POLITECNICO DI TORINO

Master of Science program in Building engineering

Master's degree Thesis

GeoBIM application for subsurface Modeling

Torino's Health, Research and Innovation Park project

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Abstract:

Three-dimensional representation of subsurface conditions has long posed challenges and uncertainties for engineers. Traditional approaches to modeling soil layers often occur in isolated environments, detached from existing infrastructure and built environments. As a result, geotechnical data is frequently excluded from multidisciplinary models, limiting coordination and accuracy in design and construction.

These limitations become especially critical in infrastructure projects requiring high geospatial precision such as tunnels, underground utilities, and railway systems where accurate knowledge of subsurface conditions must integrate seamlessly with complex infrastructure models. Building Information Modeling (BIM) has transformed the design and construction industry by offering 3D dynamic models enriched with evolving, real-time data. However, conventional BIM workflows typically lack integration with geospatial information.

To bridge this gap, recent efforts have focused on merging Geographic Information Systems (GIS) with BIM, giving rise to the concept of GeoBIM georeferenced, data-oriented 3D models. In this study, the GeoBIM approach was applied to model the subsurface conditions of Parco della Salute project in Turin, Italy, a redevelopment site with a complex contamination history.

Using visual programming via Dynamo in Autodesk Revit, a digital workflow was developed to import and visualize borehole and soil contamination data, enabling the creation of a data-rich subsurface model. The model also supports stakeholder decision-making and site remediation planning through an interactive, online repository. Importantly, soil contamination analysis was integrated into the model to identify zones of environmental risk an essential step for ensuring public health, regulatory compliance, and sustainable land reuse.

Additionally, four different modeling workflows were evaluated using Key Performance Indicators (KPIs) to assess their effectiveness for GeoBIM implementation. The results highlighted the performance of Revit combined with Dynamo as an effective GeoBIM modeling environment, offering both precise visual modeling and rich data integration capabilities.

Keywords: Building Information Modeling (BIM), GeoBIM, Autodesk Revit, Dynamo, Key Performance Indicators (KPIs),

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chapter 1 Introduction

1.1 Problem Statement

In recent years, the integration of Building Information Modeling (BIM) into civil and infrastructure projects has transformed how professionals approach design, construction, and management. While BIM is widely used for architectural and structural elements, its application in geotechnical engineering remains relatively underexplored. Subsurface conditions, such as soil stratigraphy and geotechnical properties, are often represented through 2D cross-sections or isolated borehole logs, making it difficult to fully integrate this critical data into 3D project environments. Moreover, geotechnical information related to underground conditions holds a great value for the construction industry because of the risks of the inherent uncertainty and the existence of unknown structures underground ((Tawelian & Mickovski, 2016; Zhang et al., 2016)

The emergence of GeoBIM—a fusion of geospatial data and BIM—offers promising opportunities to bridge this gap. By incorporating geotechnical information directly into the BIM environment, stakeholders can better visualize underground conditions, assess construction risks, and support more informed decision-making throughout the project lifecycle.

1.2 Research questions

This thesis aims to explore the potential of using BIM technologies to model and visualize geotechnical information within a 3D environment, alongside a repository of soil-related contamination data. The specific objectives are:

1. To develop a workflow that enables the semi-automatic creation of subsurface soil layers;

   The first objective focuses on the development of a repeatable, semi-automated workflow to generate 3D representations of soil stratigraphy based on borehole data. This approach minimizes manual modeling efforts and ensures consistency in layer geometry across a site. The workflow leverages borehole coordinates and stratigraphy depth data, interpolated into 3D soil volumes, allowing users to visualize subsurface conditions in a georeferenced context within a BIM environment.

2. To build a 3D repository of subsurface conditions enriched with environmental contamination data;

   The second objective aims to associate each soil layer with its corresponding contamination information within the model. This is achieved by embedding contamination attributes as shared parameters within Revit's mass elements. Such integration enables decision-makers to spatially correlate pollution data with soil layers, improving communication among stakeholders and guiding effective site remediation strategies.

