POLITECNICO DI TORINO

Master of Science program in civil engineering

Master’s degree Thesis

Integration of Geotechnical and Building Information Modeling for soil strata data in Civil 3D

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A mio padre

Abstract

One of the most critical and current activities in the world is construction. Infrastructure is an excellent way to meet social and economic needs. In many countries, the quality of life is connected to the infrastructure available. For this reason, construction has been a principal activity worldwide. Having this in mind, a primary step for any project should be the soil exploration of the site. Pertinent geological and geotechnical data is key to any construction project because it directly impacts the cost, time, construction hazards, and project design.

Today, in the digital age, new technology solutions are being applied to different sectors. The Architecture, Engineering and Construction industry is still catching up with implementing a new methodology known as Building Information Modeling (BIM). The concept is to support the project development by creating a virtual model as a resource for the project information that eases data analysis, saves costs, speeds up processes and avoids risks. At first, this technology was focused mainly on the tridimensional representation of superstructures. But recent research trends are exploring the benefits of extending the BIM methodology to the subsoil and substructure constructions, known as geotechnical BIM or Geo-BIM. The geological and geotechnical data are the ones that provide information about the existing soil surfaces while building information modeling (BIM) gives information about the asset in great detail. The process for the Geo-BIM implementation can be divided into three main stages, namely data collection, data interpretation and data visualization. This study investigates how to integrate geotechnical soil data into the BIM methodology. For the creation of the 3D soil surfaces, the use of commercial software AutoCAD Civil 3D and its extension, the Geotechnical Module, was chosen. The study was directed to the geotechnical soil data of the Parco della Salute, della Ricerca e dell´Innovazione, in Turin.

The results showed that the 3D surface soil modeling required huge modeling and computational efforts, mainly when dealing with highly detailed soil profiles. Thus, a good strata generalization was needed to generate a visually understandable soil model. Data collection and management were identified as one of the main challenges of

promoting geotechnical BIM. It is critical to managing the input data as the engineer or geologist knowledge to discretize and build correct information to create the model. Despite the challenges, the successful implementation of the geotechnical building information in the present case study proved capable of promoting soil data interoperability, which is an essential element in sustainable construction.

Acknowledgments

Before proceeding with this thesis argument, I would like to thank all the people who have been close to me in this professional growth stage.

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Thank you all; I would never have made it without you.

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1 Introduction

1.1 Background

Urbanization, considered as population growth towards cities or suburbs, has continuously increased over the last century. Most of the population lives in urban areas, and the number of people is still growing. In some countries, incentives are given to keep the rural population and prevail over the disappearance of some towns but without good results. The population increase, especially in urban areas, has become a problem worldwide. These circumstances drive attention toward intense construction activities to meet social and economic needs.

Exploration and excavation are critical steps in infrastructure development. All projects are executed in the territory. Exploration is intended to investigate the geotechnical properties, an essential element in construction because this depends on many factors such as project design, cost, and time development. With the knowledge of the different soil surfaces, essential decisions can be made before and during the excavation process, such as what to do with the soil (environmental impact) or how to proceed with the activities (safety reasons). This can be useful for preventing accidents that affect project costs and people. Therefore, geotechnical information is a crucial element in construction projects worldwide (Khan, Park, & Seo, 2021).

A site investigation is conducted to find the geotechnical parameters of the soil and to understand the spatial distribution of the soil layers at the construction site. Usually, the method used for investigation is to make boreholes, but different penetration types can be used depending on the geotechnical information wanted. A common site investigation to find the geotechnical properties of the soil layers is the standard penetration test SPT, in which a thick wall sample tube is driven into the ground with the help of a drop hammer of 63.5 kg mass through a height of 760 mm that penetrates the sample tube and the soil resistance to the penetration is measured. The number of blows needed to drive the sample tube for the second and third 150 mm penetration in the soil out of three consecutive 150 mm penetration is called the SPT. The advantage of using the SPT information is its empirical correlation, which can be used to calculate other geotechnical parameters of the soil, such as the angle of internal friction, relative density, shear modulus, Poisson´s ratio, and shear strength (Khan, Park, & Seo, 2021).

For the geotechnical investigation of a construction site, a minimum quantity of boreholes is usually recommended, depending on some factors, such as the area of the site and the type of construction. All these boring points have something in common: they only provide one-dimensional profile information that leaves us with spatial uncertainty, making it challenging to obtain the geotechnical characteristic at uninvestigated regions. Here is where the use of the BIM methodology can be fundamental. Proper integration of modeling and well-managing information is key for understanding geotechnical properties and types of soil surfaces on the site. For a project manager will be easier to plan and adopt the correct techniques, according to the requirements, with complete information and precise representation of the soil surfaces, for example, with the use of 3D soil surfaces models. Investigating the geotechnical properties is a prerequisite to assessing the site´s suitability for construction and a cost-effective design.

Another factor to consider is the number of minimum points to define the surface; if there is more information, the modeling is closer to reality. Many software products offer the creation of digital models: the input data's precision and quantity impact the modeling's accuracy and quality.

Studies and implementations of geotechnical BIM in countries such as Italy are still limited. The present thesis's principal objective corresponds to presenting a real case study of a construction project of the Piedmont Region in collaboration with the Politecnico di Torino, known as Parco della Salute, della Ricerca e dell´Innovazione (PSRI).

1.2 Geotechnical data (Geo) and Building Information Modeling (BIM)

The BIM (Building Information Modelling) methodologies may be one of the most significant advances, if not the most important, in the Architecture, Engineering & Construction (AEC) industries. Concisely, it consists in developing an accurate virtual model of infrastructure, say model does not only contain a precise geometric representation of the structure but a complete body of relevant data such as building information, specifications, minor details and elements, economy and costs, and even maintenance and costs programs, all needed to support the construction and subsequent helpful life of the modeled building. One of the most innovative and favorable characteristics of BIM concerning traditional AEC construction and programming practices is the way information is managed; BIM offers the possibility to have a central global digital representation or model where each set of specific design specialists can work on their particular tasks simultaneously with the others, allowing a better relationship and information flow, avoiding a considerable amount of extra and useless information, and optimizing a lot of shared processes.

In this case, the focus, which is still new in this sector, is geotechnical modeling, called Geo-BIM (where Geo refers to geographic and geotechnical). Typically, GIS has dominated all the information and activities related to the territory. It allows the management of the regions in which all built assets are. In this case, the geographic data and the geotechnical model were used Civil 3D. This software was implemented in recent years with a unique tool for geotechnical modeling called Geotechnical Module. The combination of these settings (BIM and Geotechnical) can be seen as where both processes meet and collaborate (Marrugat, 2022).

1.3 Geo-BIM integration

As mentioned before, geotechnical modeling and BIM integration can be seen as recent. The BIM model contains detailed information about the object geometry and semantics, in this case, the soil surfaces; however, it lacks the surrounding information. Spatial data is needed in the BIM model, such as the geographic or topographic information that can be provided, for example, by GIS technology, or in the case of the geotechnical Module, can be included as boreholes information in .CSV format.

BIM simulates the physical model in a virtual environment called the building information model, which contains geometric and non-geometric information. The BIM model includes not-graphical information in the graphical one, such as material information, properties of the soil, and quantities of the soil surfaces. With the integration of the information and the geometry, the engineering analysis can be done more clearly and easily. Help to make the best decision at the different stages of the project. Usually, the Industry Foundation Class (IFC) is used for exchanging graphical and 3D semantic information in BIM, which is considered an open standard format. In this case, the integration was already done with the inclusion in the software civil 3D of the geotechnical Module that facilitates the generation of 3D surfaces with the data provided by boreholes.

1.4 Geotechnical Module limitations

The Geotechnical Module extension present in Civil 3D is a new tool, still in development, and for this reason, there are some critical limitations. The principal one is that it is only a good starting point to create and visualize 3D soil surfaces; it can´t be seen as a replacement for geotechnical experience and knowledge. Additional data sources such as geology maps, web mapping services, and aerial photography are also needed for interpretation and model geology.

Another significant limitation of integrating BIM and geotechnical modeling with the use of the Geotechnical Module is that it does not support additional downhole data such as groundwater, in-situ, and laboratory test results and contaminants. It only works purely on boreholes locations and materials.

It has no data management functionality; if the data changes are not possible to quickly updated and see those changes inside the Geotechnical module.

The surfaces may have to be manipulated, mainly for the presence of lens and faults, and it only works on the local machine with a local database are some other limitations;

this means that it is not possible to different people to work at the same time in the project (Autodesk Inc., 2020).

2 Objectives

The main objective is to implement BIM to the geotechnical soil data for the construction project known as Parco della Salute, della Ricerca e dell´Innovazione in Turin, with the help of an extension of the commercial software Civil 3D known as Geotechnical Module. This construction project is in the excavation phase, so eventually, the idea is to integrate the information from the building site into the virtual model.

The process to achieve the Geo-BIM integration in the construction project can be divided into three phases: the collection of the data, the interpretation and management of the data and the visualization and management of the Geotechnical Module. The first and second part is critical because the 3D model depends on the correct asses of the input information. The activities for this part are summarized as follows:

- Collect all the stratigraphy information available
- Organized the stratigraphy information according to the requirements of the Geotechnical Module
- Soil generalization of the stratigraphy information to have a proper understanding of the 3D soil surfaces
- See the importance of the input data for creating the 3D soil surfaces

The activities for the last part are:

- Show the 3D models with the different soil generalizations
- Show how reliable is the Geotechnical Module to integrate the BIM methodology

3 State of the art

3.1 General principles of BIM

Nowadays, the BIM methodology is applied in different areas of engineering. One of these areas is Geotechnical Engineering, in which using the general principles of this methodology engages the risk and uncertainty linked to site investigation and the cost that this implies. The general principles of BIM are conformed by a crust containing the 'Process, Collaboration and the Whole Life' and the 'Digital data (3D)' core. The Process is the step in which are set and decided the methods and operations follow using a workflow organization to create, manage, and optimally share the information to guarantee interoperability, reducing as possible the loss of details of a project.

Collaboration refers to data sharing and management of the information of one project enabling team members to analyze data from different disciplines simultaneously to have a global perspective of the project to make the decisions taken easier and more correct.

The whole life is useful thanks to the digitalization of information and the collaboration in a common data environment where a project is optimized. The digitalization allows to maintain the data "assembled the life of the project so that it can be reused and improved" (Merdan, 2018).

Finally, digital data (3D) is the main principle and the way to meet the purpose of BIM methodology accomplished with the methods and formats presets on the phase of organization of data and workflow of the project.

3.2 AutoCAD Civil 3D software and Geotechnical Module extension

AutoCAD Civil 3D is a software practically designed to help in the civil engineering world. Thanks to the dynamic 3D design model, the software offers powerful features for executing infrastructure engineering projects. It also provides BIM tools that help reduce the time required for civil design, analysis, and implementation of changes (Autodesk Inc., 2020).

One of the possibilities that offer Civil 3D is geotechnical modeling. For this, an extension was created, the Geotechnical Module. The geotechnical extension was designed to work with boreholes location and geotechnical soil data, and some of the functionalities included are summarized below:

- Project management and importing geotechnical data in both CSV and AGS formats
- Creating and managing boreholes in both plan and model space
- Creating and managing soil surfaces
- Production of geotechnical Profiles Views with borehole logs strips
- Geotechnical hatch and style management.

Some concepts have to be explained to understand how civil 3D surfaces work. The first one is that the point is a crucial component of AutoCAD Civil 3D, in fact surfaces are created by interpolating all points of the same soil. The points can be used in different projects and for any activity. These points in civil 3D are known as Coordinate Geometry (COGO) points. Each COGO point, in addition to the x, y, and z coordinate information has properties that can support extra details such as ordinate, abscise, elevation, and description. Another characteristic of the point element is the unique number and name assigned to each. Borehole points are considered COGO points and are stored in the COGO point database containing information. As a BIM tool, the COGO points allow more than one person to access the data during the execution of a project, and these kinds of points are to be used outside the project and not only in one draw (Autodesk Inc., 2020).

3.3 Geotechnical Spatial Interpolation used in Civil 3D

Interpolation is the process of estimating unknown data using available data. Many techniques can be used in many different fields of study. One of the simplest methods is linear interpolation, which only requires the knowledge of two points and the constant range of change between them and beyond. From this, more sophisticated interpolation methods are available, and with it, the creation of algorithms from more complex operations (Yılmaz, 2007).

The technique generates a continuous surface from point data for this study case. From the boreholes point, information generates the soil surface strata. Concerning spatial, the geographic information systems are classed based on their nature:

- Deterministic: Uses similar points or smoothness to create a continuous surface. Some examples for this category are Global, Local, IDW and Spline approach.
- Geo-statistical: generates continuous surfaces using the given data´s properties, for example, the Kriging method.

Many interpolation methods use weighted averaging. This means that if there are points that have all other factor equals, the closest point an s point is to a grid node, more weight carries to determine the unknown value at that grid node. In other words, it is taking into account the information data and how vital or close this data is to the unknown point (Marrugat, 2022).

In AutoCAD Civil 3D, the methods for the interpolation and extrapolation of the point output are either NNI or Kriging. These methods can be used with different options summarized below:

- Grid Based Location: it uses the grid-based output location to interpolate surface points (NNI) or interpolate/extrapolate surface points (Kriging) on a grid defined within specific polygon areas selected in the drawing. After determining the areas, the grid X and Y spacing and the orientation properties can be specified;
- Centroids Location: it uses the centroids output to interpolate surface points (NNI and Kriging) at the existing surface triangle centroids within specified polygon areas selected in the drawing;
- Random Points Location: it uses the Random points output location to interpolate (NNI) or interpolate/extrapolate (Kriging) a specified number of random points within polygon areas selected in the drawing;

- Edge Midpoints Location: it uses the Edge Midpoints output location to interpolate surface points (NNI and Kriging) at the midpoints of selected surface triangle edges in the drawing. The drawing must display the triangles to choose the surface triangle edges.

If one of the last three (3) options is selected, the grid X and Y spacing and the orientation properties are disabled (Autodesk help).

NNI interpolates only within the surface, whereas Kriging can extrapolate beyond the surface border based on a selected polygon (Autodesk Inc., 2020).

3.3.1 Kriging

The kriging method is used for spatial interpolation and is an optimum tool because the technique incorporates the effect of distance and direction or degree of variation.

The general formula is formed as a weighted sum of the data:

$$z^* = \sum_{k=1}^{n} z_i \ \lambda_i$$

Where z* is the estimated value at the unknown location, z_i is the value of the know data, λ_i is the kriging weight, and n shows the number of geotechnical data samples (Marrugat, 2022).

Using the Kriging method in civil 3D software requires both a spatial continuity model and a surface data sample to determine the statistical trend on which to base for interpolating the unknown points.

For the spatial prediction using Kriging methods, the first step is to model the semivariance of the spatial process. The semivariance measures the degree of spatial dependence between samples that depends on the distance between the points (weight). Kriging provides five semivariogram models: exponential, Gaussian, Monomial, Linear (default), and Spherical. Locations are related within the range where the semivariance increases as the distances increase. All known samples in this region, called a neighborhood, must be considered when estimating the unknown point of interest. The center of the neighborhood is usually the unknown value. All known values within the neighborhood are assigned weights using the semivariogram to determine this value. These weights and known values are used to calculate the unknown value (Autodesk Inc., 2020).

Some recommendations about the sample data are made. The first one is to ensure that the sample data is appropriate for the interpolated points' locations (the output). "For example, do not select points on the opposite side of the surface to determine a trend for the interpolated/extrapolated points locations". The second one is to keep the sample data set small. This is because both the time and the amount of memory used by the algorithm proliferate with the sample set size. Autodesk suggests at most 200 sample points (Autodesk Inc., 2020).

3.3.2 Natural neighbor

The natural neighbor interpolation (NNI) selects the data samples from a subset nearest to the unknown information and interpolates the values using proportional region weights. The method is quite popular in some fields (Marrugat, 2022).

This is also considering a set of Thiessen polygons. If a new point is added to the data set, these Thiessen polygons would be modified: some would shrink in size, while none would increase. The area associated with the target Thiessen polygon taken from an existing one is called a borrowed area. "The natural neighbor interpolation algorithm uses a weighted average of the neighboring observations, where the weights are proportional to the borrowed area" (Yılmaz, 2007).

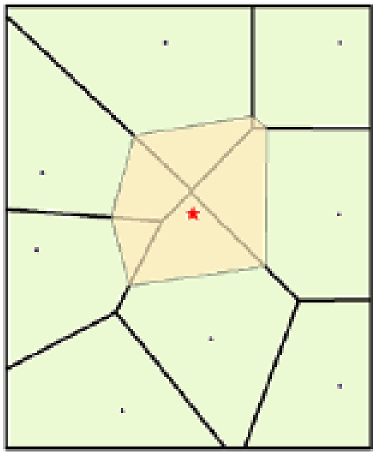

Image 1. Example of Thiessen polygon created around interpolation point

Source: (ArcGIS, n.d)

The basic equation used in natural neighbor interpolation is:

$$G(x, y) = \sum_{i=1}^{n} w_i \, f(x_i, y_i)$$

Where G(x,y) is the natural neighbor estimation at (x,y), n is the number of nearest neighbors used for the interpolation, f(x,y) is the observed value at (x,y), and w_i is the weight associated with f(x,y) (Yılmaz, 2007).

In civil 3D, the Natural Neighbor Interpolation (NNI) is used to estimate the elevation (Z) of an arbitrary point (p) from a set of points with known elevations. More specifically, the NNI method uses the information in the triangulation from the available points to compute a weighted average of the natural neighbors of point p. The number of neighbors depends on the triangulation: it is the number of points to which a new point (p) would be connected if inserted into the surface:

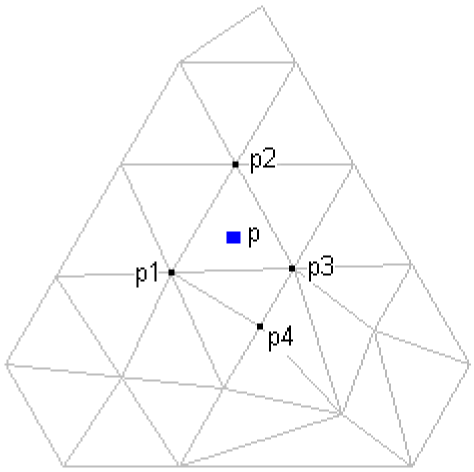

Image 2. Natural Neighbor Interpolation Scheme

Source: (Autodesk Inc., 2020)

Using NNI, you select only the output locations of the interpolated points. The elevations of the interpolated points are always based on the weighted average of the elevations of the existing neighboring points. The outcome of the NNI method is more predictable than the Kriging method (Autodesk Inc., 2020).

3.4 Geotechnical BIM integration: other methods

This chapter highlights some other methodologies and tools that can be used to integrate geotechnical data into BIM. The first one is called GIS, the abbreviation for geographic information system, and its software tool is ArcGIS. The second one is the HoleBase SI tool.

3.4.1 GIS for geotechnical BIM applications

The geographic information system (GIS) is used to model, map, integrate, and interpret the site's geotechnical properties, portraying their spatial distribution. In other words: “A geographic information system (GIS) is a system that creates, manages, analyzes, and maps all data types. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like there). This provides a foundation for mapping and analysis used in science and almost every industry. GIS helps the user understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency and better management and decision making" (Institute Environmental Systems Research, 2022).

