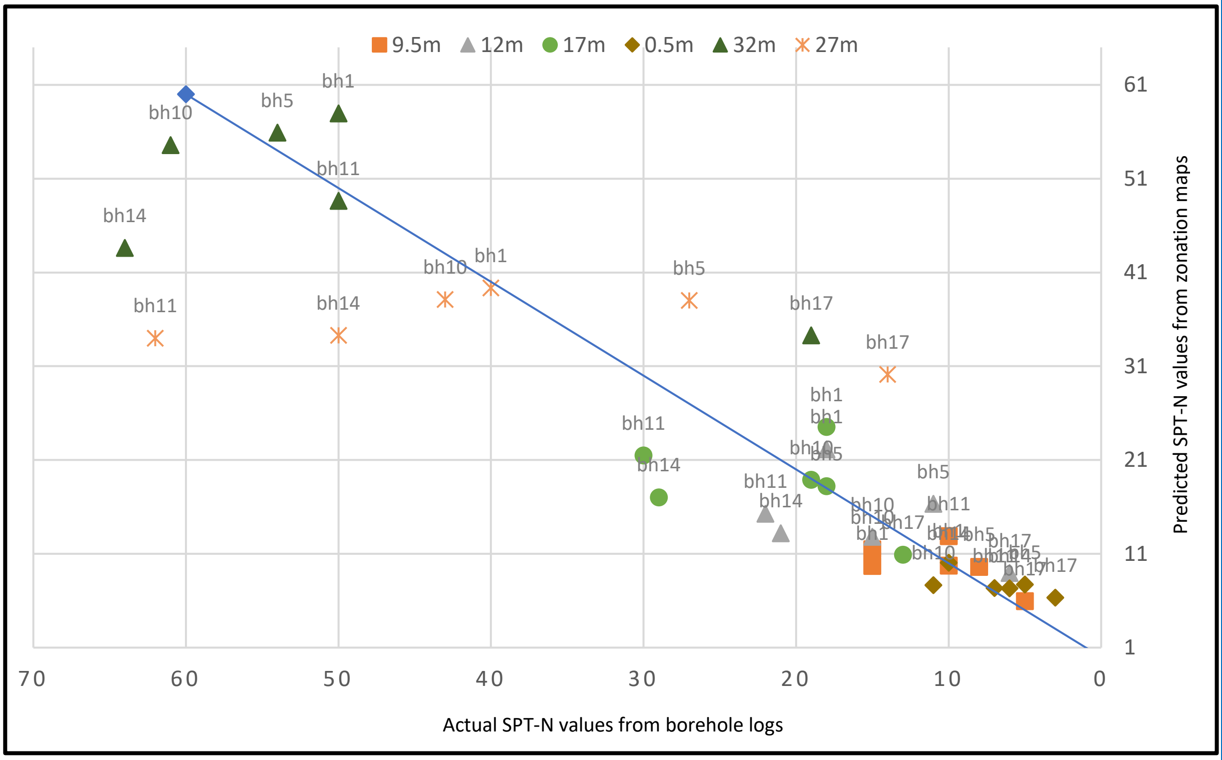


Fig. 2 Comparison of predicted and actual SPT-N values.

Table 3 regression coefficient and Comparison of predicted and actual soil types according to OSHA.

BH.No	BH01	BH05	BH10	BH11	BH14	BH17
R^2	0.9402	0.9943	0.7721	0.9803	0.7856	0.9569
Unmatched type	1	0	1	1	0	1

*R^2: refers to the ratio of variation between the actual values and the obtained values; Unmatched type: Indicates the number of depths at which the actual soil type differs from the predicted one.