1.3 Motivation

The motivation behind this thesis arises from the need to better integrate geotechnical data with BIM workflows, especially in early design and planning stages. Traditional methods often lead to fragmented or oversimplified representations of the ground conditions, which can negatively affect the accuracy of design assumptions and project execution. With development of FE (finite element) softwares, this representation became relatively accurate, however integration of these type of models with 3D models of structures/infrastructures are not an easy task. A few commercial softwares tried to overcome this issue but they often lack interoperability.

Autodesk civil 3D with the aid of Geotechnical Module extension is one of this mentioned softwares which allows the creation of soil layer with moderate accuracy using various interpolation methods (TIN, Kriging, IDW, NNI…), this workflow already used in numerous attempts to create sub surface models; moreover, it was used for the same case study which showed some limitation.

ArcGIS pro is the second software that could be used to create subsurface models with high accuracy capable of storing attribute data within themselves. The ArcGIS 3D models uses voxel base cells which stored in NetCDF format (*.nc), despite the accuracy of this type of models it is not yet interoperable with other softwares.

Leap frog Geo, is another software which could be used for subsurface modeling. The software is specifically developed for geological representation. Results have moderate accuracy both in geometry and location. Models can be exported in dwg or fbx formats. However, despite the precision no attributes could be save within the model. And not to mention that software’s license is relatively expensive.

Autodesk Revit, although it’s not geared for soil and subsurface modeling, however thanks to built-in programming environment like Dynamo or Revit API it is possible to create almost every shape, create BIM repository and integrate all the data from each stakeholder involve in the project.

The use of Revit in combination with Dynamo, visual programming tool, allows for the automation and customization of 3D subsurface model based on real borehole data. This approach supports the creation of parametric model that reflect actual soil layers and related environmental aspects (contaminations, heavy metals concentration…) providing a dynamic and spatially accurate representation of the subsurface environment. For these reasons, this study will use Revit as BIM tool and dynamo as visual programming language tool for subsurface modeling.

The study takes inspiration from a real project, the **Parco della Salute, della Ricerca e dell’Innovazione di Torino** to demonstrate the applicability of this approach in a real-world scenario.

1.4 Methodological framework

The methodology followed in this thesis is based on the development of a workflow that integrates geotechnical data into the BIM environment using Revit and Dynamo. The approach begins with the collection and structuring of borehole data, including the coordinates, depths, and corresponding soil layers and pollution data for each borehole.

As shown in *Figure 1*, this data is then processed and formatted in excel sheets to be compatible with Dynamo, where two custom scripts are used to 1. automate the generation of 3D geometries representing soil layers. And 2. Introduce the contamination contents as attribute (share parameter) to Mass volumes that represents soil layers. Then as an additional study, model, compared with the result of the other works and finally an online repository created for integrating subsurface and above ground BIM models

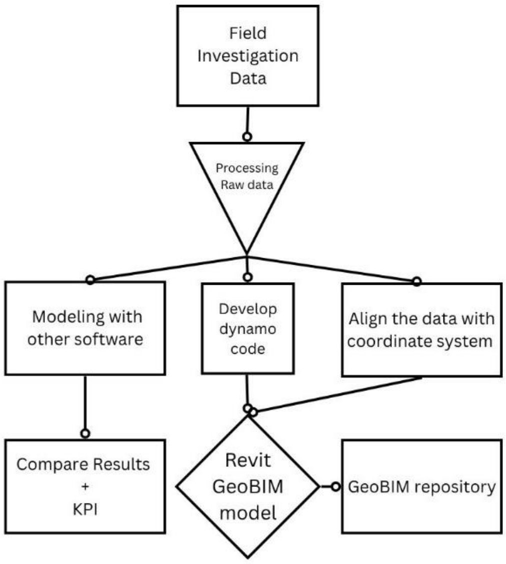


Figure 1. Frame work of the study

1.5 Structure of the Thesis

This thesis is organized into seven chapters:

- **Chapter 1 – Introduction**: Presents the context, motivation, objectives, and methodology of the research.
- **Chapter 2 – Literature Review**: Explores the current state of research and practice in BIM, GeoBIM, and the integration of geotechnical data within digital models. It also identifies existing limitations and the knowledge gap addressed by this work.
- **Chapter 3 – Case Study:** Describes the project background, location and data available on Parco della Salute project
- **Chapter 4 – Methodology**: Provides a detailed explanation of the tools used (Revit, Dynamo), the data preparation process, and the steps involved in building the 3D subsurface and contamination model.
- **Chapter 5 – Results**: Shows the visual and technical outcomes of the model, including the 3D representation of soil layers and the functionality of the Dynamo scripts.
- **Chapter 6** – **Comparison** It also discusses the effectiveness and limitations of the proposed approach, compares it to other methods (Autodesk Civil 3d, ARCGIS, Leapfrog) and reflects on possible improvements.
- **Chapter 7 – Conclusions and Future Work**: Summarizes the key findings, highlights the contributions of the thesis, and proposes future directions for research and practical implementation.

chapter 2 Literature Review

2.1 Building Information Modeling (BIM) in Civil Engineering

Civil engineering projects rely heavily on deep understanding of the physical environment in which they are built. From bridges and roads to tunnels and high-rise buildings, the success and safety of any structure are closely tied to the characteristics of the site itself. Engineers must account not only for surface factors but also for what lies beneath elements that are often invisible but critical to design and construction decisions.

Subsurface conditions, including the composition and arrangement of soil layers, groundwater levels, and the presence of contaminants, can significantly influence structural performance, construction methods, cost, and long-term maintenance. Accurately capturing and analyzing this information is therefore essential. Yet, traditionally, geotechnical and environmental data have been documented in isolation using spreadsheets, and technical reports. These formats, while informative, are often static, fragmented, and lack integration with broader design workflows, making it difficult to visualize, or analyze in coordination with architectural and structural models.

Meanwhile, the adoption of Building Information Modeling (BIM) began primarily in the field of architecture, where it transformed project delivery by shifting from 2D drafting to intelligent 3D models that integrate geometry, materials, time, and cost data. Over time, BIM has steadily expanded into civil engineering and infrastructure projects, enabling greater collaboration across disciplines, improving coordination, and enhancing the accuracy of planning and execution (Sampaio & Sampaio, 2016).

BIM's data-rich, spatially aware environment has proven to be especially valuable for large-scale infrastructure works. Its integration with technologies like GIS and IoT has further enhanced project transparency and communication among stakeholders during design and construction phases (Associated General Contractors of America, 2005). Recent research and applications such as the use of AR and BIM in bridge design (Lozano-Galant et al., 2024), digital twins for university campuses (Pavón et al., 2025), and seismic management systems for road networks (An et al., 2025) highlight BIM's growing relevance in civil engineering.

Despite this progress, BIM's focus has traditionally been above ground, with limited incorporation of subsurface conditions into the digital design environment. This gap has led to the emergence of GeoBIM, a methodology that integrates geospatial and geotechnical data into BIM workflows. By bringing underground information into the 3D model. GeoBIM enables a more comprehensive and integrated approach to civil infrastructure design and risk management.

2.2 The Emergence of GeoBIM

In search through literature one can find two distinct yet complementary definitions for GeoBIM; on one hand, GeoBIM refers to spatially accurate BIM data;

"In both the Geographic Information (Geo) and Building Information Modelling (BIM) domains, it is widely acknowledged that the integration of data from both domains is beneficial and a crucial step in facing the multi-disciplinary challenges of our built environment. The result of this integration – which can broadly be termed GeoBIM – could answer questions such as identifying an appropriate HVAC system for a building based on room usage, outside air temperature, solar exposure and traffic pollution or validating

whether a proposed built asset meets relevant planning constraints and support tasks that include logistics for construction, asset management, facilities upgrade, and road safety design improvements amongst many more."(EuroSDR GeoBIM, 2025)

on the other hand, it refers to applying BIM applications for geotechnical modeling;

"The objective of the ground model in BIM is not just to create a 3D graphic depiction of stratigraphy. Instead, it is an integral knowledge management tool based upon geotechnical and geological surveys and interpretations. To model geological information and topography of geotechnical layers, a model called GeoBIM that extends the BIM concept."(Mahmoudi et al., 2021; Zobl et al., 2011)

Both definitions are valid and used for this study.