The software is used worldwide by thousands of organizations in virtually every field thanks to its capacity to make maps that communicate, perform analysis, share information, and solve complex problems, similar to the principles of BIM. GIS technology applies geographic science with tools for understanding and collaboration. These tools can be summarized in three. Maps are the geographic container for the data layers and analytics. Data GIS integrates many layers using spatial information, including imagery, features, and base maps linked to tables. The last is spatial analysis, which lets us evaluate suitability and capability, estimate, predict, interpret and understand. In other words, "Geographic information system (GIS) manages and analyzes the spatial information about assets based on geomatics techniques. GIS is an information technology system with all the features, such as storing spatial information in a relational database. GIS stores all the information such as location, spatial, and non-spatial information about a spatial facility in the database, providing a significant advantage in spatial and temporal analysis" (Khan, Park, & Seo, 2021).

Focus the attention on the geotechnical field; GIS can store the geotechnical parameter information in a geodatabase that can be used for the spatial distribution of the area of interest. This is crucial from a geotechnical point of view, as was said before. Usually, the data comes in the form of boreholes (points), and there is a need for spatial interpolation to create the soil surfaces.

How to share the information between different software completely, in the end, having a complete information model is one of the current issues. The standard format for GIS data for exchanging geographical and semantic information is City Geography Markup Language (CityGML). Many applications can share this open data model and standard format. In the other part, the standard format for exchanging graphical and 3D semantic information for BIM is the Industry Foundation Class (IFC). The object-oriented hierarchy contains geometry information with predefined attributes and relationships (Khan, Park, & Seo, 2021).

According to the literature, three kinds of methods can be adopted to integrate the two systems: BIM data integration into GIS, GIS data integration into BIM, and integration of BIM and GIS into a new platform.

For BIM data integration into GIS, were created different software components but usually focused on specific fields. In one study, a multi-purpose geometric network model (MGNM) was designed to facilitate indoor and outdoor connections for emergency response and pedestrian route planning. A CityGML extension called GeoBIM was created to integrate the IFC semantic information, which concludes the technical transfer of IFC semantic information into CityGML. “BIM and GIS have been integrated for indoor spatial analysis. Autodesk Revit was used to model the IFC-based BIM model and exported to ArcGIS using the data interoperability tool” (Khan, Park, & Seo, 2021). The studies show that integrating BIM data and GIS was very effective and resulted in positive results. The methodology can be summarized in two steps: extracting the BIM model's information and then integrating it with GIS.

For the inverse case, GIS data into BIM, also depending on the information goal, different software components were created as a plugin in BIM that optimizes the construction supply chain management (CSCM). In the specific case of Autodesk, an example was using the Revit software as a BIM tool and ArcGIS as a GIS tool, which was integrated into Infraworks preserving geometrical and semantic information (Khan, Park, & Seo, 2021).

For geotechnical modeling, the application of BIM and GIS integration is limited, and its use has yet to be fully utilized. However, a study was found. This study attempts to use the entity IfcGeotechnicalAssembly, and their subtypes, IfcBorehole, IfcGeomodel, and IfcGeoslice, for the representation of the geotechnical information in BIM. According to the study, the first step is to collect the geotechnical investigation into a database. It is essential to mention that with GIS, any geotechnical parameter obtained from the geotechnical site investigation can be used and is not limited to specific parameters. Second, the geospatial interpolation technique is applied using GIS to collect data; different interpolation methods can be chosen to manipulate it statistically. Finally, the geotechnical zonation map is visualized, and more parameters are appended to the geotechnical BIM model to enhance its functionality using BIM (Khan, Park, & Seo, 2021).

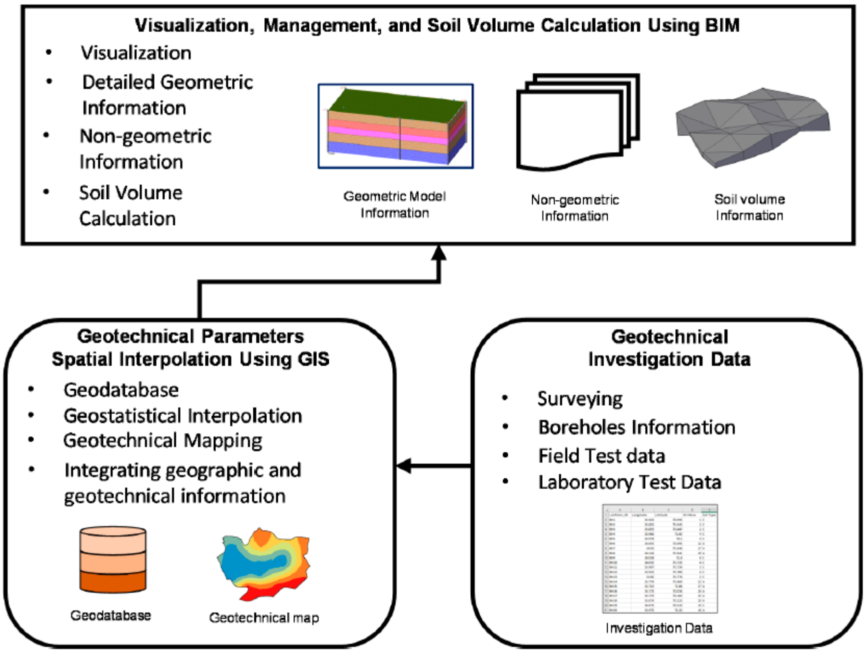

Image 3. Workflow scheme for a GIS-BIM geotechnical integration

Source: (Khan, Park, & Seo, 2021)

3.4.2 HoleBASE SI tool

HoleBASE SI is an extension for AutoCAD Civil 3D that allows quick and easy inclusion of all geotechnical data in the BIM process. “HoleBASE SI is a state of the art geotechnical knowledge management system that will help you control your geotechnical project data and archive. HoleBASE SI’s unique features allow you to manage your data throughout the lifetime of a project and access historical information alongside your current project, transforming the way you archive and manage site investigation” (Bentley, s.f.).

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3.5 Examples of BIM in geotechnical engineering

3.5.1 The Silvertown Tunnel

The Silvertown tunnel is a road tunnel under construction beneath the River Thames between the Greenwich Peninsula and Silvertown. The length of the tunnel is about 1400 meters; the number of lanes is four, two per bore. The tunnel is intended to reduce congestion through the Blackwall Tunnel; both tunnels will be tolled when it opens in 2025.

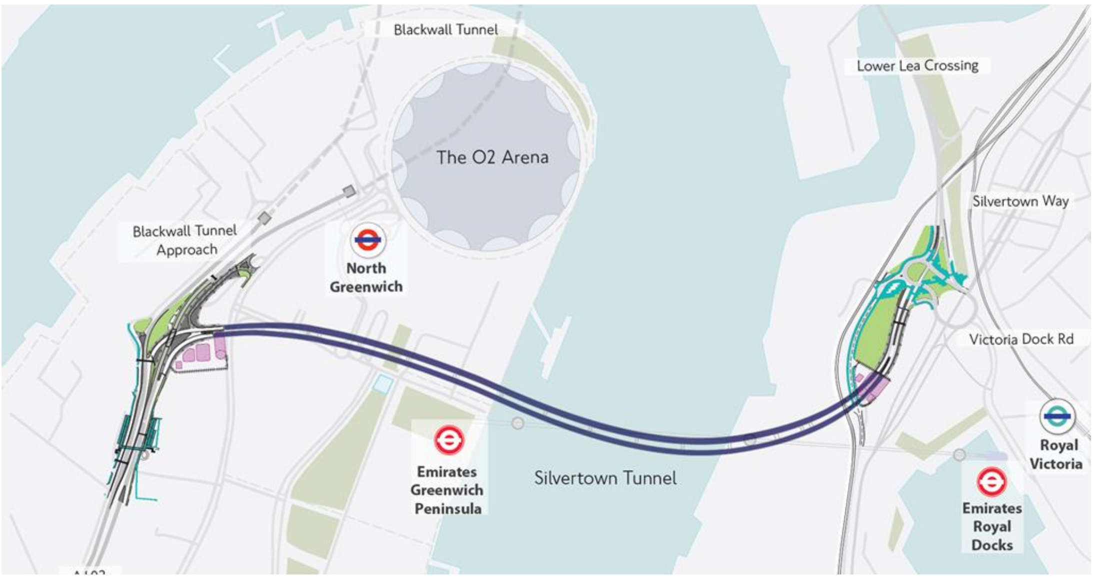


Image 4. Plan scheme of the Silvertown Tunnel

For this project, the implementation of geotechnical BIM was fundamental. From t is possible to understand that the project should face many challenging problems: due to its location beneath the River Thames and some existing buildings. A geotechnical better see and understanding of the surface's soil conditions can reduce the overall project cost and risk. The decision made thanks to the information the site collected from historical maps to more recent projects with digital data, was to use this information to: first, compare the available geotechnical knowledge in a geotechnical data management system; second, develop a 3D ground model of the site and ground conditions to improve the model and geotechnical data during the project.

As an initial win, the number of research holes necessary for the site investigation was reduced, saving project time and cost, by analyzing the historical and available data within the model environment.

The software used was AutoCAD Civil 3D and HoleBASE SI extension as the geotechnical database. This allows a rapid workflow and enables updated geotechnical data to be ready and viewed with the larger model (Merdan, 2018).

3.5.2 Peshawar region case study

The Peshawar region (*Image 5*) was selected to implement the method of integrating BIM and GIS for geotechnical property modeling and zoning.

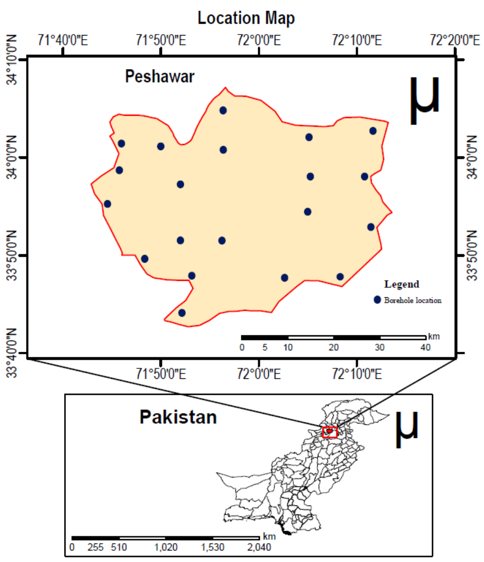


Image 5. Location map of the Peshawar region case study

The geotechnical exploration data, such as boreholes, were collected from the soil mechanics and local geotechnical investigation consultants. A total of 20 boreholes were selected from the dataset, making a grid pattern throughout the whole region for spatial interpolation.

The results show that the GIS technique adequately maps the geotechnical parameters that can help the planners and construction manager in the critical decision about safe construction site selection before initiating construction.

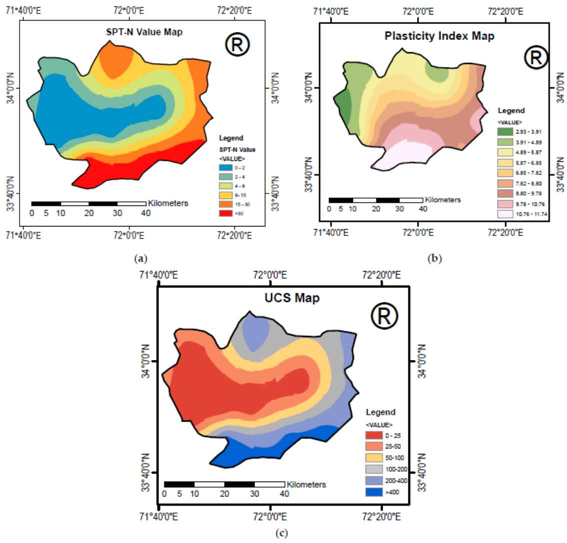


Image 6. Geotechnical parameters map results from GIS

To show the successful integration between GIS and BIM, the AutoCAD Map 3D was opened inside the Civil 3D software, which supports the export and import of CityGML based models. The result was the three-dimensional visualization of the soil layers by different colors and depths.

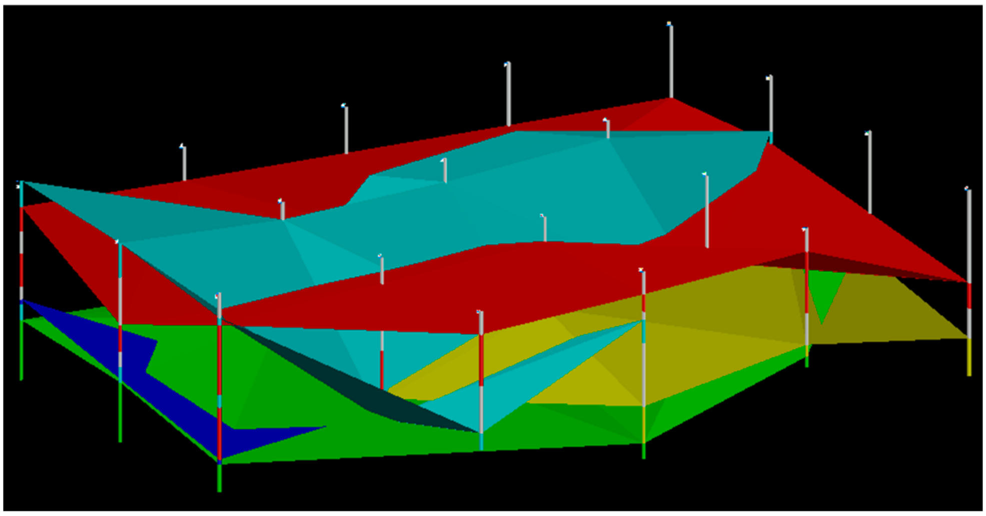


Image 7. Three-dimensional borehole visualization of geotechnical layers

4 Parco della Salute, della Ricerca e dell´ Innovazione

4.1 General aspects

Turin is the capital of one province of Italy, Piedmont. It is located in northern Italy and is mainly on the western bank of the Po River, below the Susa Valley, and surrounded by the western Alpine arch. More specifically, the case study is located on the edge between the Nizza Millefonti and Lingotto areas in the southwest part of Turin, as shown in Image 8.

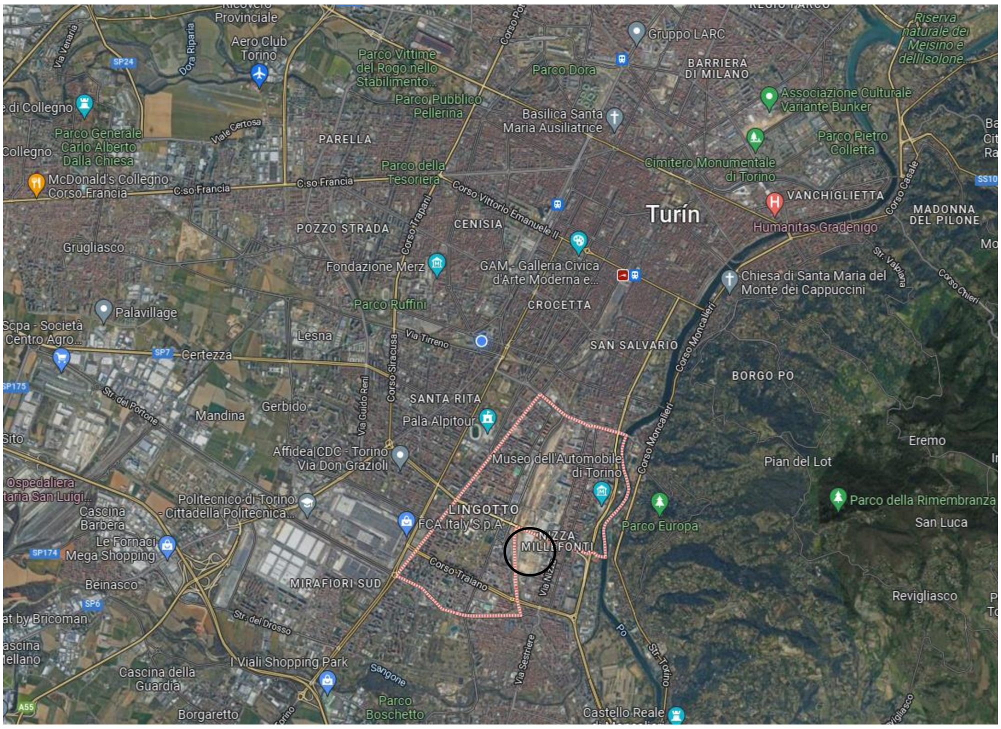


Image 8. Location map of the city of Turin

Image 9 shows a zoom-in of the previous image, in which the area of the whole project (dotted line) and our study area (red line) can be appreciated—located between the Lingotto train station and the Po River and visually easy to find with the tallest building in Turin, la Torre della Regione Piemonte. Delimited by streets Nizza, Farigliano, Canelli, Passo Buole.

Image 9. Location map of the study area

This project is known as Parco della Salute, della Ricerca e dell´Innovazione, and is of interest for implementing the proposed method of integrating geotechnical modeling with BIM. The project is divided into different areas due to the phases of the building construction. Between the one sud and one nord districts, 176.000 m2 is achieved. The study area for our case is referred to one nord, as shown in Image 10.

Image 10. Property area of Parco della Salute, della Ricerca e dell´Innovazione

Source: (G., 2018)

It is important to remember that this area is part of an old industrial facility of the Fiat Avio (Image 11).

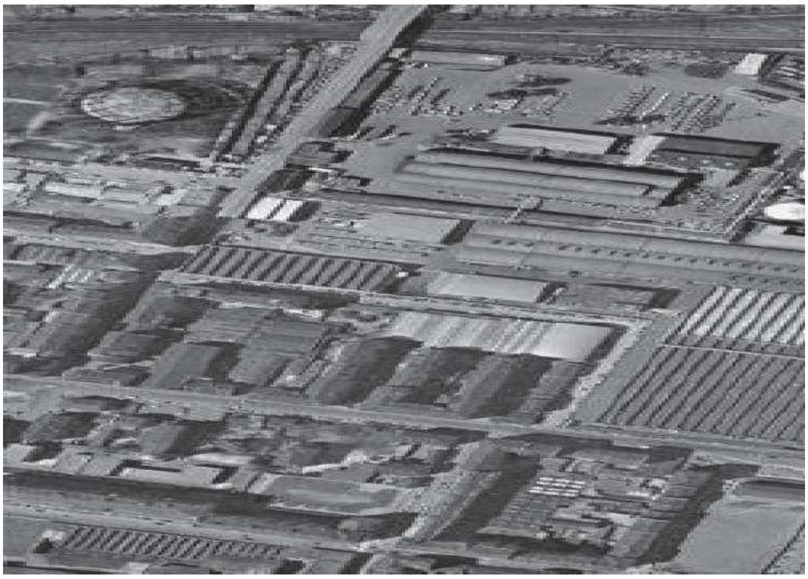


Image 11. Aerial photography of the ex-industrial Fiat Avio (the year 1979)

Source (Calafiore & Leanza, 2018)

This means that this area has not only buildings in elevation but also some underground structures that were demolished and can modify the natural stratigraphy. Being an industrial area during its operation is critical to the environmental impact, and, in the following years, some interventions were developed to lower the effect (Calafiore & Leanza, 2018).