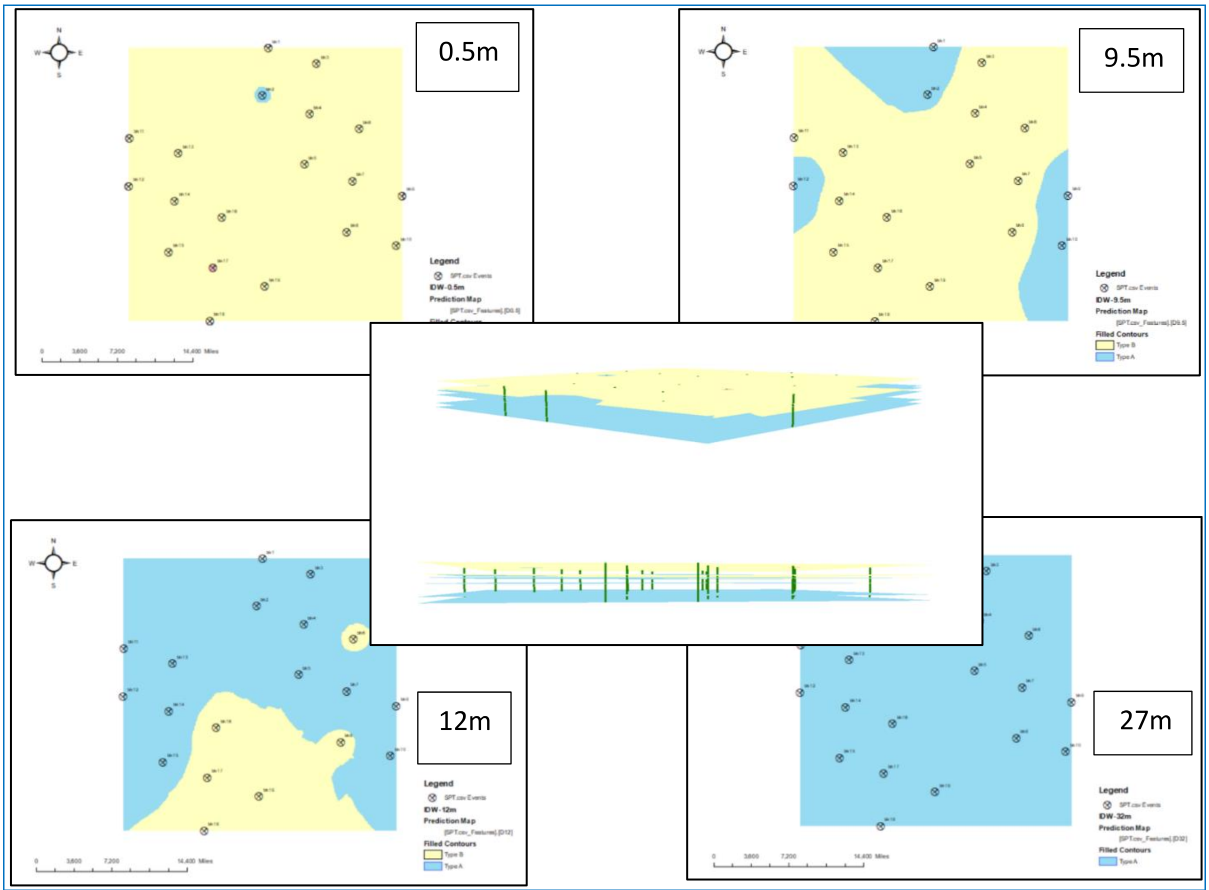


Fig. 3 soil zonation maps at different depth.

3.2 transforming data from GIS to Civil3d

Data is transferred from geographic information systems to the Civil3D work environment by extracting the data in a compatible format, such as IFC or DWG. The DWG (AutoCAD) format was a common format between the two tools, through which data represented by terrain, layer thickness, and infrastructure are transferred. After extracting the data, the next step is to drop it into its correct location by ensuring that the coordinate systems between the two tools match to avoid spatial differences. It is then displayed in a grid image, as shown in Figure (4) at step (5), which represents the topography of layers, ready to be represented in three dimensions with test pits.

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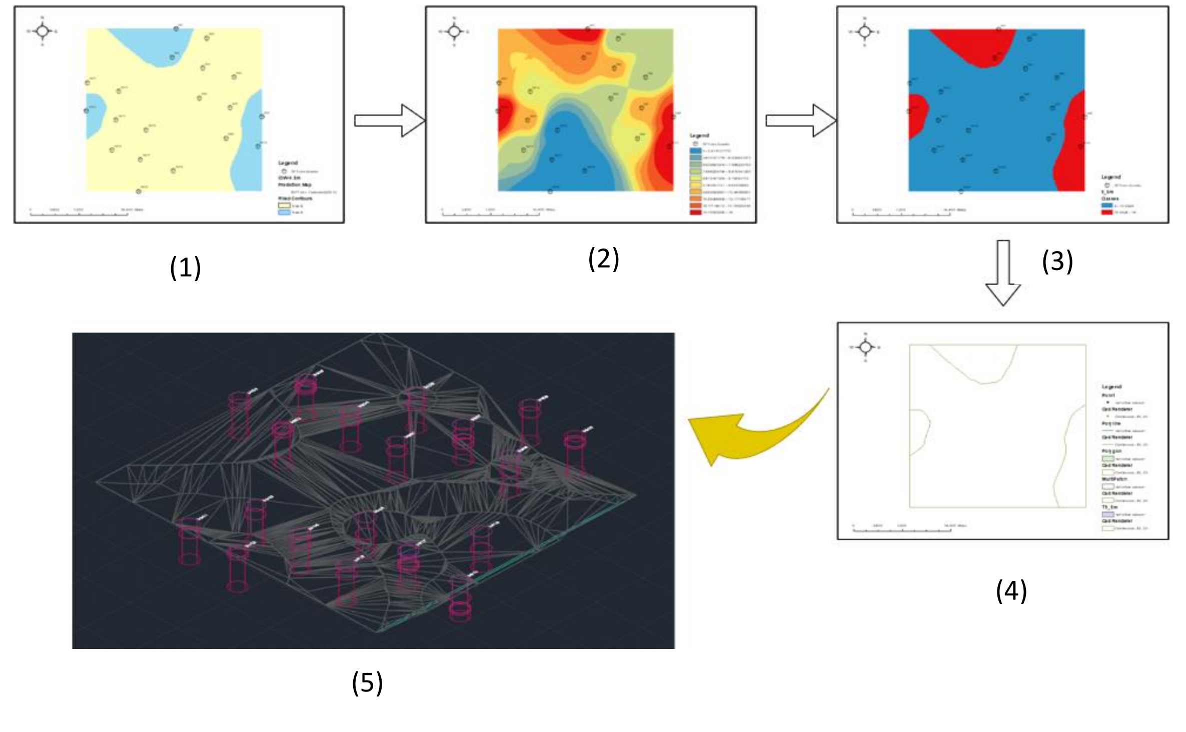