GeoBIM represents the integration of geospatial data with BIM models. It allows for the contextualization of BIM elements within real-world terrain, topography, and underground data, such as utilities, tunnels, and soil layers. The combination of spatial accuracy from GIS and the object-based modeling of BIM opens new opportunities in planning, risk analysis, and interdisciplinary collaboration.

In the context of geotechnics, GeoBIM holds the potential to improve design decisions by visualizing how subsurface conditions interact with structural components.

Traditionally, geotechnical data such as boreholes, soil types, and stratigraphy are represented in 2D borehole logs or Excel spreadsheets. In recent years, multiple methodologies were developed to help represent this data in 3D environments:

In the study of (Fonsati et al., 2023) four workflows were investigated using ARCGIS, RockWorks, Civil 3D using "Geotechnical Module" extension and finally Novapoints 21. Fonsati investigated capability of each workflow as software tool for geotechnical modeling, compared each workflow as the terms of output and finally evaluated the capability of each workflow as integration with BIM process.

Fonsati's broke down each workflow as the terms of input, process and output.

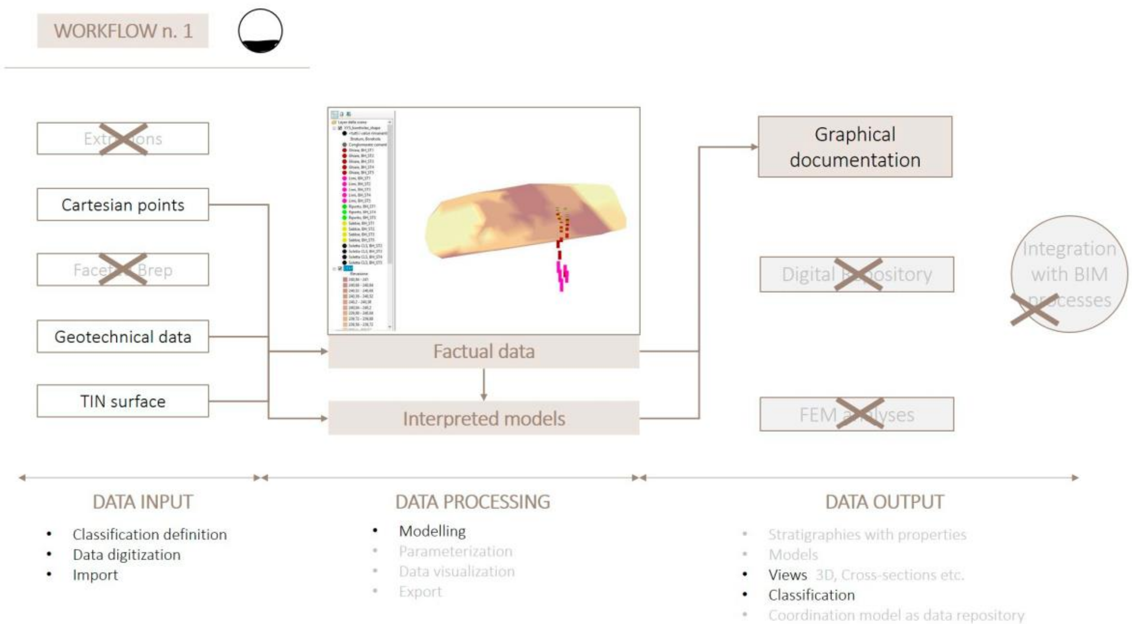


Figure 2. ArcGIS workflow

Using ArcGIS, Fonsati was not able to complete BIM integration process as ArcGIS was not able to produce file format “suitable for interoperability”.