4.2 Subsoil structure: geological, geomorphological, and stratigraphic aspects

The whole area of the project is located, as the majority of Turin, on the alluvial fan generated due to the glacial and interglacial phenomena that occurred in the Pleistocene. This alluvial fan, opposed to the tertiary formations of the Turin hill, has been longitudinally modeled over time by the watercourses that flow from the Alps towards the plain and, at the basis, by the Po.

In the following Image 12, which is part of the Geological map of Italy, is highlighted the general area of analysis, located at the end of the alluvial fan, in terrains of fluvial-glacial and defined as “Gravelly-sandy deposits with red-orange paleosoil, primarily terraced, corresponding to the foundation level of the high plain joining up with the Rissi morainic circles (Calafiore & Leanza, 2018).

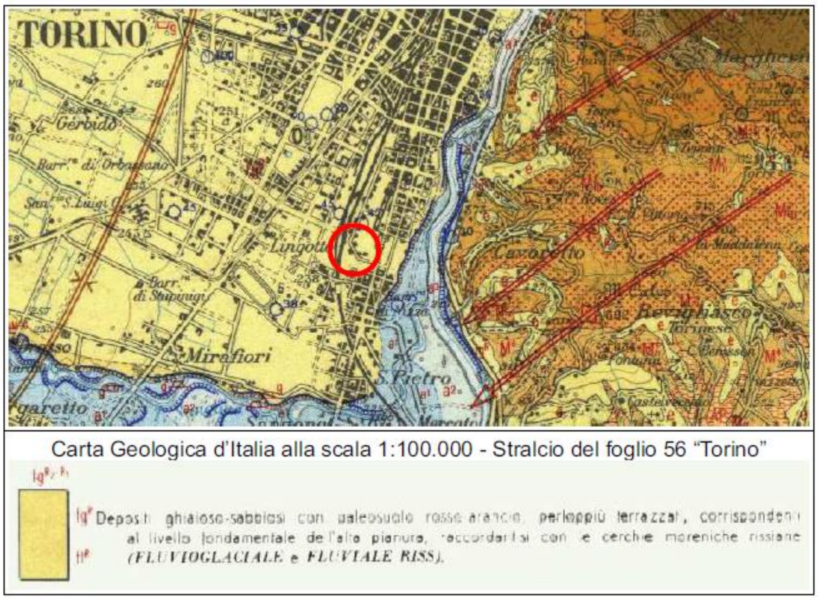


Image 12. Geological map of Italy- Scale 1:100000- Extract from page 56 “Turin.”

The Geological map of Italy, different scale, shows us a more specific area of the project. This is part of the Frassinere System-Subsystem of Col Gianesco, made of gravelly sands and sandy gravels with heterometric clasts of quartzites, serpentinites, and gneisses subordinately of prasinites, calc schists, and gray marbles (Image 13).

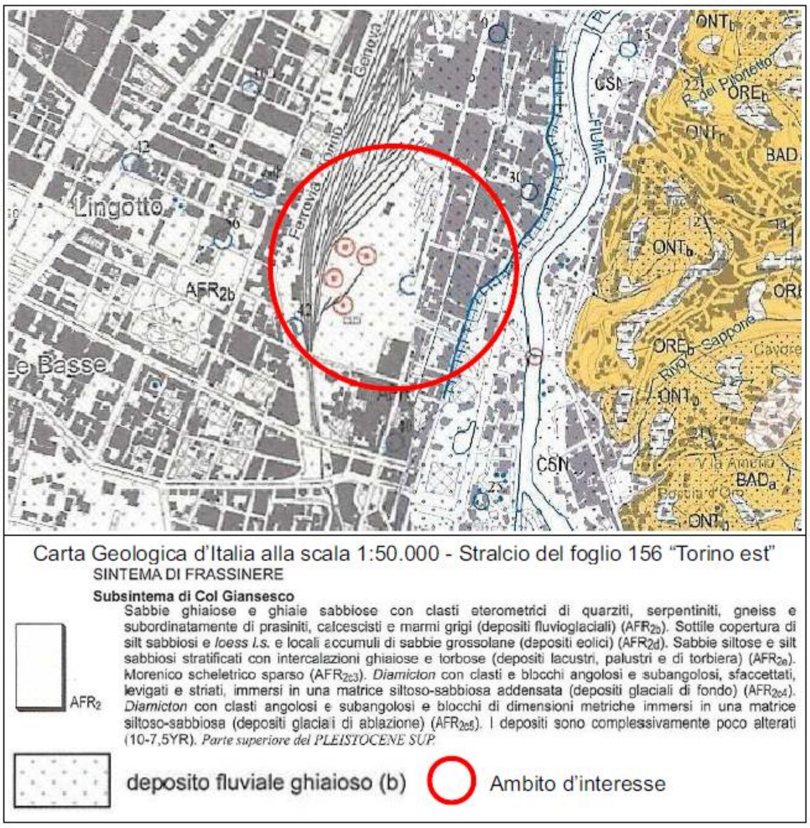


Image 13. Geological map of Italy- Scale 1:50000- Extract from page 156 “Turin est”:

4.2.1 Stratigraphic general structure

The southwest area of Turin is located in the final sector of the alluvial fan, characterized from top to bottom by three lithostratigraphic units:

- the surface deposits of the Quaternary age originated during the last glacial and interglacial periods, consisting of an alternation of coarse alluvial sediments, sandy gravels, sandy-silty gravels, and local conglomerate lenses, with finer horizons (sands, silts, clays); this complex has a variable thickness from about twenty to fifty meters; there are also some cemented levels having a thickness from decimeter to metric
- the Plio-Pleistocene deposits of the Villafranchiano, consisting of alternating silt-clayey sediments, originating following lake episodes and gravel-sandy levels linked to fluvial activity

- the Pliocene complex of the Sabbie di Asti, consisting of generally fossil-bearing sandy and silt-sandy alternations (Calafiore & Leanza, 2018)

4.2.2 Stratigraphic local structure

For the specific area of the project (PSRI), the typical stratigraphy is characterized by the absence of Pleistocene deposits of the Villafranchiano; this means that the alluvial quaternary deposits are directly in contact with the Sabbie di Asti.

On a big vertical scale, the above units in the area are the following:

- The surface deposits reach a variable depth between 35 and 40 meters from the ground level
- The Sabbie di Asti unit is found about 40 meters from the ground level

The local structure of the assessment is geological and stratigraphic, saying that the whole area of the project presents a thickness of fill material consisting of soil mixed with fragments of bricks and, more rarely, with fragments of work. The granulometry of this backfill material is variable: in some cases, fine (mainly silty); in others, gravelly or sandy with pebbles. The thickness varies from a few tens of centimeters to a few meters (Calafiore & Leanza, 2018).

Furthermore, in the northern portion of the area, the presence of a fine-grained, silty and clayey horizon of variable thickness (between 0.5 and 4.5 meters) is found, often between 5 and 10 meters deep from ground level, above which fill material is always located, which can reach thicknesses of up to 5 meters (Calafiore & Leanza, 2018).

This horizon is present on both sides of the Lingotto underpass and was also identified during construction of the adjacent Palazzetto per il ghiaccio.The clays that make it up are somewhat plastic, moderately consistent, and have a variable color from brown to gray. Sometimes they contain more consistent nodules or various clasts.Various past hypotheses have been formulated regarding the clayey lens's origin, attributing both artificial and natural sources. Natural origins would seem more probable.This lens could represent an abandoned river meander or derive from a secondary channel tributary towards the Po (Calafiore & Leanza, 2018).

The following figure schematically summarizes the local lithostratigraphic structure consisting of an anthropic cover of highly variable thickness (from a few decimeters to a few meters) and composed of gravelly soil with a fine matrix containing fragments of past workings, followed by a substrate made up of sands and gravels with pebbles and clayey and conglomerate intercalations, with the sandy silts of the Asti Sands Unit at the base (Calafiore & Leanza, 2018).

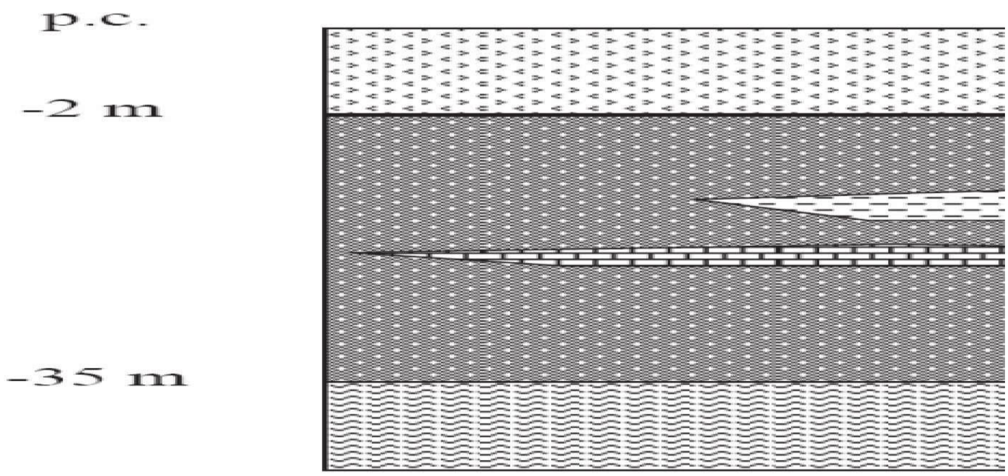


Image 14. Schematic representation of the local lithostratigraphic structure

4.2.3 Hydrogeology local structure

In the project area, the water table oscillates between 12 and 14 meters from the ground level.

From the different site investigations made in the past, some data was derived for the hydrogeology characteristics of the subsoil (these are average values):

- Unsaturated zone: Permeability= between 3 to 6 x 10^{-6} m/s
- Saturated zone: Permeability=1,6 x 10^{-3} m/s

  Trasmitibility=0,032 m/s

  Hydraulic gradient= between 0,0028 to 0,0034

5 Methodology

5.1 Workflow

From the beginning, it was defined that the project was going to be divided into three stages: the collection of the geotechnical data, the processing of the geotechnical data, and the visualization of the 3D model of the soil surfaces. For this purpose, different digital tools were used to facilitate each step of the modeling process; accounting for the necessary information needed by each software, a primary workflow was defined, as shown below.

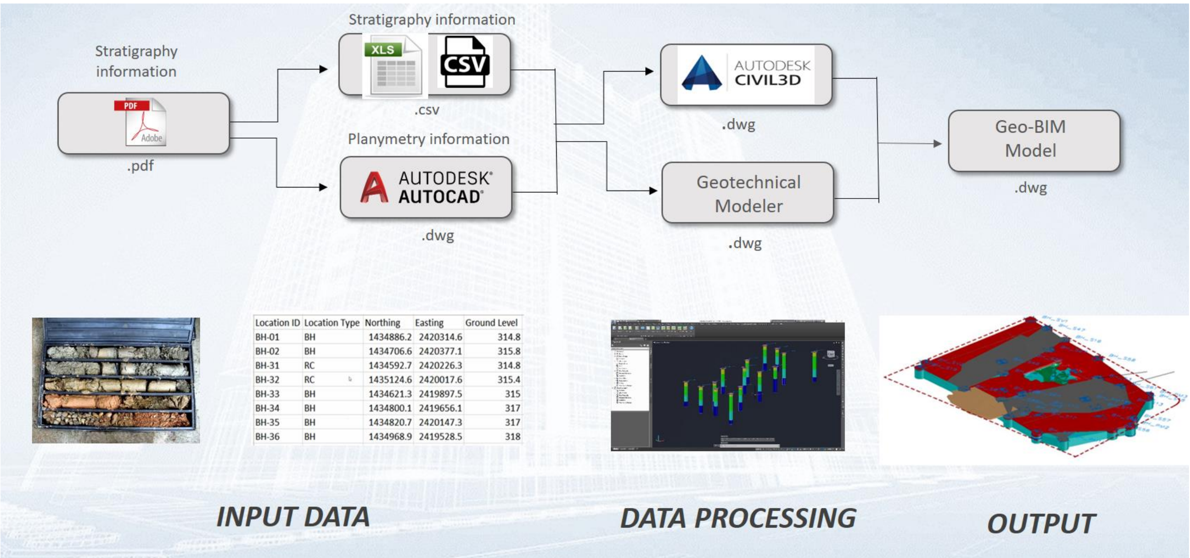


Image 15. Workflow scheme

The initial documents for the project were .pdf files; they contained initial information about the geological and environmental data. This information was collected into four groups: stratigraphy, analytic tables, planimetry, and environmental certificates. Two main formats can be used for importing the information into civil 3D: AGS (Association of Geotechnical and Geo-Environmental Specialists) or CSV (Comma Separated Variable). For this case, was use the CSV format, in which two or three files for the mapping are required: Location Details.csv, Field Geological Descriptions.csv, and/or Orientation and Inclination.csv, as shown in Image 16 below.

Filename	Requirement	Description
Location Details.csv	Mandatory	Bore hole type and position information
Field Geological Descriptions.csv	Mandatory	Strata and banding information
Orientation and Inclination.csv	Optional	Used for inclined bore holes

Image 16. Excel files are mandatory and optional

The Location Details file contains a location ID, the location type, easting and northing location, and ground level for each borehole (Image 17). In this case, the coordinate system that was used to georeferenced the location of the boreholes of the project is related to the World Geodetic System 84 (WGS), a standard system for cartography, geodesy, and satellite navigation also integrated as a reference system in civil 3D. The other information was taken from the documents collected by the Piedmont region.

Column Heading	Description	Mandatory	Example
Location ID	Location unique ID	Yes	BH0001
Location Type	Type of activity at location	Yes	RC
Easting	Easting or longitude of the location of hole	Yes	123456.4
Northing	Northing or latitude of the location	Yes	232467.3
Ground Level	Ground level relative to datum of location or start of traverse	Yes	35.43

Image 17. Location details

The Field Geological Descriptions file contains the geological strata information made of the location ID, the depth of each surface (top and base,) and three (3) columns that insert a code to describe the strata. It is only mandatory to set one of these; in this case, it was helpful to make different scenarios of the soil surfaces, one more generalized than the other, to asses a correct visual model.

Column Heading	Description	Mandatory	Example
Location ID	Location identifier	Yes	BH001
Depth Top	Depth to the TOP of stratum	Yes	7.43
Depth Base	Depth to the BASE of description	Yes	8.12
Legend Code	Legend code		102
Geology Code	Geology code	One must be set	LC
Geology Code2	Second geology code		SAND

Image 18. Field geological description

The last file is optional and contains information on the direction of the boreholes when they are not vertically down.

Column Heading	Description	Mandatory	Example
Location ID	Location identifier	Yes	BH001
Orientation	Orientation of hole (degrees Clockwise from north)		135
Inclination	Inclination of hole (measured positively down from horizontal in deg)		75

Image 19. Orientation and inclination description

This file required previous geotechnical knowledge and experience because the geotechnical module of Civil 3D is only a starting point to model geology. For this reason, stage two is the interpretation of data; this step consists of the process of the collected data in a way that the Geotechnical Module output makes sense for engineering decisions.

The final part shows the 3D soil surfaces output model and cross-sections.

5.2 Geotechnical Investigation Data/Information collection

The geological investigation of a construction site is a requirement for every engineering and construction project. The idea of making a site investigation is to identify the distribution of the soil layer and the groundwater table location. Then with this information, it is possible to know the site soil's mechanical and physical characteristics. Usually, all this information can be obtained by the same exploration method, or it can be correlated with the data obtained in it: as with the cone penetration test (CPT) and standard penetration test (SPT).

The geological investigation is a key point in planning any construction. Many decisions and activities depend on the type of soil found on the site. This has a direct impact on the time and cost of the project: such as the design of the foundation. And another issue, at least in Italy, is the environmental impact: what to do with the excavated soil becomes important to consider during the planning and design of a construction.

There are many types of geotechnical investigation. One of the most common is the boreholes. It consists of penetrating the soil using a hand-operated or drilling rig. The machinery and techniques to advance the hole depends on the manufacturer, the geological conditions, and the purpose. In common words, it is practically an empty tube of a fixed diameter that is pushed into the soil and take samples at each depth. The way the tube goes into the ground and with the help of some additional tools, can also give information about the geotechnical parameters.

Image 20. Equipment for borehole investigation in the study area

Source: *(Carsico S.R.L., 2022)*

Image 21. Sample box from borehole SG-1 depth between 0.00-5.00m

Source: *(Carsico S.R.L., 2022)*

An important division is from where the site information is obtained: in situ or from a laboratory. In the case of the in-situ investigations, the data used correlations to find the geotechnical parameter. On the other hand, the information is obtained from laboratory tests and can divide into different categories such as strength, compaction, and classification. Image 22 shows the most significant laboratory test parameters functional to develop a complete geotechnical integration with BIM. As was mentioned before, with BIM integration, the idea is to include in the virtual model the important and useful possible information to help the engineers to make decisions during all the phases of a project. In this case, the model only focuses on the correct asses of the soil surfaces using Civil 3D (Khan, Park, & Seo, 2021).

Category	Parameters
Strength	Compressive strength Cohesion Shear strength Tensile strength Angle of internal friction Poisson's ratio Elastic modulus
Classification	Liquid limit Plastic limit Plasticity index Moisture content Unit weight Specific gravity
Compaction	California bearing ratio Maximum dry density Optimum moisture content

Image 22. Geotechnical data that can be included in the 3D model

Source: *(Khan, Park, & Seo, 2021)*

The borehole dataset can be collected from several preselected spatial locations with different depth intervals.

A critical step for 3D modeling was processing and interpreting the geotechnical data. This data was asses before the model so that a valuable and coherent model could be drawn for practical uses. The geotechnical data was in different formats, collected through the years by different "authors," which had to be understood and processed. Image 18 shows the name/code, data, and author and extracts the file collected by the Piedmont Region for the old stratigraphy.

Stratigrafie

NOME FILE (o codice documento)	DATA	AUTORE	ESTRATTO DA
S-1990-S1	09/08/1990	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1990-S2	23/08/1990	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1990-S3	24/08/1990	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1990-S4	29/08/1990	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1990-S5	28/08/1990	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SGE 1	24/10/1991	ABRATE	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SGE 2	XX/XX/1991	ABRATE	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SGE 3	XX/XX/1991	ABRATE	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SGE 4	31/10/1991	ABRATE	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 1A	20/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 1B	20/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 2A	25/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 2B	25/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 3A	28/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-SP 3B	28/03/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-Spi 1	25/06/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-Spi 2	04/07/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-Spi 3	28/06/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-Spi 4	02/07/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-1991-Spi 5	20/06/1991	RADAELLI CASTELLOTTI	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-PM12	25/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-PM13	28/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-POZZO A	XX/XX/2005	XXX	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-POZZO B1	XX/XX/2005	XXX	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-POZZO B2	XX/XX/2005	XXX	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-POZZO C1	XX/XX/2005	XXX	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-POZZO C2	XX/XX/2005	XXX	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 56	20/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 57	20/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 58	19/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 59	24/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 60	24/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 61	19/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 62	13/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 63	13/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 64	13/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-2005-S 65	13/10/2005	EUROGEO	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-XXXX-SOT 1	XX/XX/XXXX	SICOS	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-XXXX-SOT 2	XX/XX/XXXX	SICOS	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)
S-XXXX-SOT 3	XX/XX/XXXX	SICOS	PROGETTO DEFINITIVO NUOVO PALAZZO REGIONE (2008)

Image 23. Name file, date, and author of the stratigraphy information collected by the Piedmont region

Source: *(Calafiore M. L., 2019)*

t is essential to consider that the stratigraphy was provided by multiple authors and can have different descriptions for the same soil surface. Also, through the years, some superficial surfaces may have been modified for external actions. In addition, Image 24 shows the more recent stratigraphy information name/code, data, author, and extract the file.