Fig. 4 Process of transforming data from GIS(ArcMap) to Civil3d.

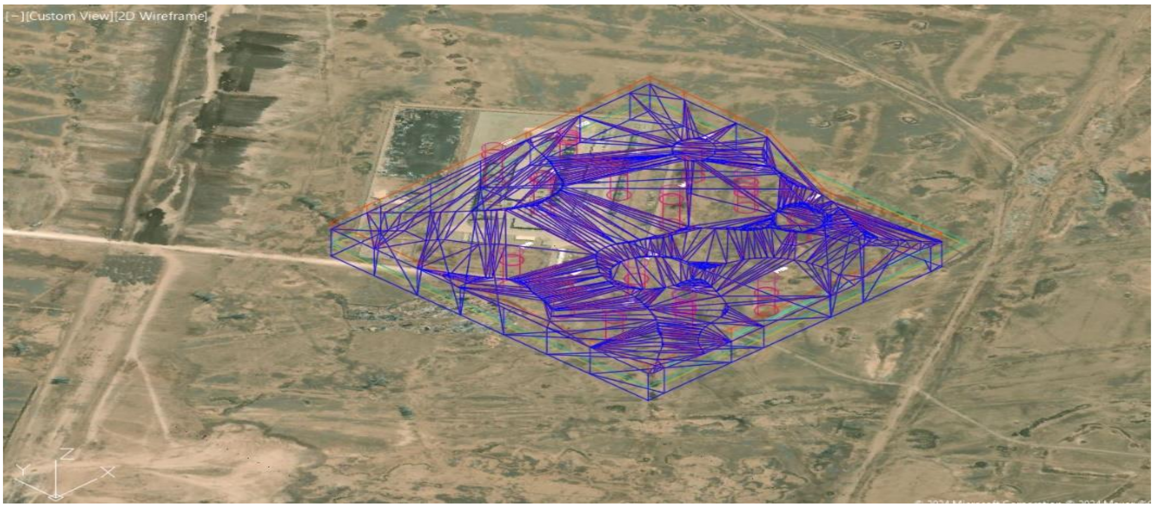

Fig. 5 The grid image of the topographic layers of study area.

3.3 3Dvisualization of data in Civil3D and estimating volume

the nature of the data is determined and defined within the Civil3D work environment, such as connecting the set of lines (contour line) that represent the terrain to form a surface that is easy to deal with.

Finally, the surfaces are merged. complete the final representation of the three-dimensional model and estimate the volume of each layer, which facilitates the process of comprehensive understanding of the soil layers and decision-making Figure (6).