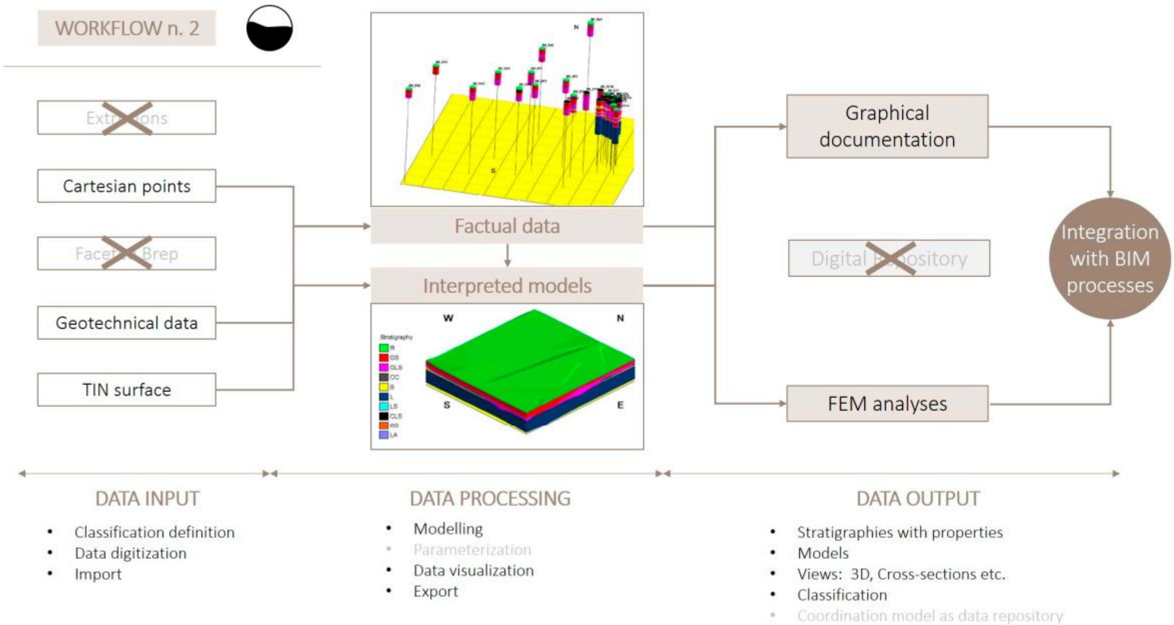


Figure 3. RockWorks workflow

“Rockworks allowed the visualization of boreholes, topographic surfaces, and subsoil layers, as well as the generation of full stratigraphy, maps, cross-sections, and volumes.”(Fonsati et al., 2023)

In the later step, Fonsati exported the DAE format of the model into Autodesk Revit via Autodesk 3ds max, however in this process only the geometry was preserved and all the related attributes were lost during the procedure.