Name file or code	Data	Author	Extract from
SG1	9/02/2022	Unieco Golding Ambiente	REPORT INDAGINI GEOGNOSTICHE
SG2	10/02/2022	Unieco Golding Ambiente	REPORT INDAGINI GEOGNOSTICHE
SG3	15/02/2022	Unieco Golding Ambiente	REPORT INDAGINI GEOGNOSTICHE
SG4	18/02/2022	Unieco Golding Ambiente	REPORT INDAGINI GEOGNOSTICHE

Image 24. Name file, date, and author of the more recent stratigraphy information collected by the Piedmont region

5.3 Data interpretation

After collecting all the information available, we can proceed to unify the data over a similar description and organize it in the CSV files as is required for the Civil 3D software. A soil generalization was needed, for this was helpful use the three codes in the Field Geological Description file. In other words, a generalization based on the dominant compositions was made to simplify the modeling efforts and visualization soil model.

As has been mentioned many times, soil interpretation and generalization rely heavily on professional judgment and experience.

5.4 Management and visualization in Civil 3D

AutoCAD Civil 3D program is used to create drawings, designs, and project documentation in civil engineering design. Nowadays, one of the most exciting tools is that it supports BIM (Building Information Modeling). It has many features for civil engineering. Still, in this case, only two were used: the first one is the geolocation module, in our case related to the boreholes information, and the second one is the geotechnical module.

5.4.1 Geolocation Module

The geolocation module is used to georeferenced. In our case, the geotechnical module requires the coordinates (easting and northing) of the boreholes, so the geolocation module was used to check that the coordinates were correct. The module allows us to relate the borehole points to a satellite or other types of map integrated into civil 3D.

To use the geolocation module, follow the next steps:

The first step is to click on the edit drawing settings, as shown in Image 25.

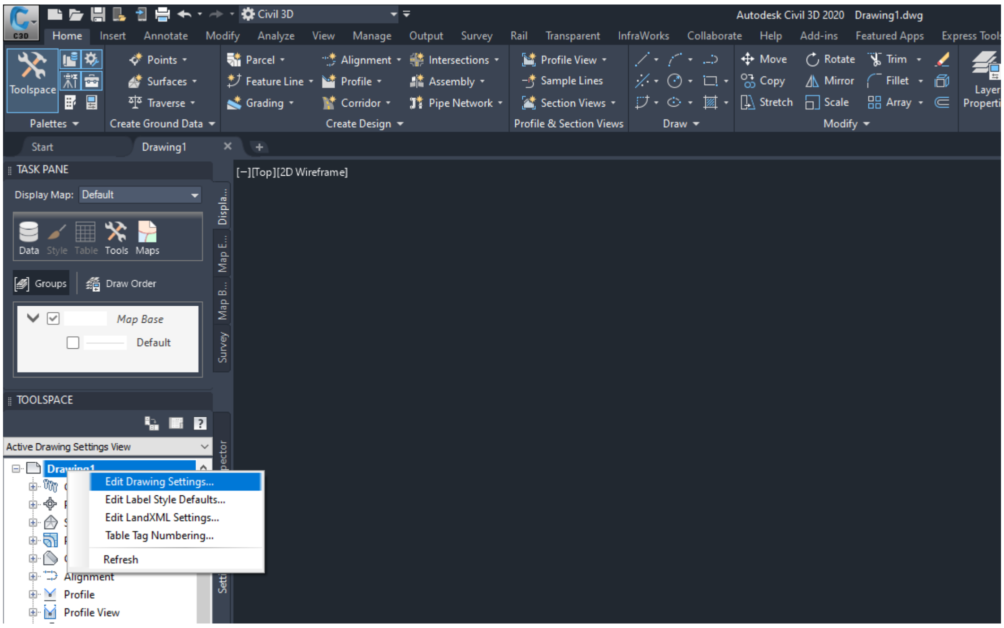


Image 25. Box dialog for opening the geolocation module

Then is selected the georeferenced system relates to our information. In this case, UTM 84 was used.

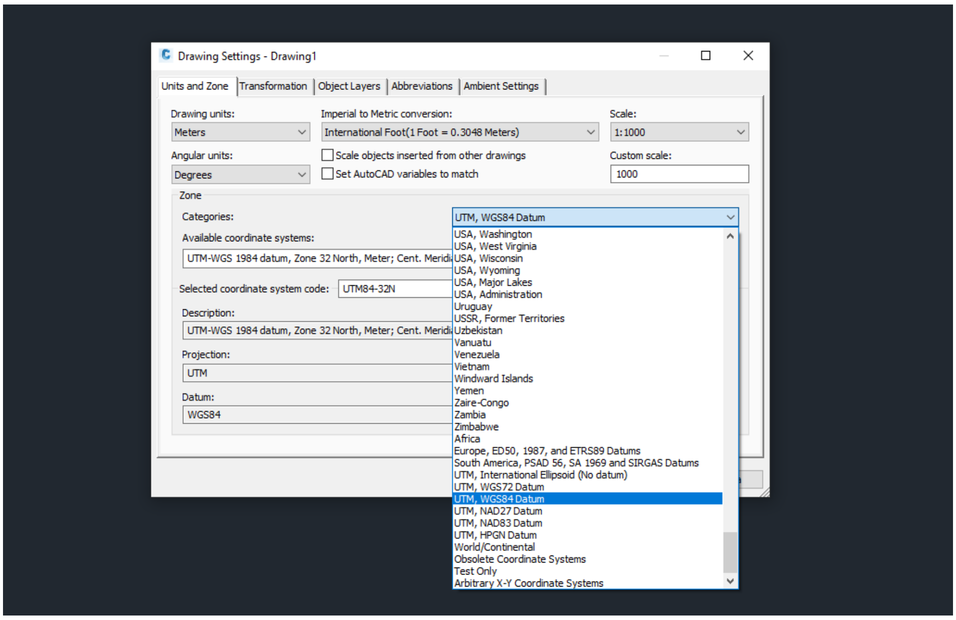


Image 26. Georeferenced system use

After choosing the system, it must upload the coordinate system information. For Turin, this is the Zone 32 North.

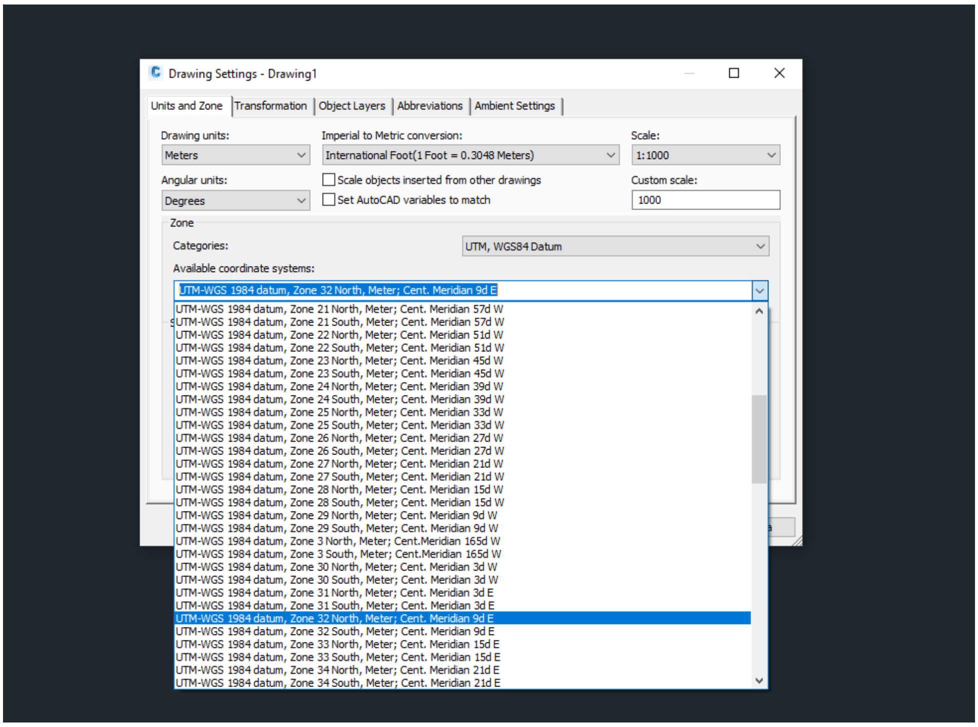


Image 27. Georeferenced of Turin city

Finally, the extension for geolocation appears in the bar menu, and it is possible to turn on the map of the previous coordinate system (Image 28).

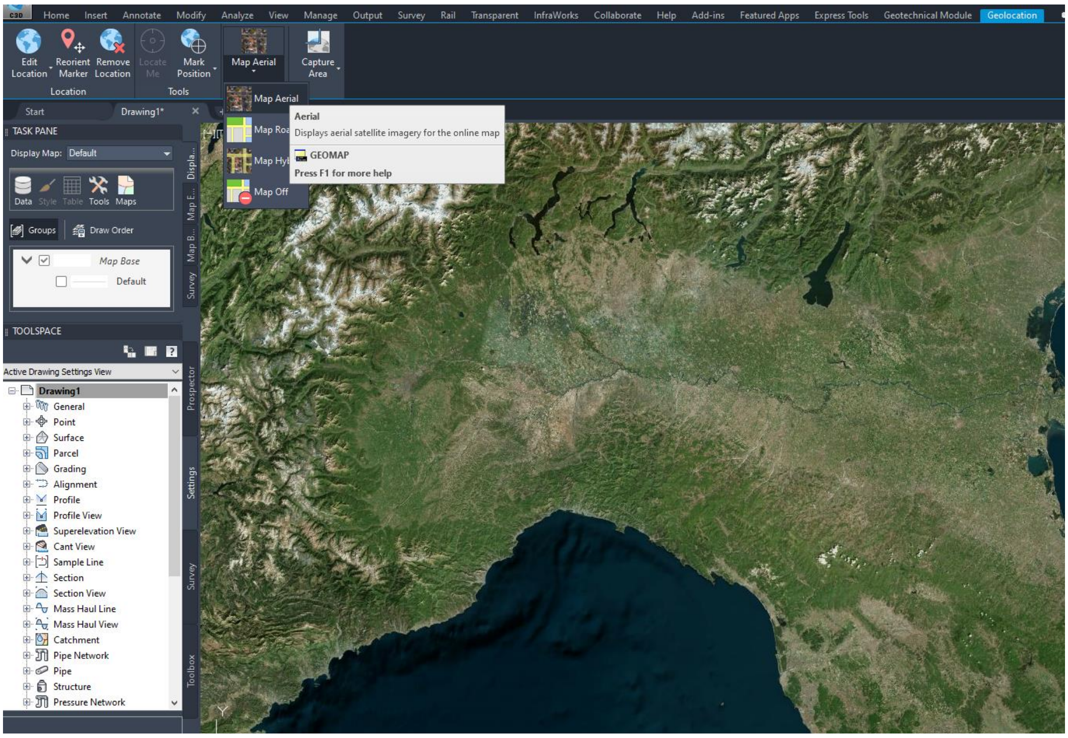


Image 28. Map selection Geolocation Module

5.4.2 Geotechnical Module

The geotechnical information collected from a borehole is the key to proper modeling. However, the borehole results are derived from a specific boring point. This means that the borehole dataset provides only one-dimensional information about underground soil, which leaves spatial uncertainties. This required a geospatial interpolation technique to apply to the dataset to interpolate the data for the uninvestigated location. The goal is to determine the soil surfaces and information along the whole area of the site, also because for time and cost the initial investigation number of boreholes is limited.

To use the geotechnical module, follow the next steps:

The first step is to connect to the appropriate database; in fact, one of the limitations of the Geotechnical Module is that it only works on a local machine.

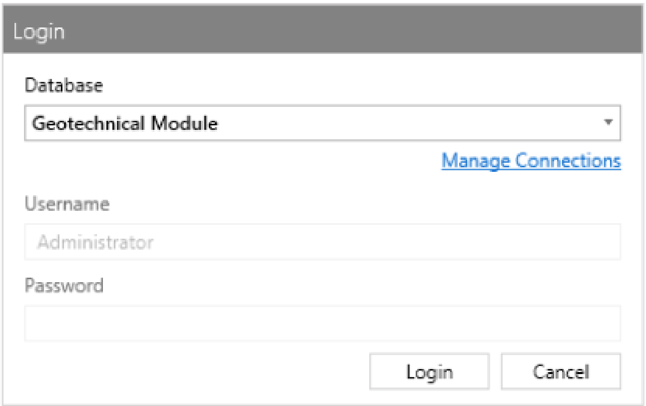


Image 29. Connect login dialog

Then is time to create or open a project.

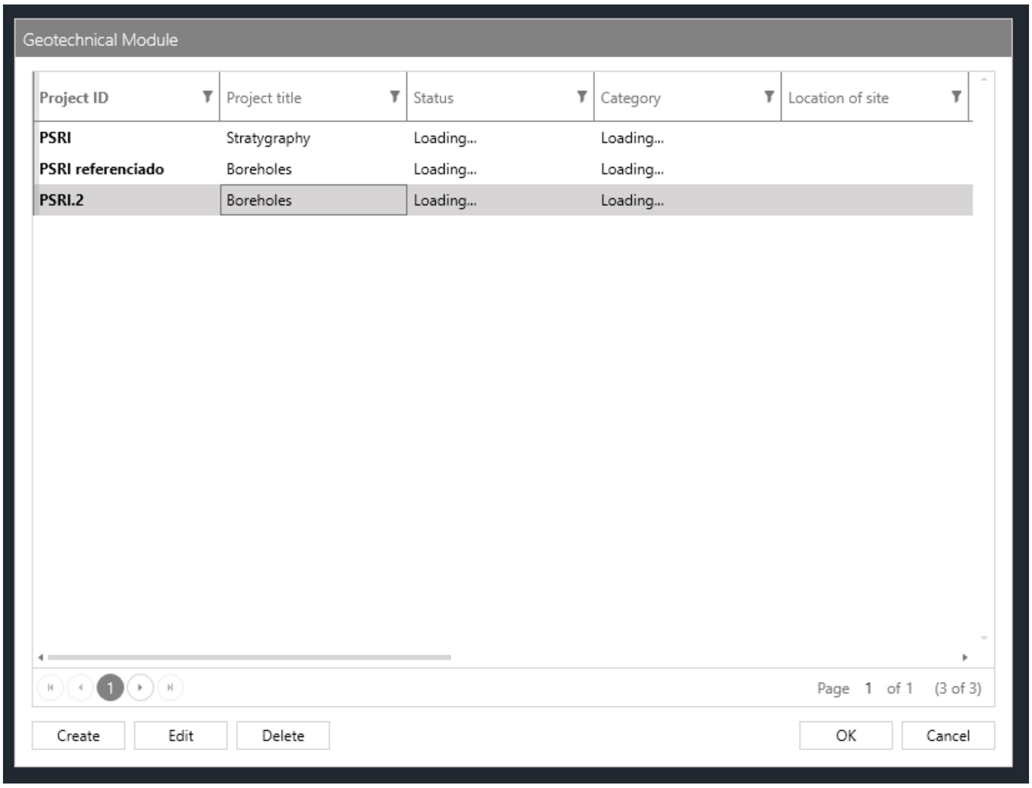


Image 30. Project list dialog

Some boxes should be filled for creating a new project; see Image 31 below, such as Project ID, Name, Status, and Category. The other ones are optional.

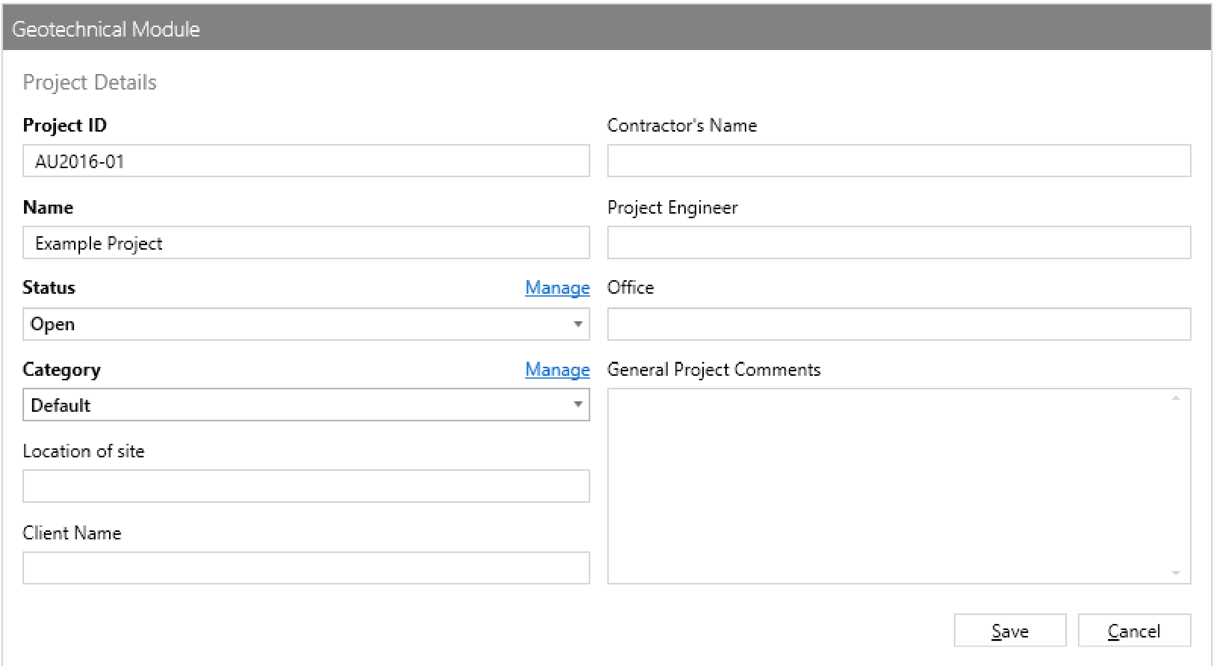


Image 31. Creating a project dialog

In the following, Image 32 shows the box where add the CSV. Files to import: Location Details, Field Geological Descriptions, and optional the Orientation and Inclination.