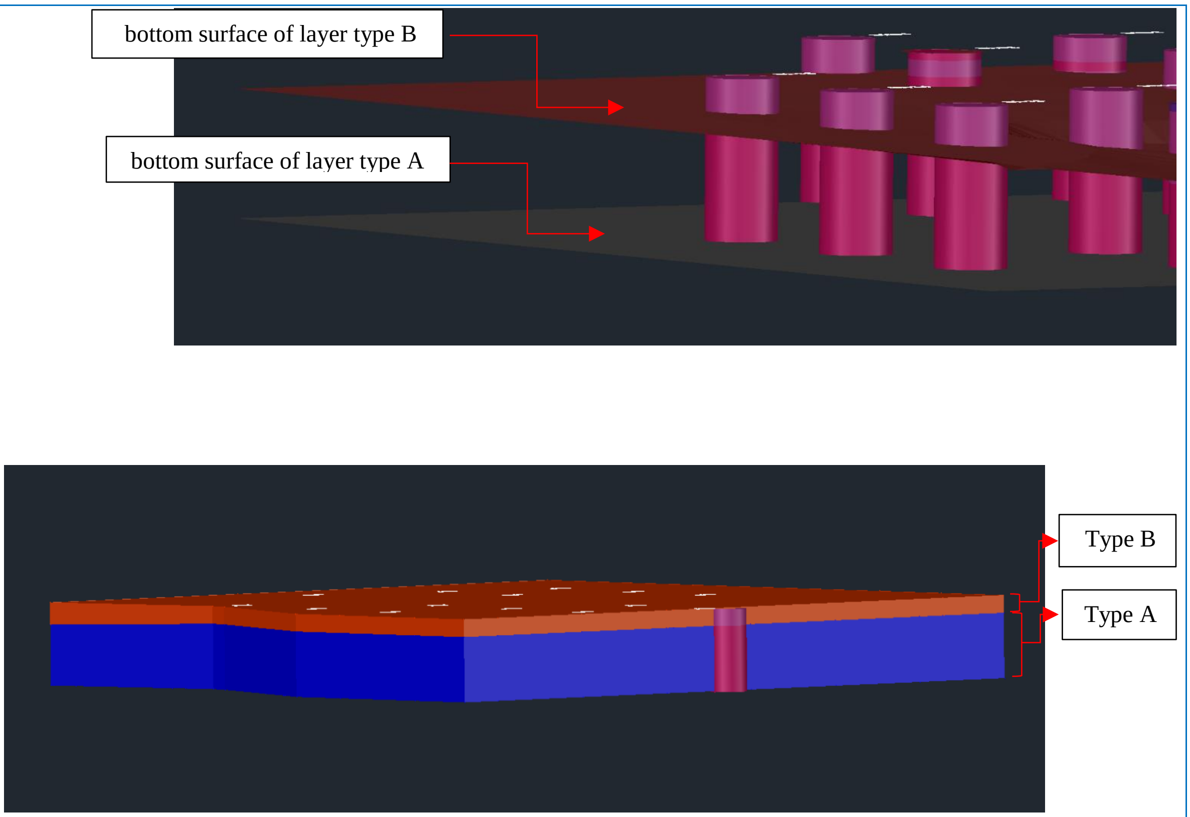

Fig. 6 3D visualization of soil layers and borehole.

Table 4 Layers volume.

Name of layer	Area of layer 2D	Volume
Layer type B	135486.17 m^2	1623448.33 m^3
Layer type A	135486.17 m^2	4405686.39 m^3
Total		6029134.72 m^3

3.4 display 3D model in IFC open viewer

It is considered one of the software tools used to create a common environment for the construction industry to share models in a way that facilitates communication between them and allows adding properties to the model, measuring lengths, modifying them, and deleting them.