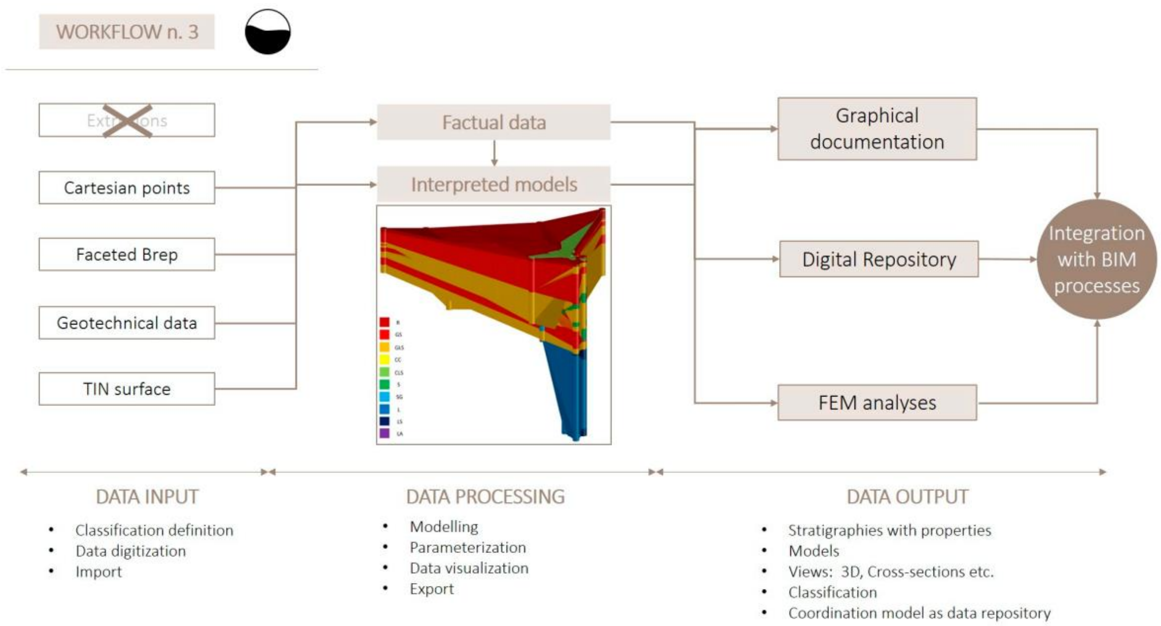


Figure 4. Autodesk Civil 3D workflow

The civil 3d workflow involved using "Geotechnical Module" extension to model soil layers with Triangular Irregular Network (TIN) surfaces, as reported *"The three-dimensional solid model was automatically generated once the upper (Top) and bottom (Base) surfaces for each stratigraphic unit had been defined ",* however intermediate layers were not distinguishable and the surface generated showed several points of discontinuity.

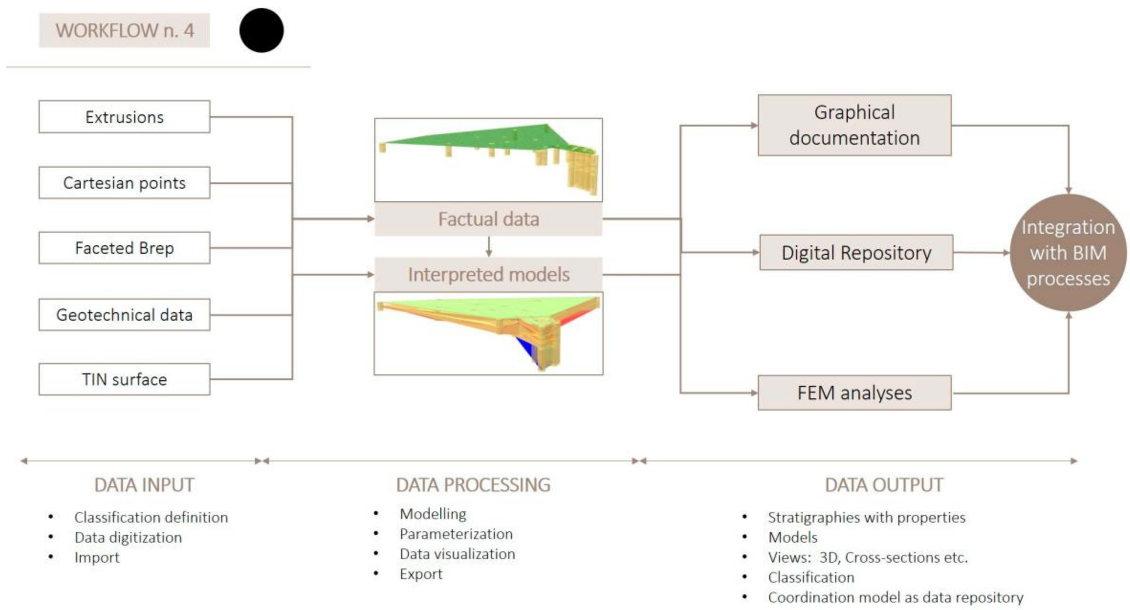
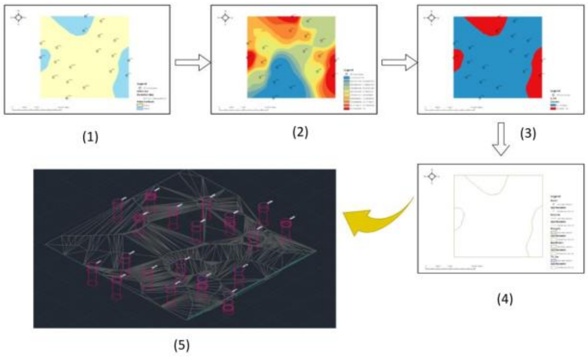