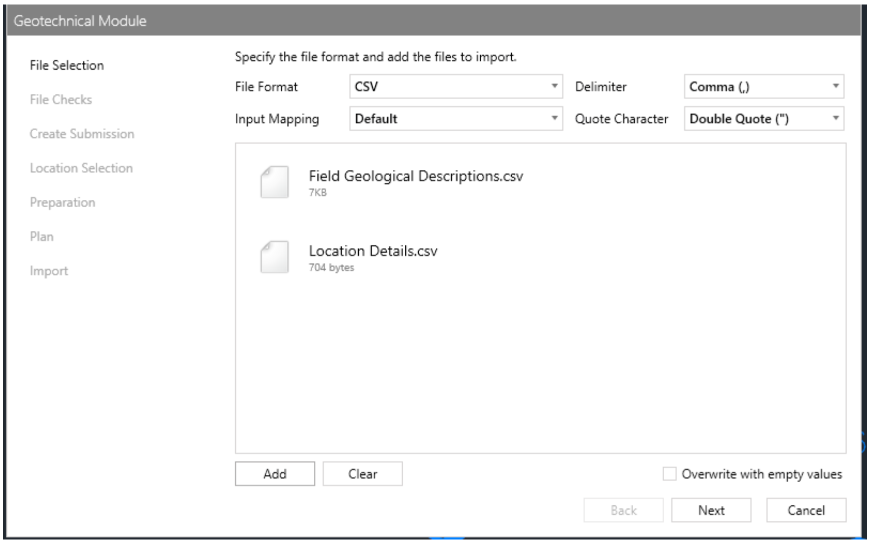
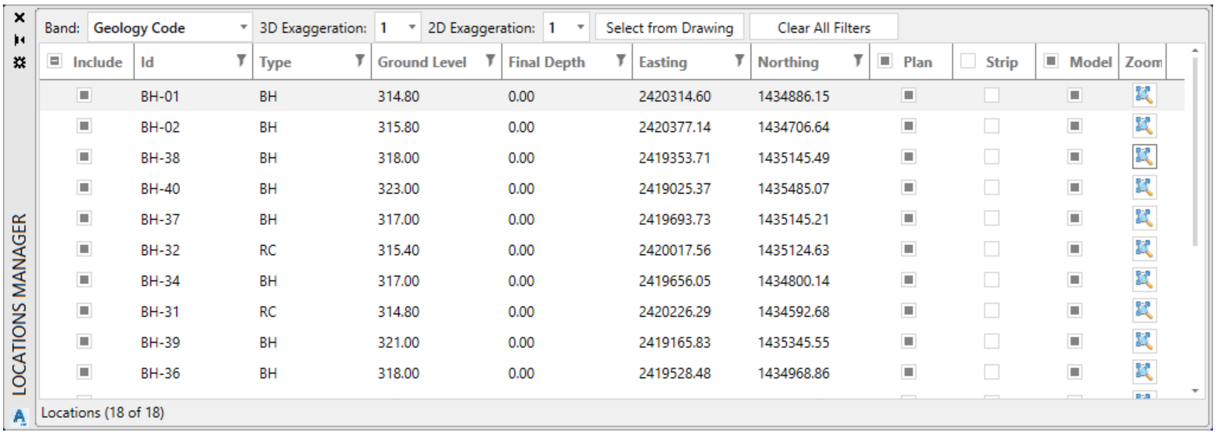


Image 32. Import Geotechnical data as CSV. files

The Geotechnical module provides management tools that help understand, visualize and manage the information: the location (Image 33) and the strata manager (Image 34).

The two of them provide an option name as Band by. This is used to specify the type of geotechnical data to create the surfaces on. This is a key tool for seeing the different kinds of surfaces created by the soil generalization made in the data interpretation. Another tool that can be used is the checkbox. Include to see only the information about the boreholes on.

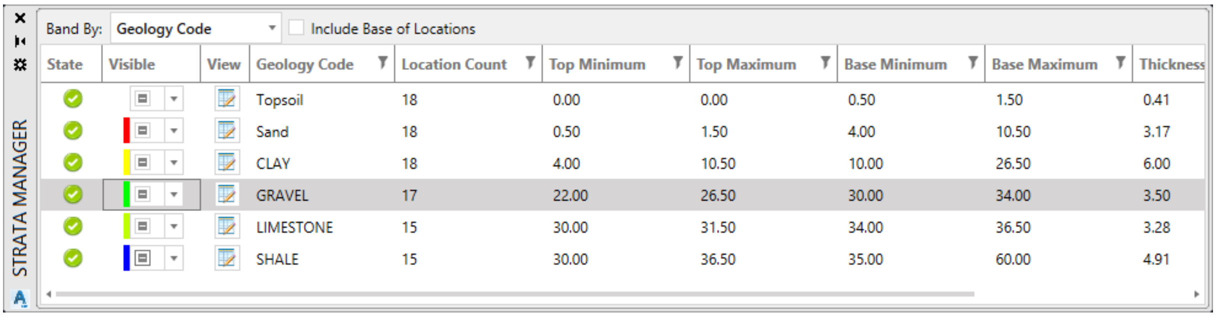


Include	Id	Type	Ground Level	Final Depth	Easting	Northing	Plan	Strip	Model	Zoom
■	BH-01	BH	314.80	0.00	2420314.60	1434886.15	■	□	■	
■	BH-02	BH	315.80	0.00	2420377.14	1434706.64	■	□	■	
■	BH-38	BH	318.00	0.00	2419353.71	1435145.49	■	□	■	
■	BH-40	BH	323.00	0.00	2419025.37	1435485.07	■	□	■	
■	BH-37	BH	317.00	0.00	2419693.73	1435145.21	■	□	■	
■	BH-32	RC	315.40	0.00	2420017.56	1435124.63	■	□	■	
■	BH-34	BH	317.00	0.00	2419656.05	1434800.14	■	□	■	
■	BH-31	RC	314.80	0.00	2420226.29	1434592.68	■	□	■	
■	BH-39	BH	321.00	0.00	2419165.83	1435345.55	■	□	■	
■	BH-36	BH	318.00	0.00	2419528.48	1434968.86	■	□	■	

Locations (18 of 18)

Image 33. Boreholes location manager Geotechnical Module

The strata manager is used to create and display strata surfaces; these surfaces are standard Civil 3D surfaces that can be edited and manipulated.



State	Visible	View	Geology Code	Location Count	Top Minimum	Top Maximum	Base Minimum	Base Maximum	Thickness
			Topsoil	18	0.00	0.00	0.50	1.50	0.41
			Sand	18	0.50	1.50	4.00	10.50	3.17
			CLAY	18	4.00	10.50	10.00	26.50	6.00
			GRAVEL	17	22.00	26.50	30.00	34.00	3.50
			LIMESTONE	15	30.00	31.50	34.00	36.50	3.28
			SHALE	15	30.00	36.50	35.00	60.00	4.91

Image 34. Strata manager Geotechnical Module

The following images show the boreholes’ plan and model (Image 35 and Image 36) and an example of 3D surface strata (Image 37).

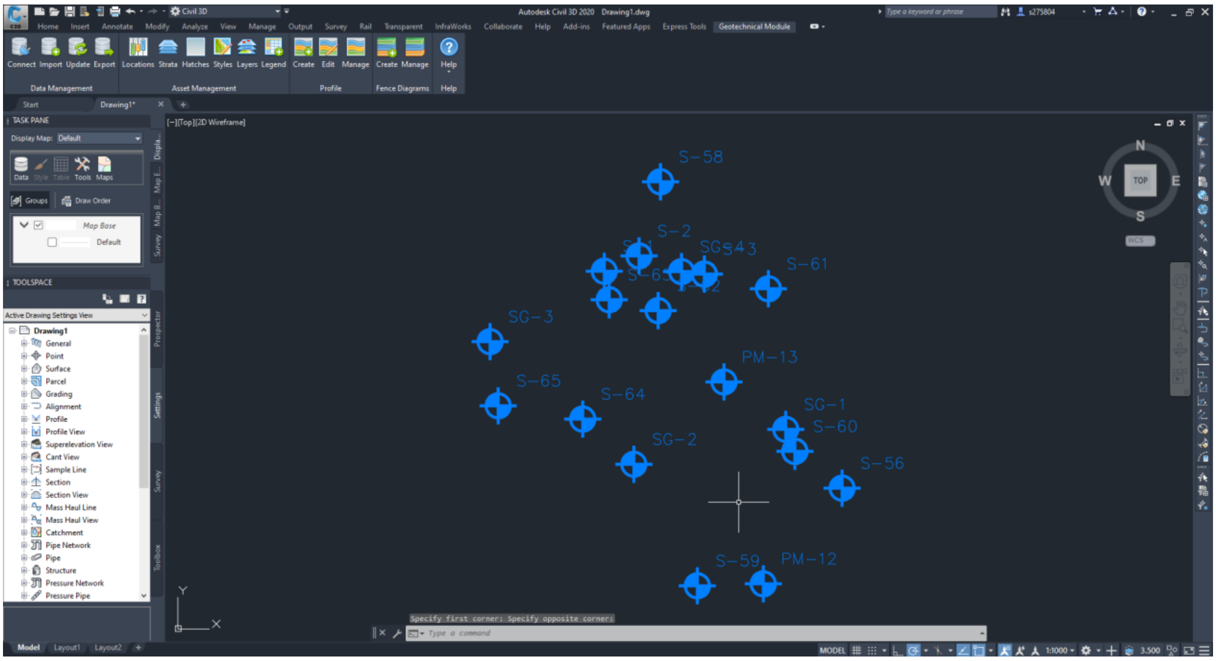


Image 35. Plan of the boreholes

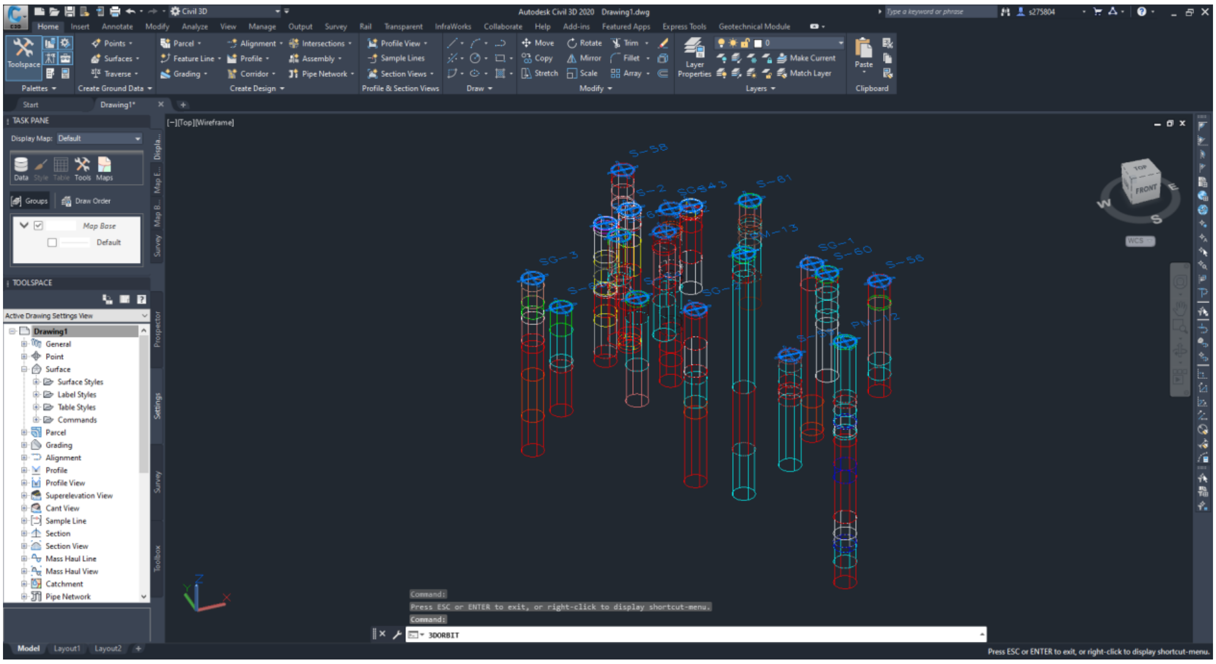


Image 36. 3D model of the boreholes

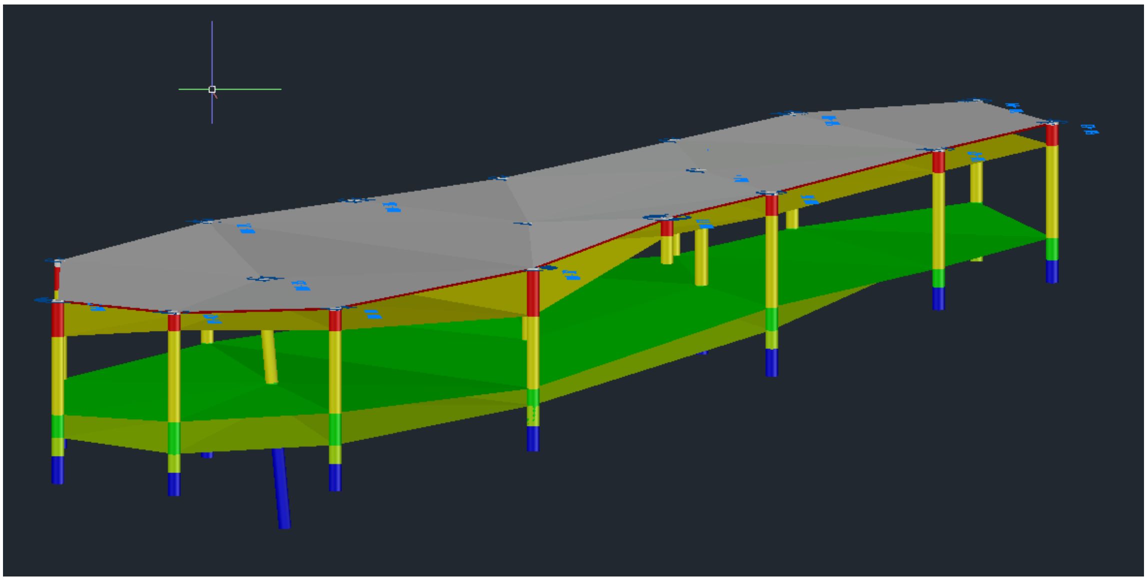


Image 37. A 3D model example of the soil surfaces strata

6 Study case: PSRI

6.1 Data Collection

This project is currently in development, and the recompilation of borehole data of the study area was already done. The borehole data was collected from the Piedmont region entity in two documents: the first one is the recompilation of the old information taken through the years, from 1990 until 2005, not only for boreholes but all kinds of soil exploration. The second one consists of four (4) boreholes made in 2022 and is the more recent information on the study area. Table 1 shows the stratigraphy information present in the documents mentioned before; this corresponds to the information on the whole site of the project.

Name	File
S1	R2_11_2019
S2	R2_11_2019
S3	R2_11_2019
S4	R2_11_2019
S5	R2_11_2019
SGE1	R2_11_2019
SGE2	R2_11_2019
SGE3	R2_11_2019
SGE4	R2_11_2019
SP1	R2_11_2019
SP2	R2_11_2019
SP3	R2_11_2019
Spi1	R2_11_2019
Spi2	R2_11_2019
Spi3	R2_11_2019
Spi4	R2_11_2019
Spi5	R2_11_2019
PM12	R2_11_2019
PM13	R2_11_2019
A	R2_11_2019
B	R2_11_2019
C	R2_11_2019
S56	R2_11_2019
S57	R2_11_2019
S58	R2_11_2019
S59	R2_11_2019
S60	R2_11_2019
S61	R2_11_2019
S62	R2_11_2019
S63	R2_11_2019
S64	R2_11_2019
S65	R2_11_2019
SOT1	R2_11_2019
SOT2	R2_11_2019
SOT3	R2_11_2019
SG1	Report indagini geognostiche
SG2	Report indagini geognostiche
SG3	Report indagini geognostiche
SG4	Report indagini geognostiche

Table 1. Name and file of the stratigraphy information data collection

Focus on the study area documents of the Piedmont region about the PSRI project; the stratigraphy information available is shown in Table 2.

Name	Code	Zone ubication	Stratigraphy available	File
SG4	---	Nord 1	YES	Report indagini
SG3	---	Nord 1	YES	Report indagini
SG2	---	Nord 1	YES	Report indagini
SG1	---	Nord 1	YES	Report indagini
S65	10300	Nord 1	YES	R2_11_2019
S64	10300	Nord 1	YES	R2_11_2019
S63	10300	Nord 1	YES	R2_11_2019
S62	10300	Nord 1	YES	R2_11_2019
S61	10300	Nord 1	YES	R2_11_2019
S60	10300	Nord 1	YES	R2_11_2019
S59	10300	Nord 1	YES	R2_11_2019
S58	10300	Nord 1	YES	R2_11_2019
S56	00300	Nord 1	YES	R2_11_2019
S3	10300	Nord 1	YES	R2_11_2019
S2	12300	Nord 1	YES	R2_11_2019
S1	12345	Nord 1	YES	R2_11_2019
PM13	10300	Nord 1	YES	R2_11_2019
PM12	00300	Nord 1	YES	R2_11_2019

Table 2. Stratigraphy information study area

This file also contains environmental information, to which for each borehole was added code, as is shown in the table below:

Code	Description
10000	Heavy metals
02000	Light hydrocarbons
00300	Heavy hydrocarbons
00040	Code PCB
00005	Code IPA

Table 3. Environmental codes

The different soil surfaces, ground level and depth for each borehole were collected from the exploration data. The geographic location of the boreholes also benefited from more practical use and a requirement for the use of Civil 3D. Table 4 is presented this information.

Location ID	Northing	Easting	Ground Level [m]	Depth [m]
S-1	4986830,61	394654,68	234	30
S-2	4986838,99	394673,71	234	30
S-3	4986829,04	394709,45	234	30
PM-12	4986659,55	394741,73	234	35
PM-13	4986770,00	394720,21	234	35
S-56	4986711,90	394784,86	234	16
S-58	4986879,55	394685,45	234	15
S-59	4986658,46	394705,63	234	15
S-60	4986732,04	394759,02	234	16
S-61	4986821,01	394744,51	234	15
S-62	4986809,04	394684,18	234	15
S-63	4986814,99	394657,38	234	15
S-64	4986749,69	394642,89	234	15
S-65	4986756,96	394596,60	234	15
SG-1	4986744,07	394754,01	234	25
SG-2	4986724,97	394670,88	234	25
SG-3	4986792,06	394592,17	234	25
SG-4	4986830,39	394696,99	234	25

Table 4. Location, ground level, and depth of boreholes information

Among all the data, a total of 18 boreholes were selected as our input data for the creation of soil surfaces using the Geotechnical Module. In the following Table 5 shows the information for the Location Detail file.

Location ID	Location Type	Northing	Easting	Ground Level
S-1	1990	4986830,61	394654,68	234
S-2	1990	4986838,99	394673,71	234
S-3	1990	4986829,04	394709,45	234
PM-12	2005	4986659,55	394741,73	234
PM-13	2005	4986770	394720,21	234
S-56	2005	4986711,9	394784,86	234
S-58	2005	4986879,55	394685,45	234
S-59	2005	4986658,46	394705,63	234
S-60	2005	4986732,04	394759,02	234
S-61	2005	4986821,01	394744,51	234
S-62	2005	4986809,04	394684,18	234
S-63	2005	4986814,99	394657,38	234
S-64	2005	4986749,69	394642,89	234
S-65	2005	4986756,96	394596,6	234
SG-1	2022	4986744,07	394754,01	234
SG-2	2022	4986724,97	394670,88	234
SG-3	2022	4986792,06	394592,17	234
SG-4	2022	4986830,39	394696,99	234

Table 5. Stratigraphy Location Detail CSV file

For the stratigraphy, the information was transcribed from the pdf files (Image 38) into excel, as shown in Table 6.