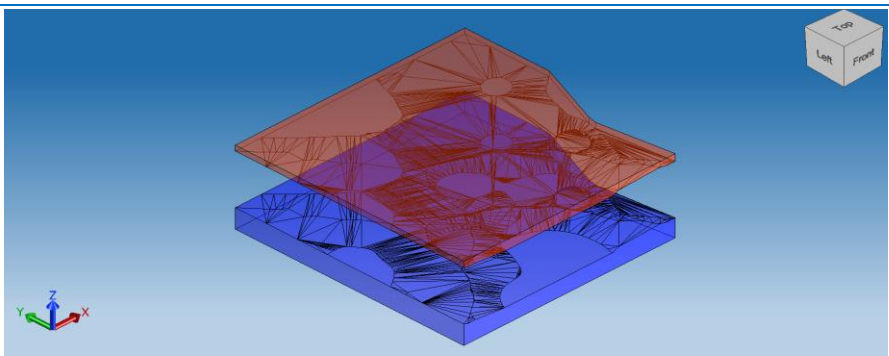

Fig. 7 model in x-ray as a separated layer

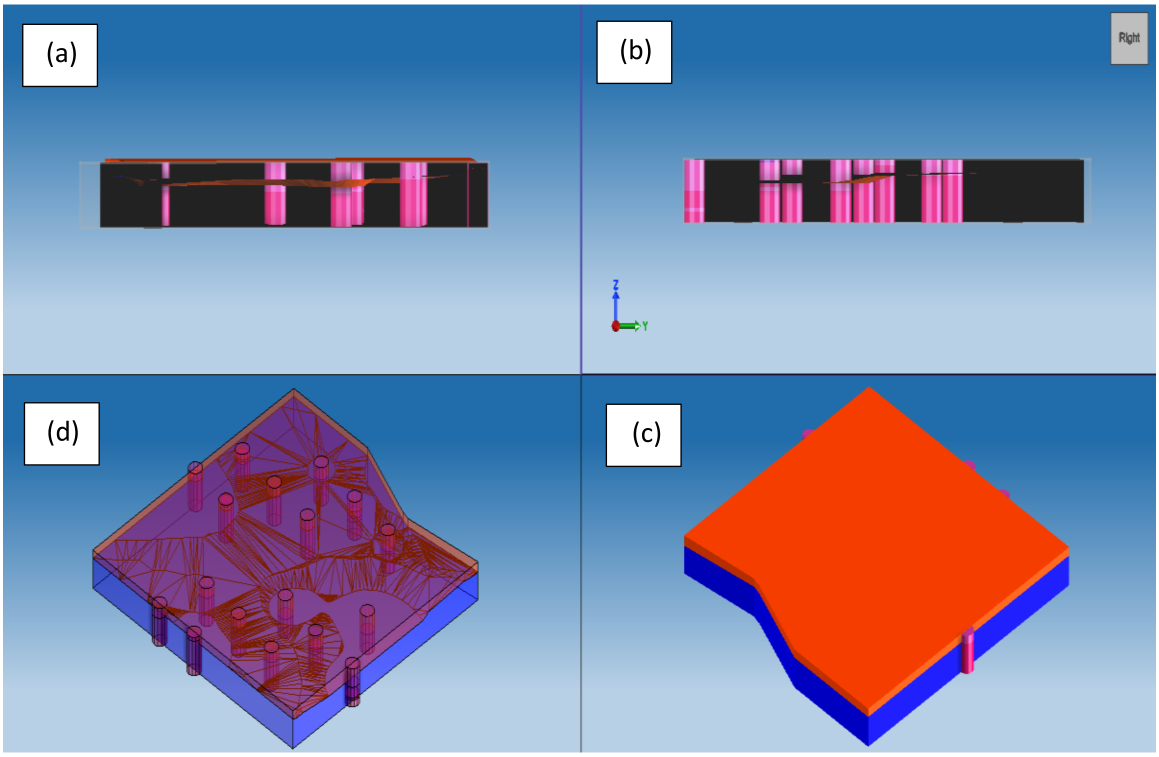

Fig. 8 (a)cross section of model in y-direction (b) cross section of model in x-direction, (c)model as 3d block (d) model in x-ray.

4. Conclusions

The goal of this research paper is to integrate spatial interpolation information obtained from geographic information systems with building information modeling, which was created on soil plot information, specifically SPT. This process allows dividing areas and layers of the subsoil into basic types in a way that will enable the user to know the nature of the soil that is dealing with. Furthermore, identifying the risks that can be faced. Therefore, the necessary measures are taken, and a database that includes data for the region and the governorate is provided. The results of this study were as follows:

- Soils at depths of more than 9.5 meters are represented by type A soil, which constitutes approximately 73% of the study area's volume. This type of soil is very suitable for engineering structures.
- Soils at lower depths were found to be type B soils, which constitute approximately 27% of the study area's volume, and their average SPT was 13.

It is planned that the project mentioned in this research paper will expand to include larger areas in the designated governorate to enhance the validity of the method and the data available in the municipality, For more informed urban planning.

5.Limitation

1- It requires trial and error to find the parameter values that give the least amount of error, and this requires time and effort.

2- We need to manually transfer the contour line layers to collect them on one platform.

3- outlier values in one layer are not predicted in the interpolation process because the prediction depends on the majority of values that represent the surface.

6.Future work

Developing an automatic technique to perform the parameter change process with the greatest possible probability of finding the least possible error. Providing a tool to transfer data between the two platforms directly without changing the shape file format. Isolating layers with a small range of variation reduces the presence of abnormal values in a single layer and performs the interpolation process more accurately. Performing the interpolation process in the form of cross-sections within the soil instead of surface sections, thus directly predicting the different depths of the layers. Representing groundwater flow within the three-dimensional representation of the soil.

Symbols

GIS: geographic information system

BIM: building information modeling

OSHA: Occupational Health and Safety Organization

IFC: industrial foundation classes

OK: Ordinary kriging

SPT: Spatial interpolation test

HBIM: Heritage building information modeling

RMSE: Root mean square error

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