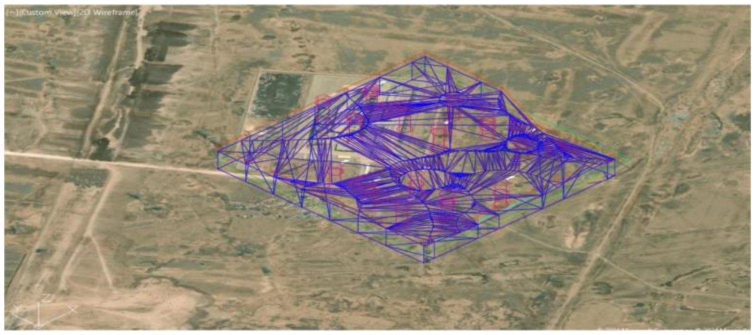
Figure 5. Novapoints workflow

Last workflow involved using Trimble NovaPoints, which is a BIM-authoring platform for infrastructures and terrain modeling. "Civil 3D Connector" used to allow data interchange between Novapoints and Civil3D. Despite the accuracy and moderate level of interoperability, [*software only supports triangular interpolation, layers with fewer than three points cannot be represented…. It was not possible to distinguish volumes based on materials, and the tool only allowed for two distinctions: cut volumes and fill volumes. Different materials could not be graphically displayed; this was possible only through the attribute tables] (Fonsati et al., 2023).*

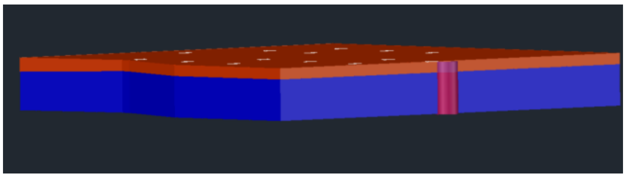
Ammar et al 2024, tried to develop a workflow which involved georeferencing the boreholes and create contour line using ArcGIS, then transfer these data into Autodesk Civil 3D to create soil layers volume. Finally, the model exported as IFC and represented using IFC open viewer. (Ammar & Reem, 2024)



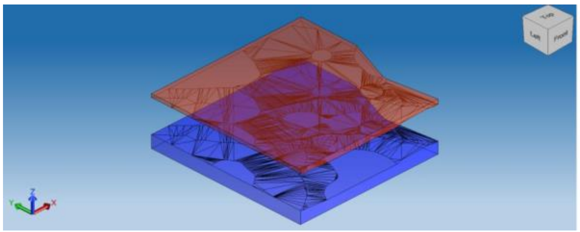
a) Process of transforming data from GIS to Civil3d



b) The grid image of the topographic layers of study area



c) Visualization of soil layers and borehole



d) Model in x-ray as a separated layer

Figure 6. workflow adopted by Ammer et al.

Based on Ammer et al report, this workflow required trial and error to find the parameter values that give the least amount of error. Moreover, it was needed to manually transfer the contour line layers to collect them on one platform.

Lai et al 2023 used Leapfrog for subsurface modeling and integration with BIM model in early design stage of Sydney metro station. This integration resulted in a powerful tool for interface impact assessment on metro tunnel which enabled design team to visualize constraint associated with ground condition and the dense built environment. (Lai et al., 2023)