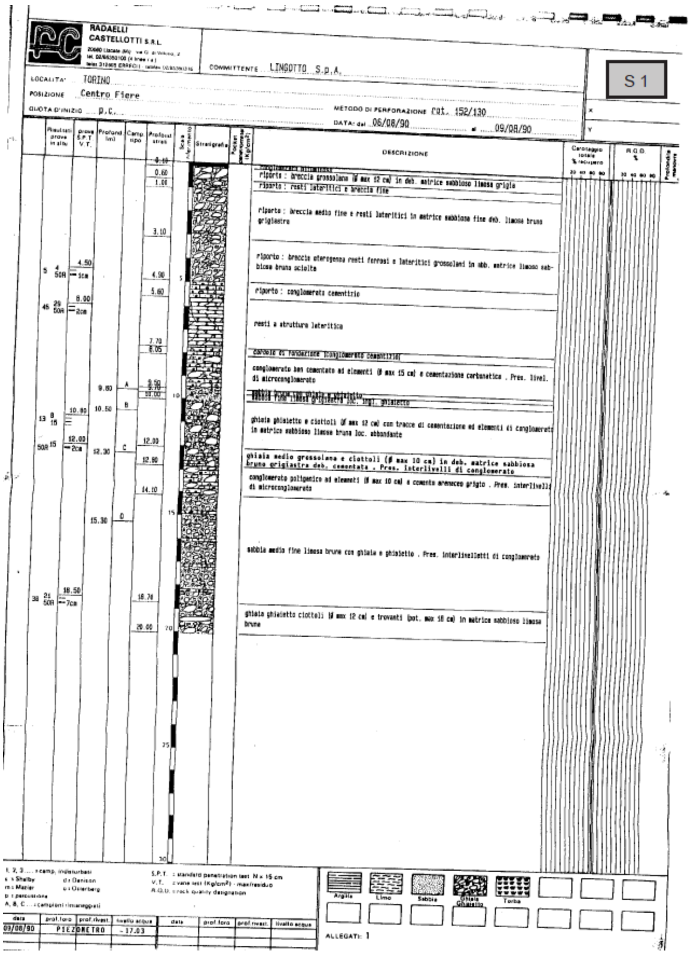


Image 38. Stratigraphy S-1 pdf file.

Source: *(Calafiore M. L., 2019)*

Location ID	Top depth [m]	Base depth [m]	Stratigrafia completa
S-1	0	0.1	Conglomerato bituminoso
S-1	0.1	0.6	Riporto: breccia grossolana (d max 12 cm) in deb. matrice sabbiosa limosa grigia
S-1	0.6	3.10	Riporto: resti lateritici e breccia fine
S-1	3.10	4.90	Riporto: breccia medio fine e resti lateritici grossolani in abbondante matrice limoso sabbiosa bruna sciolta
S-1	4.90	5.60	Riporto: conglomerato cementizio
S-1	5.60	7.70	Resti a struttura lateritica
S-1	7.70	8.05	Cordolo di fondazione (conglomerato cementizio)
S-1	8.05	9.50	Conglomerato ben cementato ad elementi (d max 15 cm) e cementazione carbonatica. Presenza di livelli di microconglomerato
S-1	9.50	9.70	Sabbia bruna con ghiaia e ghiaietto
S-1	9.70	10.00	Sabbia fine limosa grigiastra loc. ingl. ghiaietto
S-1	10.00	12.00	Ghiaia ghiaietto e ciottoli (d max 12 cm) con tracce di cementazione ed elementi di conglomerato in matrice sabbioso limosa bruna loc. abbondante
S-1	12.00	12.80	Ghiaia medio grossolana e ciottoli (d max 10 cm) in deb. matrice sabbiosa bruno grigiastra debolmente cementata. Presenza di interlivelli di conglomerato
S-1	12.80	14.10	Conglomerato poligenico ad elementi (d max 10 cm) a cemento arenaceo grigio. Presenza interlivelli di microconglomerato
S-1	14.10	18.70	Sabbia medio fine limosa bruna con ghiaia e ghiaietto. Pres. interlivelletti di conglomerato
S-1	18.70	20	Ghiaia ghiaietto ciottoli (d max 12 cm) e trovanti (pot. max 18 cm) in matrice sabbioso limosa bruna

Table 6. Stratigraphy S-1 excel file

Some information about the georeferenced module. As the information about the location of the boreholes concerning a coordinated global system was not found, was proceed to use google earth helps. Knowing the boundary of the study area was selected as an easily identifiable visual point with the WGS84 coordinate system. AutoCAD measured the distance north and west from this point to the boreholes to find the corresponding coordinates.

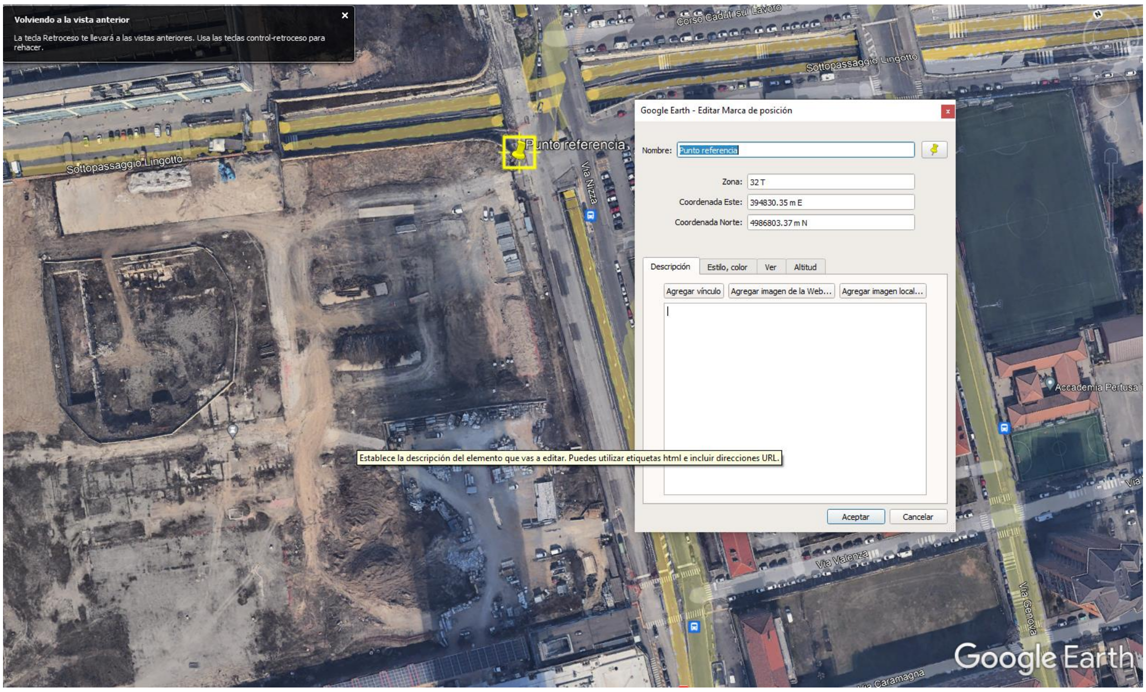


Image 39. Point as reference for coordinates

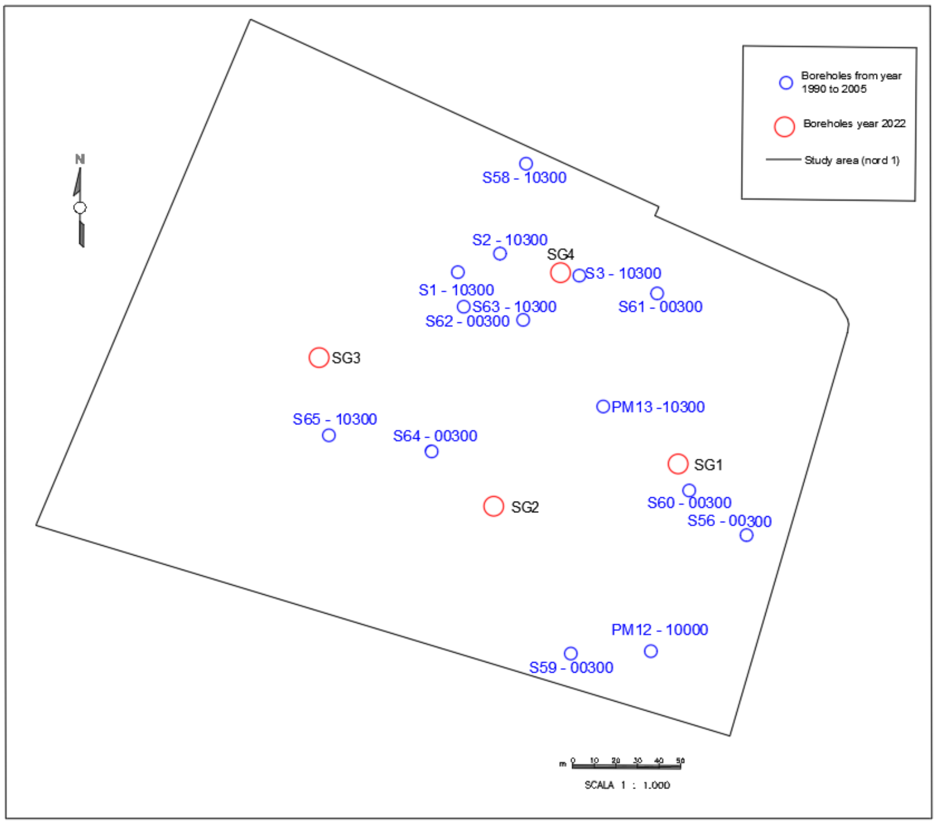


Image 40. Boreholes plan in AutoCAD

Finally, the coordinates and the geolocation module corroborated the location of the boreholes in AutoCAD Civil 3D (Image 41).

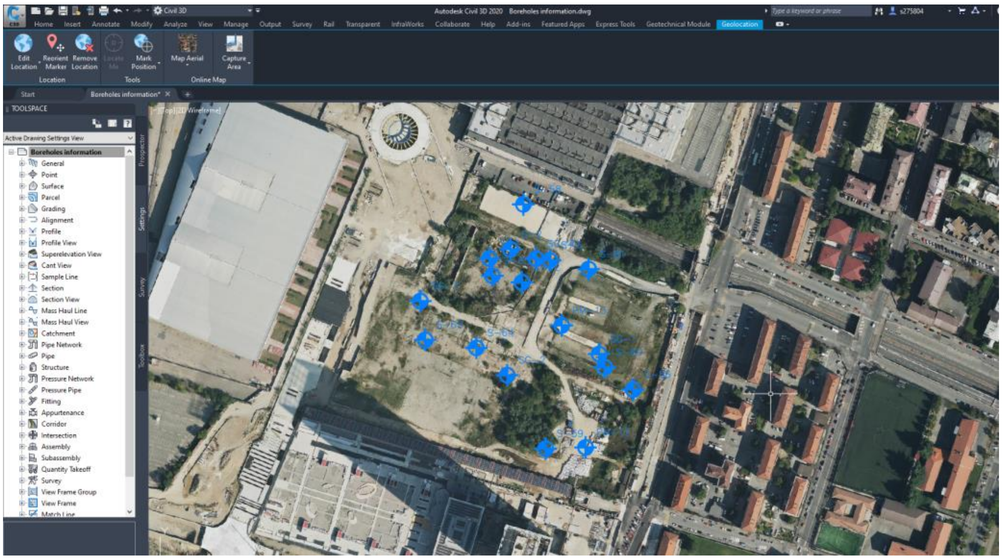


Image 41. Boreholes geolocation in Civil 3D (study area)

6.2 Data management and interpretation

This section explains how the collected data was organized to be understood and processed. After all the stratigraphy information was passed from the pdf files to an excel database, as was shown in Table 6 above, the next step was to refine the valuable information for the soil surface 3D modeling so the color and dimension of the grains were omitted.

After choosing the essential information for creating the first 3D surface model (geology code column), we obtained 34 kinds of soil surfaces, as shown in Table 7. With the help of the Geotechnical Module is possible to see how many soils are present.

1	Bituminous conglomerate	3
2	Rubble	1
3	Remains	2
4	Cement conglomerate	3
5	Sand	8
6	Gravel	7
7	Pebbles	1
8	Silt	2
9	Reinforced concrete	8
10	Organic	1
11	Cement	2
12	Rubble-Remains	2
13	Sand-Gravel	7
14	Gravel-Pebbles	13
15	Gravel-Sand-Pebbles	10
16	Gravel-Sand-Pebbles-Remains	3
17	Sand-Pebbles	7
18	Gravel-Pebbles-Remains	1
19	Pebbles-Reinforced concrete	1
20	Gravel-Sand-Remains	2
21	Gravel-Remains	1
22	Remains-Cement	1
23	Conglomerate-Gravel	4
24	Clay-Silt	1
25	Gravel-Silt	1
26	Gravel-Silt-Pebbles	1
27	Cement- Silt	1
28	Gravel-Pebbles-Sand	1
29	Sand-Silt	1
30	Silt-Sand	1
31	Gravel-Sand-Silt	1
32	Sand-Gravel-Pebbles	1
33	Gravel-Pebbles-Sand-Silt	1
34	Sand-Silt-Gravel-Pebbles	1

Table 7. Soil surfaces and presence quantity

One of the limitations of the Geotechnical Module is the creation of lenses or faults, so for the first soil generalization, the soils with only one presence were included in another type of soil. Table 8 shows the soils contained in another principal soil and the borehole ID present for easy identification.

	Principal soil	Other soils								
SOIL GENERALIZATION #1	Gravel	Rubble	Rubble-Remains	Rubble-Remains	Cement conglomerate	Cement conglomerate	Gravel-Remains	Organic	Gravel-Remains	Gravel-Silt
		S1	S1	S2	S2	S3	SG-4	SG-4	S64	SG-4
	Reinforced concrete	Remains-Cement	Cement	Cement	Pebbles-Reinforced concrete	Cement-Silt				
		SG-3	S59	S62	S59	S61				
	Sand	Pebbles	Silt	Sand-Silt	Silt-Sand	Clay-Silt				
		PM-12	S62	S61	S61	SG-4				
	Gravel-Pebbles	Gravel-Silt-Pebbles	Gravel-Silt	Silt	Gravel-Pebbles-Remains					
		SG-4	SG-4	SG-4	S59					
	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles-Remains	Gravel-Sand-Pebbles-Remains	Gravel-Sand-Pebbles-Remains	Sand-Silt-Gravel-Pebbles	Gravel-Pebbles-Sand-Silt				
		S56	S58	S59	S61	S60				
	Gravel-Sand	Gravel-Sand-Remains	Gravel-Sand-Remains	Pebbles						
		S62	S63	PM-12						
	Conglomerate	Remains	Cement conglomerate	Conglomerate-Gravel	Bituminous conglomerate					
		S1-SG3	S1-S2-S3	SG1-SG2-SG3-SG4	S1-S2-S3					

Table 8. First soil generalization scheme organization

After making this first soil generalization, the resultant soils (geology code 2 column) are shown in Table 9 with their presence quantity.

Number	Soil	Presence quantity
1	Conglomerate	7
2	Sand	10
3	Gravel	9
4	Reinforced concrete	11
5	Sand-Gravel	10
6	Gravel-Pebbles	15
7	Gravel-Sand-Pebbles	13
8	Sand-Pebbles	7

Table 9. Soil surfaces resulted from the first soil generalization

But a correct soil generalization, and a common practice in geotechnical engineering, is to generalize the soil profiles based on dominant compositions. For this part, was not only take into consideration the description for each layer in the stratigraphy's but also the information provided in the chapter 4.2 about stratigraphic general and local structure. Table 10 shows the second soil generalization, organized by principal soil and borehole ID.

	Fragment of past workings	Filling material	Sand and Gravel	Gravelly soil with fine matrix
S1	Bituminous Conglomerate	Rubble	Sand-Gravel	Gravel-Pebbles
	Remains	Rubble-Remains	Sand	Cement Conglomerate
	Cement Conglomerate	Cement Conglomerate	-	-
S2	Bituminous Conglomerate	Gravel	-	Gravel
	Cement Conglomerate	Rubble-Remains	-	Gravel-Pebbles
	-	Sand	-	Cement Conglomerate
S3	Bituminous Conglomerate	-	Sand	Gravel-Pebbles
	Cement Conglomerate	-	-	Gravel
PM-12	Reinforced concrete	-	Gravel-Sand-Pebbles	Gravel-Pebbles
	-	-	Sand-Gravel	Pebbles
	-	-	Pebbles	-
	-	-	Sand	-
	-	-	Gravel	-
PM-13	Reinforced concrete		Gravel-Sand-Pebbles	Gravel-Pebbles
S-56	Reinforced concrete	Gravel-Sand-Pebbles-Remains	Sand-Pebbles	Gravel-Pebbles
	-	-	Gravel-Sand-Pebbles	-
S-58	-	Gravel-Sand-Pebbles-Remains	Sand-Gravel	-
	-	-	Sand-Pebbles	-
	-	-	Sand	-
S-59	Cement	Gravel-Pebbles-Remains	Gravel-Sand-Pebbles	-
	Pebbles-Reinforced concrete	-	Sand-Gravel	-
	-	-	Gravel-Sand-Pebbles-Remains	-
S-60	Reinforced concrete	Gravel-Pebbles	Gravel-Sand-Pebbles	-
	-	-	Sand-Gravel	-
	-	-	Gravel-Pebbles-Sand-Silt	-
S-61	Reinforced concrete	Sand-Pebbles	Gravel-Sand-Pebbles	-
	Cement-Silt	-	Sand-Silt	-
	-	-	Sand-Gravel	-
	-	-	Gravel-Pebbles-Sand-Silt	-
S-62	Cement	Gravel-Sand-Remains	Silt	Gravel-Pebbles
	-	-	Sand-Pebbles	-
	-	-	Gravel-Sand-Pebbles	-
S-63	Reinforced concrete	-	Gravel-Sand-Remains	Gravel-Pebbles
	-	-	Gravel-Sand-Pebbles	-
	-	-	Sand-Pebbles	-
S-64	Reinforced concrete	Gravel-Remains	Gravel-Sand-Pebbles	-
	-	-	Sand-Pebbles	-
S-65	Reinforced concrete	-	Gravel-Sand-Pebbles	Gravel-Pebbles
	-	-	Sand-Gravel	-
SG-1	-	Sand-Pebbles	-	Gravel-Pebbles
	-	-	-	Conglomerate-Gravel
	-	-	-	Gravel
SG-2	-	Gravel	Sand	Gravel-Pebbles
	-	-	Gravel-Sand-Pebbles	Conglomerate-Gravel
SG-3	Remains-Cement	Remains	Sand	Gravel-Pebbles
	Reinforced concrete	-	Sand-Pebbles	Gravel
	-	-	-	Conglomerate-Gravel
SG-4	Organic	Gravel-Remains	Gravel-Sand-Pebbles	Clay-Silt
	Conglomerate-Gravel	Sand-Gravel	Gravel-Silt-Pebbles	Sand
	-	-	-	Gravel-Pebbles
	-	-	-	Gravel-Silt
	-	-	-	Gravel

Table 10. Second soil generalization scheme organization

After making this second soil generalization, the resultant soils (legend code column) are shown in Table 11 with their presence quantity.

Number	Soil	Presence quantity
1	Fragments of past workings	15
2	Filling material	13
3	Sand and Gravel	16
4	Gravelly soil with fine matrix	13

Table 11. Soil surfaces resulted from the second soil generalization

Table 12 shows the information used for the Field Geological Description files for the S-1 borehole information. The other boreholes' Field Geological Description files are presented at the end of the document as annexes.

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-1	0	0.1	Fragment of past workings	Bituminous Conglomerate	Conglomerate	Conglomerato bituminoso
S-1	0.1	0.6	Filling material	Rubble	Gravel	Riporto: breccia grossolana (d max 12 cm) in deb. matrice sabbiosa limosa grigia
S-1	0.6	3.10	Filling material	Rubble-Remains	Gravel	Riporto: resti lateritici e breccia fine
S-1	3.10	4.90	Filling material	Rubble-Remains	Gravel	Riporto: breccia medio fine e resti lateritici grossolani in abbondante matrice limoso sabbiosa bruna sciolta
S-1	4.90	5.60	Filling material	Cement Conglomerate	Conglomerate	Riporto: conglomerato cementizio
S-1	5.60	7.70	Fragment of past workings	Remains	Conglomerate	Resti a struttura lateritica
S-1	7.70	8.05	Fragment of past workings	Cement Conglomerate	Conglomerate	Cordolo di fondazione (conglomerato cementizio)
S-1	8.05	9.50	Fragment of past workings	Cement Conglomerate	Conglomerate	Conglomerato ben cementato ad elementi (d max 15 cm) e cementazione carbonatica. Presenza di livelli di microconglomerato
S-1	9.50	9.70	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia bruna con ghiaia e ghiaietto
S-1	9.70	10.00	Sand and Gravel	Sand	Sand	Sabbia fine limosa grigiastra loc. ingl. ghiaietto
S-1	10.00	12.00	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia ghiaietto e ciottoli (d max 12 cm) con tracce di cementazione ed elementi di conglomerato in matrice sabbioso limosa bruna loc. abbondante
S-1	12.00	12.80	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia medio grossolana e ciottoli (d max 10 cm) in deb. matrice sabbiosa bruno grigiastra debolmente cementata. Presenza di interlivelli di conglomerato
S-1	12.80	14.10	Gravelly soil with fine matrix	Cement Conglomerate	Conglomerate	Conglomerato poligenico ad elementi (d max 10 cm) a cemento arenaceo grigio. Presenza interlivelli di microconglomerato
S-1	14.10	18.70	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia medio fine limosa bruna con ghiaia e ghiaietto. Pres. interlivelletti di conglomerato
S-1	18.70	20	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia ghiaietto ciottoli (d max 12 cm) e trovanti (pot. max 18 cm) in matrice sabbioso limosa bruna

Table 12. S-1 borehole Field Geological Description

6.3 Visualization and Management (Civil 3D)

AutoCAD Civil 3D 2022, with the extension of the Geotechnical Module, was used as the geotechnical BIM tool for the present study. Specifically, the soil data was modeled by importing the CSV files mentioned above into the software. When the model was completed, random sections were cut through the 3D model to visualize the cross-sectional profile. The profile was then compared with the soil profile and interpreted for any discrepancies to ensure the correctness of the modeling (Lee, et al., 2021).

7 Results

The first modeling attempt was performed by generating a 3D surface model based on the detailed data extracted from the investigation site reports. The modeling involved data from a restricted but enough number (18) of boreholes, but due to the number of soil surfaces generated, the result was highly complicated. Thirty-four types of soil were found, but many were present only in one borehole (lens cases), and the software doesn´t model this information. Practically, only 16 types of soil material can be interpolated to generate the surfaces as a representation of the case study's different compositions of the in situ soils (Image 42). From a 3D soil surfaces model like this, extracting useful information for practical design is very difficult.

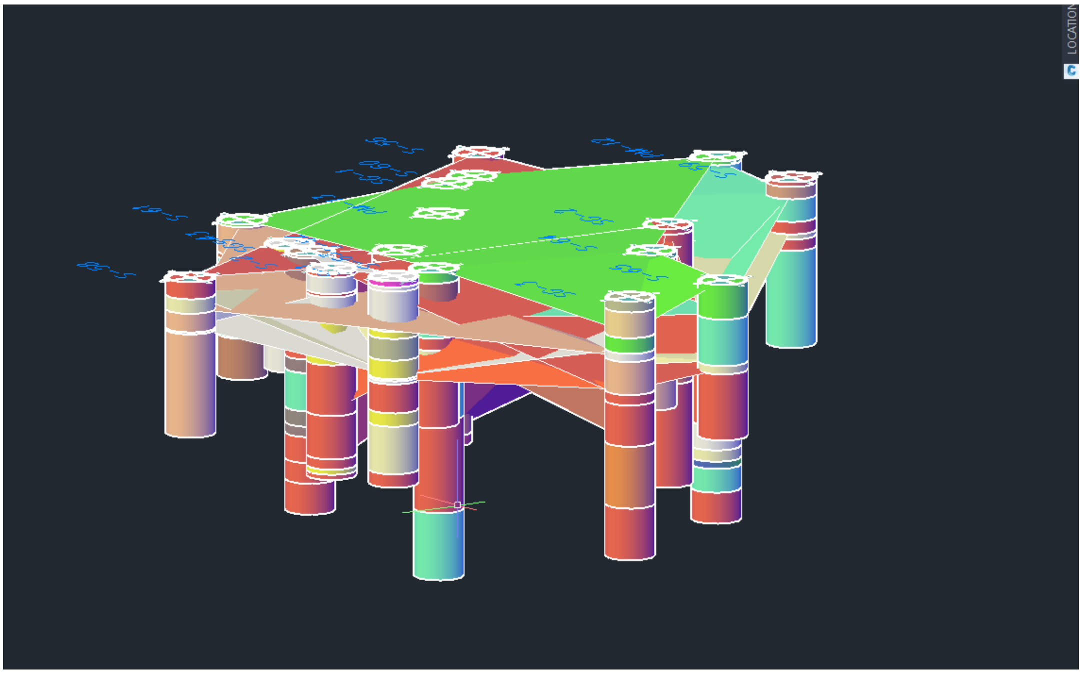


Image 42. 3D soil surface model for the case study based on detailed soil investigation data

Because of the detailed soil data was not possible to produce presentable soil strata, numerous overlaps of soil layers are visible, and much information is not interpolated due to lens conditions.

The second attempt aimed to generate a cleaner and more presentable 3D soil model (Image 43) by generalizing the soil strata; almost all the lenses of diverse soil material was bedded into the principal soil layers. A total of 8 types of soil were used, Table 8 above. This attempt successfully interpolated the soil data but are still visible numerous overlaps of soil layers in the cross-sectional profile provided in Image 40, that should be manually correct.

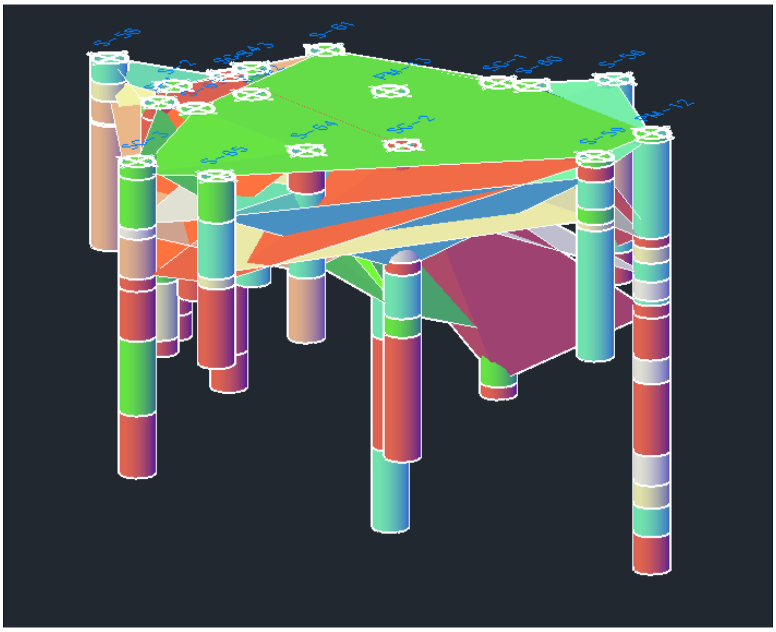


Image 43. 3D soil surface model for the case study based on the first generalization

The third attempt aimed to generate, again, a cleaner and more presentable 3D soil model. For the input data was made an enormous soil generalization base on the local and general stratigraphy description, only four dominant soils were used into the model. Likewise, substantial modeling efforts to calibrate the model to make a presentable soil surface model was required. Some of the soil layers were modeled as continuous, not being the case, so this was assumed to diminish gradually until they intersected with the other soil layer. In other cases, a soil layer was on top of another, and another was at the bottom, meaning that there are different strata layers and should not be interpolated as one layer. Practically and in reality, for soil strata, only the same soil types in adjacent boreholes and the same position strata should be linked up to form the soil layers.

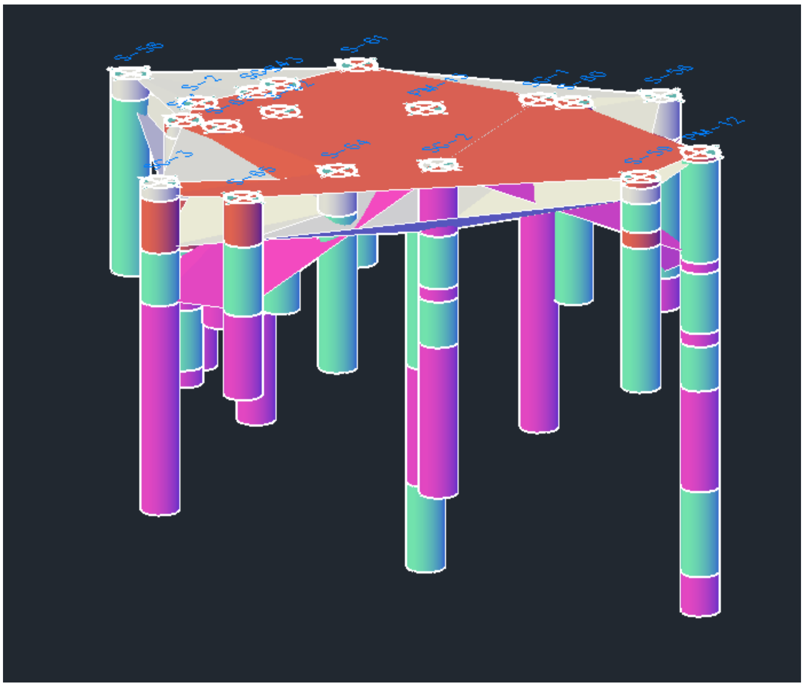


Image 44. 3D soil surface model for the case study based on the second generalization

8 Conclusions

The results showed that the 3D surface soil modeling required huge modeling and computational efforts, mainly when dealing with highly detailed soil profiles, as in the study case. Despite this, with correct asses of the data, successful integration of geotechnical soil data with the BIM methodology through a tridimensional model created with the extension known as Geotechnical Module for the case study of the Parco della Salute, della Ricerca e dell´Innovazione, can be done. Other following conclusions can be drawn from the study:

- all the stratigraphy data was successfully collected for the study case, thanks to the compiled pdf files. Although much of the borehole information in this file could not relate to our specific area.
- The information required manual effort to be organized, but now an excel database for the (18) boreholes is available. More easy management of the data.
- The soil generalizations were opportunely reached but, without proper knowledge of geology, are not entirely reliable.
- A 3D surface model was successfully generated for the case study using commercial software AutoCAD Civil 3D 2022, with the extension of the Geotechnical Module. The modeling procedures can be divided into three stages: data collection, interpretation, and visualization.
- 3D surface modeling requires significant modeling and computational efforts, mainly when dealing with highly detailed soil profiles due to intense human interventions in this study case. A good soil profile generalization is required necessary for the data interpretation stage.
- Surface models with different levels of detailing could serve various engineering applications with their advantages/shortcomings. The model based on detailed data can be used for detailed analysis and designs of substructures. The model based on a generalized soil profile is best for presentation purposes.
- Surfaces dynamic cross-sectional profiles were successfully generated for the case study.

- The extension only allows visualization of 3D surfaces (geometric information) but has no functionality for visualizing other geotechnical data.
- Geotechnical BIM is still a relatively new concept in Italy's construction industry. For the present case study, it was evident that many processes still require manual operations, such as input data, soil generalization, data interpretation, and lens creation.

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10 Annexes

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-2	0	0.05	Fragment of past workings	Bituminous Conglomerate	Conglomerate	Conglomerato bituminoso
S-2	0.05	0.40	Filling material	Gravel	Gravel	Riporto: ghiaietto e ghiaia in matrice sabbiosa grigiastra
S-2	0.40	2.00	Filling material	Rubble-Remains	Gravel	Riporto: breccia (d max 9 cm) e resti lateritici in matrice sabbiosa deb. limosa bruno grigiastra
S-2	2.00	2.30	Filling material	Gravel	Gravel	Riporto: ghiaietto e ghiaia in matrice sabbiosa grigiastra
S-2	2.30	4.60	Filling material	Sand	Sand	Riporto: sabbia fine limosa marrone ingl. rara breccia (d max 5 cm) e resti lateritici
S-2	4.60	8.90	Fragment of past workings	Cement Conglomerate	Conglomerate	Conglomerato cementizio . Pres. tondino (d 3 cm) a 6.30 m
S-2	8.90	10.00	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbioso deb. limosa marrone bruna
S-2	10.00	12.00	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbiosa deb. limosa grigrio verdastra
S-2	12.00	13.80	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbiosa deb. limosa marrone grigiastra
S-2	13.80	14.50	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto e ghiaia e rari ciottoli (d max 8 cm) in matrice sabbiosa limosa marrone
S-2	14.50	16.60	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto, ghiaia e rari ciottoli (d max 12 cm) in matrice sabbiosa deb. limosa bruna
S-2	16.60	18.00	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto, ghiaia e rari ciottoli (d max 9 cm) in matrice sabbiosa deb. limosa marrone
S-2	18.00	19.00	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbiosa deb. limosa marrone grigia. Pres. interlivello di conglomerato
S-2	19.00	19.50	Gravelly soil with fine matrix	Cement Conglomerate	Gravel	Conglomerato e cemento arenaceo vacuolare molto fratturato loc. deb. cementato
S-2	19.50	20.00	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbiosa deb. limosa marrone

Table 13. S-2 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-3	0	0.05	Fragment of past workings	Bituminous Conglomerate	Conglomerate	Conglomerato bituminoso
S-3	0.05	0.80	Fragment of past workings	Cement Conglomerate	Conglomerate	Conglomerato cementizio
S-3	0.80	1.00	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto ghiaia e ciottoli in matrice sabbioso limosa marrone
S-3	1.00	1.20	Sand and Gravel	Sand	Sand	Sabbia limosa marrone ingl. raro ghiaietto
S-3	1.20	3.00	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaietto e ghiaia in matrice sabbiosa deb.limosa marrone grigia
S-3	3.00	5.00	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto ghiaia e ciottoli (d max 12 cm) in matrice sabbiosa deb. limosa marrone grigia
S-3	5.00	7.50	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaietto ghiaia e ciottoli (d max 12 cm) in matrice sabbiosa deb. limosa. Idem c.s marrone bruna
S-3	7.50	10.30	Sand and Gravel	Sand	Sand	Sabbia da fine a finissima limosa marrone. Loc. Pres. rari resti vegetali
S-3	10.30	11.20	Sand and Gravel	Sand	Sand	Sabbia limosa marrone bruna ingl. ghiaietto e rara ghiaia
S-3	11.20	12.00	Sand and Gravel	Sand	Sand	Sabbia fine limosa bruno nocciola loc. ingl. Raro ghiaietto

Table 14. S-3 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
PM-12	0	0.3	Fragment of past workings	Reinforced concrete	Reinforced concrete	Calcestruzzo
PM-12	0.3	4.5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ghiaia grossolana e sabbia deb. limosa di colore marrone, con ciottoli (presenza di qualche scoria a 2,00 m)
PM-12	4.5	8.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia fine deb. limosa color grigio, con ghiaia da media a grossolana, con ciottoli
PM-12	8.0	8.8	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli in matrice sabbiosa fine e ghiaia
PM-12	8.8	10.0	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia fine e ghiaia medio grossolana
PM-12	10.0	11.5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ciottoli, ghiaia e sabbia
PM-12	11.5	11.8	Sand and Gravel	Pebbles	Sand	Ciottoli
PM-12	11.8	13.0	Sand and Gravel	Sand	Sand	Sabbia fine deb. limosa grigia
PM-12	13.0	13.4	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia fine deb. limosa grigia, con ghiaia grossolana e ciottoli nella parte finale (13-13,4 m)
PM-12	13.4	14.4	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli e ghiaia in matrice sabbiosa limosa marrone
PM-12	14.4	17.8	Sand and Gravel	Gravel	Gravel	Ghiaia da media a grossolana, sabbiosa e limosa di color marrone
PM-12	17.8	19.7	Gravelly soil with fine matrix	Pebbles	Sand	Ciottoli (anche decimetrici) in scarsa matrice sabbiosa deb. limosa (livelletti di Ceppo)
PM-12	19.7	25.5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia e ciottoli anche decimetrici in matrice sabbiosa limosa marrone
PM-12	25.5	27.9	Sand and Gravel	Sand	Sand	Sabbia da fine a media
PM-12	27.9	29.0	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia e ghiaia grossolana
PM-12	29.0	29.7	Sand and Gravel	Pebbles	Sand-Gravel	Ciottoli grigi
PM-12	29.7	32.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da media a grossolana deb. limosa color marrone, con ghiaia da media a grossolana o con ciottoli
PM-12	32.0	35.0	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia e ciottoli in matrice sabbiosa deb. limosa

Table 15. PM-12 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
PM-13	0	0.5	Fragment of past workings	Reinforced concrete	Reinforced concrete	Calcestruzzo
PM-13	0.5	2.5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia con ghiaia e ciottoli deb. limosa. Presenza di laterizi
PM-13	2.5	3.5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli e ghiaia in matrice sabbiosa
PM-13	3.5	12.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da fine a media deb. limosa grigia con ghiaia grossolana e ciottoli anche decimetrici (livello di ceppo)
PM-13	12.0	19.5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da fine a media deb. limosa grigia con ghiaia grossolana e ciottoli anche decimetrici (livello di ceppo). Cambia il colore verso i 15-20 m perché si entra in falda
PM-13	19.5	28.5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli e ghiaia grossolana in matrice sabbiosa limosa
PM-13	28.5	35.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da fine a media localmente deb. limosa. Presenza di livelli con ciottoli e ghiaia

Table 16. PM-13 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-56	0	3.0	Filling material	Gravel-Sand-Pebbles-Remains	Gravel-Sand-Pebbles	Riporto: ciottoli, ghiaia e sabbia, laterizi, probabile riempimento di uno scantinato con le macerie della demolizione degli edifici preesistenti
S-56	3.0	3.3	Fragment of past workings	Reinforced concrete	Reinforced concrete	Calcestruzzo
S-56	3.3	11.3	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Sabbia da media a fine ghiaiosa debolmente limosa di colore grigio chiaro con ciottoli
S-56	11.3	13.5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia media color marrone con ghiaia e rari ciottoli
S-56	13.5	16.0	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia con ciottoli in matrice sabbioso limosa color grigio

Table 17. S-56 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-58	0	1.6	Filling material	Gravel-Sand-Pebbles-Remains	Gravel-Sand-Pebbles	Riporto: ghiaia e sabbia color marrone, rari ciottoli e laterizi
S-58	1.6	3.0	Sand and Gravel	Sand-Gravel	Sand-Gravel	Ghiaia grossolana con sabbia limosa
S-58	3.0	4.8	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Sabbia ghiaiosa con qualche ciottolo, presenza di scorie
S-58	4.8	5.0	Sand and Gravel	Sand	Sand	Sabbia fine debolmente limosa color marrone rossastro
S-58	5.0	15.0	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Sabbia da fine a media color marrone ghiaiosa con rari ciottoli

Table 18. S-58 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-59	0	0.4	Fragment of past workings	Cement	Reinforced concrete	Cemento
S-59	0.4	1.6	Filling material	Gravel-Pebbles-Remains	Gravel-Pebbles	Riporto: ghiaia con ciottoli e laterizi
S-59	1.6	3.8	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da debolmente a limosa con ghiaia e rari ciottoli. Presenza di scorie marrone scuro
S-59	3.8	5.0	Fragment of past workings	Pebbles-Reinforced concrete	Reinforced concrete	Ciottoli e calcestruzzo
S-59	5.0	5.5	Sand and Gravel	Sand-Gravel	Sand-Gravel	Ghiaia con sabbia fine
S-59	5.5	6.6	Sand and Gravel	Gravel-Sand-Pebbles-Remains	Gravel-Sand-Pebbles	Sabbia da debolmente a limosa con rari ciottoli e ghiaia, presenza di laterizi
S-59	6.6	16.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ghiaia e sabbia fine da debolmente a limosa con ciottoli. Livello piú grossolano costituito da ciottoli da 10.00 a 10.50 mt.

Table 19. S-59 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-60	0	0.6	Fragment of past workings	Reinforced concrete	Reinforced concrete	Cemento armato
S-60	0.6	2.0	Filling material	Gravel-Pebbles	Gravel-Pebbles	Ghiaia con ciottoli in matrice sabbioso limosa marrone. (Probabile terreno di riporto)
S-60	2.0	3.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia con ghiaia e rari ciottoli, colore marrone
S-60	3.0	5.0	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia fine, grigia, con ghiaia da medio a grossolana
S-60	5.0	6.3	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ciottoli e ghiaia, con sabbia debolmente limosa nocciola grigiastra
S-60	6.3	7.5	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia con ghiaia da media a grossolana, nocciola grigiastra
S-60	7.5	15.0	Sand and Gravel	Gravel-Pebbles-Sand-Silt	Gravel-Sand-Pebbles	Ghiaia da medio a grossolana e ciottoli, con sabbia fine, grigia, da debolmente limosa a limosa

Table 20. S-60 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-61	0	0.2	Fragment of past workings	Reinforced concrete	Reinforced concrete	Calcestruzzo
S-61	0.2	3.0	Filling material	Sand-Pebbles	Sand-Pebbles	Riporto: materiale di varia natura, presenza di legname, sabbia e ciottoli di colore marrone rossastro
S-61	3.0	3.5	Fragment of past workings	Cement-Silt	Reinforced concrete	Calce e cemento
S-61	3.5	4.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ghiaia con ciottoli e sabbia
S-61	4.0	4.6	Sand and Gravel	Sand-Silt	Sand	Sabbia limosa grigio scura
S-61	4.6	5.6	Sand and Gravel	Silt-Sand	Sand	Limo sabbioso marrone rossastro
S-61	5.6	6.5	Sand and Gravel	Sand-Gravel	Sand-Gravel	Ghiaia grossolana con sabbia debolmente limosa color rossastra
S-61	6.5	11.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia color marrone con ghiaia e rari ciottoli
S-61	11.0	15.0	Sand and Gravel	Gravel-Pebbles-Sand-Silt	Gravel-Sand-Pebbles	Sabbia da fine a media color grigio ghiaiosa localmente debolmente limosa con ciottoli

Table 21. S-61 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-62	0	0.8	Fragment of past workings	Cement	Reinforced concrete	Cemento
S-62	0.8	2.1	Filling material	Gravel-Sand-Remains	Sand-Gravel	Riporto: sabbia debolmente limosa con ghiaia e laterizi
S-62	2.1	2.5	Sand and Gravel	Silt	Sand	Limo sabbioso grigio marrone
S-62	2.5	7.5	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Sabbia ghiaiosa grigia con rari ciottoli anche decimetrici
S-62	7.5	10.0	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia debolmente sabbiosa color marrone con rari ciottoli
S-62	10.0	15.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia e ghiaia con ciottoli

Table 22. S-62 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-63	0	1.0	Fragment of past workings	Reinforced concrete	Reinforced concrete	Cemento armato
S-63	1.0	4.8	Sand and Gravel	Gravel-Sand-Remains	Sand-Gravel	Sabbia debolmente limosa con ghiaia con laterizi ed altri manufatti sporchi di olio di colore nerastro
S-63	4.8	6.3	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia debolmente limosa color marrone con ghiaia e rari ciottoli
S-63	6.3	7.5	Sand and Gravel	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa color grigio con ciottoli
S-63	7.5	8.3	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia debolmente limosa color marrone beige con ghiaia
S-63	8.3	14.0	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia da debolmente sabbiosa a sabbiosa localmente limosa con ciottoli
S-63	14.0	15.0	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli e ghiaia con croste di ghiaia cementata costituente " ceppo"

Table 23. S-63 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-64	0	0.5	Fragment of past workings	Reinforced concrete	Reinforced concrete	Cemento armato
S-64	0.5	3.0	Filling material	Gravel-Remains	Gravel	Riporto: ghiaia debolmente sabbiosa con laterizi
S-64	3.0	4.6	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia di colore grigio con ghiaia e rari ciottoli
S-64	4.6	6.3	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da fine a media color marrone chiaro con ghiaia e ciottoli
S-64	6.3	9.8	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ghiaia debolmente limosa di colore grigio con sabbia e ciottoli
S-64	9.8	15.0	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Sabbia eterometrica localmente debolmente limosa con rari ciottoli. Presenza di croste di ghiaia cementata constituente " ceppo"

Table 24. S-64 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
S-65	0	3.3	Fragment of past workings	Reinforced concrete	Reinforced concrete	Laterizi, materiali vari di riempimento, calcestruzzo
S-65	3.3	5.0	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia da media a fine con rara ghiaia e ciottoli
S-65	5.0	7.8	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia debolmente ghiaiosa e ghiaosa con ciottoli
S-65	7.8	8.6	Sand and Gravel	Sand-Gravel	Sand-Gravel	Sabbia ghiaiosa color grigio
S-65	8.6	11.5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia debolmente limosa con ciottoli color marrone
S-65	11.5	15	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ciottoli, ghiaia debolmente limoso sabbiosa

Table 25. S-65 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
SG-1	0	3	Filling material	Sand-Pebbles	Sand-Pebbles	Materiale di riporto. Sabbia grossa con ciottoli, da debolmente addensata a sciolta in matrice ghiaiosa, presenza di frammenti di laterizio e di asfalto (0,50-0.80), colore marrone-rossastro.
SG-1	3	10	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa, in matrice sabbiosa, con presenza di ciottoli, poligenici, pluricentimetrici, da subarrotondati a subangolosi, di colore grigio-azzurro. (Deposito alluvionale recente)
SG-1	10	15	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa grossa, di colore marrone-rossastro, con presenza di ciottoli eterometrici, poligenici, sub-arrotondati, diam max 8 cm. Passate di ghiaia grossa ciottolosa, con colorazione grigio - azzurro, da sciolto a debolmente addensato.
SG-1	15	16	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia cementata, conglomeratica, passante a ghiaia sabbiosa, con ciottoli eterometrici, poligenici, sub-arrotondata.
SG-1	16	17	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Tra 16,0 -17,0 livello maggiormente compatto per presenza di matrice sabbiosa-limosa, di colore variabile da marrone rossastro a marrone biancastro.
SG-1	17	20	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	15,0-16,0 e 17,0-18,0 livelli litologici: ghiaia cementata in matrice sabbioso-limosa
SG-1	20	24	Gravelly soil with fine matrix	Conglomerate-Gravel	Conglomerate	Conglomerato con passate di ghiaia sabbiosa, da mediamente ad altamente cementata, di colorazione marrone rossastra.
SG-1	24	25	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaia sabbiosa, da cementata a mediamente compatta, con maggiore frazione fine di sabbia limosa.

Table 26. SG-1 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
SG-2	0	0,5	Filling material	Gravel	Gravel	Materiale di riporto, ghiaia grossa sabbiosa, di colorazione grigio - azzurro, sciolta
SG-2	0,5	3	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Materiale naturale; ghiaia sabbiosa grossa, debolmente limosa, di colore marrone -brunastro, con presenza di ciottoli eterometrici, poligenici, subarrotondati (diam. max 6 cm) (quarziti e serpentiniti)
SG-2	3	5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa, di pezzatura grossa, con ciottoli poligenici, diam. max 6-8 cm, sub-arrotondati, eterometrici, (quarziti e serpentiniti), di colore bruno - rossastro
SG-2	5	9	Sand and Gravel	Sand	Sand	Sabbia ghiaiosa, da debolmente addensata a sciolta, di colore marrone-rossastro, a granulometria grossa.
SG-2	9	10	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa, grossa, debolmente limosa, con ciottoli poligenici, eterometrici, diam.max 6 cm
SG-2	10	13,5	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Sabbia grossa frammista a ghiaia grossa, da debolmente a mediamente limosa, di colore bruno-rossastro, con presenza di ciottoli eterometrici, poligenici, sub-arrotondati, taluni fortemente alterati.
SG-2	13,5	15	Gravelly soil with fine matrix	Conglomerate-Gravel	Conglomerate	Ghiaia sovraconsolidata, conglomerato, di colore grigio - azzurro, passante a ghiaia sabbiosa addensata (presenza notevole di limo in matrice).
SG-2	15	20	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa conglomeratica, in matrice limoso - sabbiosa; frequenti ciottoli eterometrici, poligenici, sub-arrotondati (cambio di colore per diverso rapporto di matrice, da grigio-azzurro a marrone rossastro). Evidenza di conglomerato.
SG-2	20	21,5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa conglomeratica, in matrice limoso - sabbiosa; frequenti ciottoli eterometrici, poligenici, sub-arrotondati (cambio di colore per diverso rapporto di matrice, da grigio-azzurro a marrone rossastro). Evidenza di conglomerato.
SG-2	21,5	23	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Cambio litologico, con ghiaia grossa in matrice sabbioso - limosa, da debolmente addensata a sciolta, ciottolosa, poligenica, sub-arrotondata, diam. max 10 cm, di colore marrone-rossastro (21,5-23,0 m).
SG-2	23	23,5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa conglomeratica, in matrice limoso - sabbiosa; frequenti ciottoli eterometrici, poligenici, sub-arrotondati (cambio di colore per diverso rapporto di matrice, da grigio-azzurro a marrone rossastro). Evidenza di conglomerato.
SG-2	23,5	25	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Con intercalazioni maggiormente sabbioso - limose (23,5-25,0 m), di colorazione da grigio ad azzurro.

Table 27. SG-2 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
SG-3	0	1	Filling material	Remains	Conglomerate	Materiale di riporto; frammenti di asfalto immersi in una matrice sabbioso-ghiaiosa di colorazione grigio-rossastro (0,0-1,0 m),
SG-3	1	3,5	Fragment of past workings	Remains-Cement	Reinforced concrete	Frammenti di laterizio rosso e cemento (1,0-3,5 m)
SG-3	3,5	5	Fragment of past workings	Reinforced concrete	Reinforced concrete	Calcestruzzo poco consolidato tra 3,0 - 3,8 m e fortemente consolidato tra 3,8 - 5,0 m (muro di fondazioni)
SG-3	5	5,8	Sand and Gravel	Sand	Sand	Passaggio di livello da calcestruzzo consolidato a materiale grossolano di sabbia ghiaiosa grossa frammista a matrice di cemento
SG-3	5,8	9	Sand and Gravel	Sand-Pebbles	Sand-Pebbles	Materiale naturale di sabbia ghiaiosa, con ciottoli centimetrici (diam. max 8 cm) di colore bruno - rossastro
SG-3	9	10	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa da cementata a sovraconsolidata, con molta matrice fine limosa e ciottoli poligenici sub-arrotondati di colore marrone-brunastro (diam. max 6 cm)
SG-3	10	11	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaia grossa, ciottolosa, di colore variabile da grigio - azzurro a bruno - rossastro. Evidenza di conglomerato a 14,5 m. Passate maggiormente matriciali limoso-sabbiose comprese tra 11,0-14,0 m.
SG-3	11	14	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaia grossa, ciottolosa, di colore variabile da grigio - azzurro a bruno - rossastro. Evidenza di conglomerato a 14,5 m. Passate maggiormente matriciali limoso-sabbiose comprese tra 11,0-14,0 m.
SG-3	14	15	Gravelly soil with fine matrix	Conglomerate-Gravel	Conglomerate	Ghiaia grossa, ciottolosa, di colore variabile da grigio - azzurro a bruno - rossastro. Evidenza di conglomerato a 14,5 m. Passate maggiormente matriciali limoso-sabbiose comprese tra 11,0-14,0 m.
SG-3	15	20	Gravelly soil with fine matrix	Conglomerate-Gravel	Conglomerate	Conglomerato con ghiaia grossa, ciottolosa, addensata in matrice sabbiosa-limosa, di colorazione grigio-azzurro (diam. max 8 cm). Cambio litologico con sabbia grossa e ghiaia, da sovra-addensata a mediamente addensata, di colore marrone-beige, con presenza di ciottoli eterometrici, poligenici, sub arrotondati.
SG-3	20	22,5	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa in matrice sabbiosa - limosa, con ciottoli (diam. max 8 cm), da mediamente a debolmente addensata, di colore marrone - rossastro (da 20,0 a 22,5 m) variabile a grigio - azzurro (22,5-25,0 m)
SG-3	22,5	25	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa in matrice sabbiosa - limosa, con ciottoli (diam. max 8 cm), da mediamente a debolmente addensata, di colore marrone - rossastro (da 20,0 a 22,5 m) variabile a grigio - azzurro (22,5-25,0 m)

Table 28. SG-3 borehole Field Geological Description

Location ID	Top depth [m]	Base depth [m]	Legend code	Geology code	Geology code 2	Stratigrafia completa
SG-4	0	0,2	Fragments of past workings	Organic	Gravel	Terreno vegetale, con resti di apparati radicali
SG-4	0,2	2,8	Filling material	Gravel-Remains	Gravel	Materiali di riporto, con ghiaia grossa in matrice sabbiosa grossa, con colorazione da grigio - azzurro a marrone - rossastro (per evidenze di laterizio rosso, mattone, compreso tra 1,5 e 2,8 m da p.c.).
SG-4	2,8	3,2	Fragments of past workings	Conglomerate-Gravel	Conglomerate	Presenza di ghiaia grossa ed evidenza di un frammento di conglomerato cementato (10 cm)
SG-4	3,2	5	Filling material	Sand-Gravel	Sand-Gravel	Materiali di riporto costituiti da sabbia con ghiaia grossa, da debolmente a mediamente addensata, per presenza di matrice limosa, di colorazione variabile da marrone - rossastro (3,2-4,0) a marrone - nerastro (4,3-5,0 m), con odore fetido.
SG-4	5	7	Gravelly soil with fine matrix	Clay-Silt	Sand	Materiale naturale, con alternanza di argilla e limo, con colorazione differente da grigio verdastro scuro a marrone rossastro. In dettaglio, tra 5,0-7,0 di colore grigio - verde e tra 7,0 - 9,0 m di colore marrone - rossastro. Tra 8,40 - 9,0 livello costituito da sabbia limosa compatta con matrice in ghiaia grossa.
SG-4	7	8.40	Gravelly soil with fine matrix	Clay-Silt	Sand	Materiale naturale, con alternanza di argilla e limo, con colorazione differente da grigio verdastro scuro a marrone rossastro. In dettaglio, tra 5,0-7,0 di colore grigio - verde e tra 7,0 - 9,0 m di colore marrone - rossastro. Tra 8,40 - 9,0 livello costituito da sabbia limosa compatta con matrice in ghiaia grossa.
SG-4	8.40	9	Gravelly soil with fine matrix	Sand	Sand	Tra 8,40 - 9,0 livello costituito da sabbia limosa compatta con matrice in ghiaia grossa.
SG-4	9	10	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia sabbiosa con rari ciottoli, poligenici, subarrotondati (diam. max 10 cm) in matrice limosa da debolmente addensata a sciolta.
SG-4	10	11,3	Gravelly soil with fine matrix	Gravel-Silt	Gravel	Ghiaia sabbiosa con limo, da addensata a mediamente addensata, di colore marrone - rossastro
SG-4	11,3	15	Sand and Gravel	Gravel-Sand-Pebbles	Gravel-Sand-Pebbles	Ghiaia grossa, conglomeratica, con sabbia limosa e rari ciottoli poligenici, sub-arrotondati (taluni in stato di alterazione evidente), di colore grigio - azzurro.
SG-4	15	16,5	Sand and Gravel	Gravel-Silt-Pebbles	Gravel-Pebbles	Ghiaia grossa ciottolosa, in alternanza a limo sabbioso con rari ciottoli.
SG-4	16,5	17,5	Gravelly soil with fine matrix	Gravel-Silt	Gravel-Pebbles	Maggiore componente matriciale, di limo argilloso compatto, con presenza di ghiaia secondaria in posizione matriciale.
SG-4	17,5	20	Gravelly soil with fine matrix	Silt	Gravel-Pebbles	Cambiamento litologico, con maggiore componente ghiaiosa-ciottolosa (taluni ciottoli risultano essere in evidente stato di alterazione), di colore variabile da grigio - azzurro a marrone - beige.
SG-4	20	22	Gravelly soil with fine matrix	Gravel-Pebbles	Gravel-Pebbles	Ghiaia grossa, con ciottoli, eterometrici, poligenici, sub-arrotondati, diam. max 10 cm, in matrice sabbioso - limosa.
SG-4	22	25	Gravelly soil with fine matrix	Gravel	Gravel	Ghiaia grossa, ciottolosa, da debolmente addensata a sciolta (ciottoli eterometrici) di colore grigio - azzurro.

Table 29. SG-4 borehole Field Geological Description