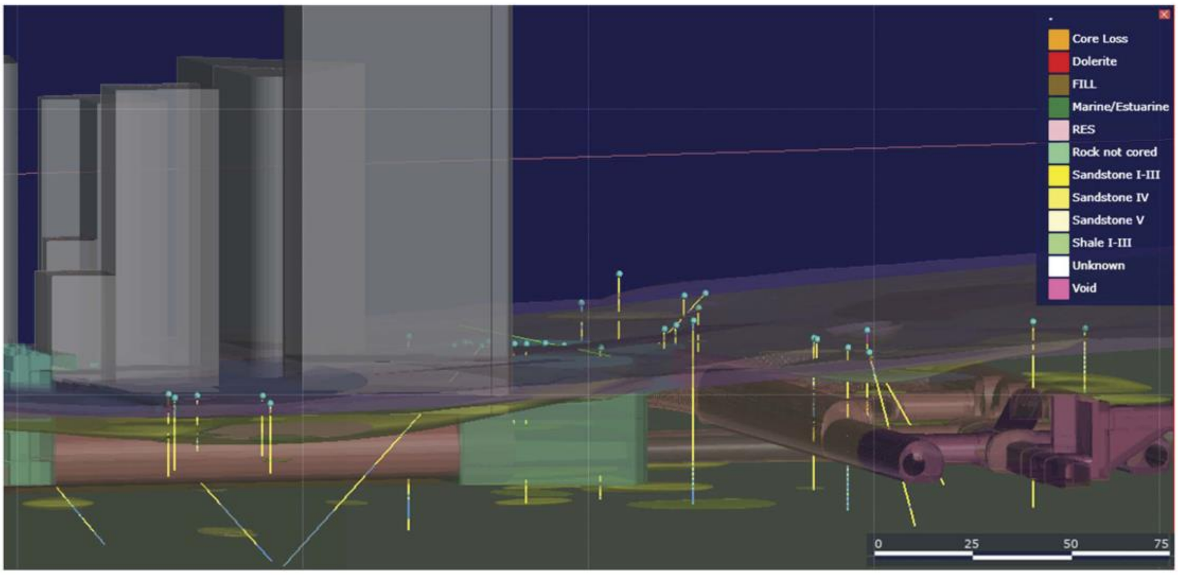


Figure 7. integration of Leapfrog subsurface model and BIM model (Lai et al., 2023)

Although, as Lai et al. reported, using Leapfrog for subsurface modeling seems to be a good solution specially with high interoperability rate. However, Leapfrog license is relatively costly. Moreover, the software is commonly used for big areas and accuracy of the interpolation in smaller areas with high subsurface complexity is ambiguous.

In short it could be said that, efforts have been made to bring this data into BIM environments using custom tools and manual modeling, but challenges remain:

- Lack of standardized methods for integrating borehole data.
- Limited software in the market (with limited functionalities) for 3D geotechnical modeling.
- Manual processes that are time-consuming and prone to error.

Recent studies have attempted to use visual programming tools like Dynamo for automating repetitive modeling tasks, particularly in soil layer visualization and even this study is also focused on developing this type of workflow however, these methods are often project-specific and rarely generalized for broader use.

2.3 Visual programming language and BIM

Programming's role in BIM began with early research into digital building representations. In 1975, Charles M. Eastman introduced the "Building Description System," a prototype that laid foundational concepts for BIM by enabling the modeling of building components and their relationships.(Gajendran & Brewer, 2012). In 1985, Jonathan Ingram developed Sonata, the first system to integrate characteristics of modern BIM into a single application, enabling users to create a unified building model.(Wikipedia, 2025)

Early programming required knowledge of textual programming languages, which posed a barrier for many designers unfamiliar with coding. (Vogt, 2016) and integrating various software tools and ensuring compatibility between different systems was a difficult task. (Gajendran & Brewer, 2012) To address the challenges associated with textual programming, visual programming languages (VPL) were introduced. VPLs allow users to create programs by manipulating visual elements rather than writing code. (Calvano et al., 2022). This approach simplifies the programming process, making it more accessible to designers and architects. (Vogt, 2016)

Two major VPL were introduced into BIM domain: 1. Dynamo 2. Grasshopper. In this study Dynamo, visual programming language in cooperation with Autodesk Revit (as the BIM tool) were used.

Since the introduction of dynamo as VPL extension tool in Autodesk Revit, numerous studies conducted to automatize modeling tasks, create parametric design and also develop algorithms for facility management and building managements system (BMS) operations.

Thabet et al, used dynamo to automate linking life cycle data into BIM for the purpose of facility management. They are also described the “complexity of the owner’s proprietary information needs and the resulting automated workflow that extracts and exports data from Revit into an Excel format that can directly link into the FM system”(Thabet et al., 2022)

Rocha et al, used dynamo to reconstruct BIM elements from point cloud data. In this study they modeled topography, structural and architectural using algorithm from point. Moreover, they compared the result of automated modeling with manual method, although manual reconstruction of elements had hire accuracy, however at no point these differences were higher than 16mm. (Rocha & Mateus, 2024)

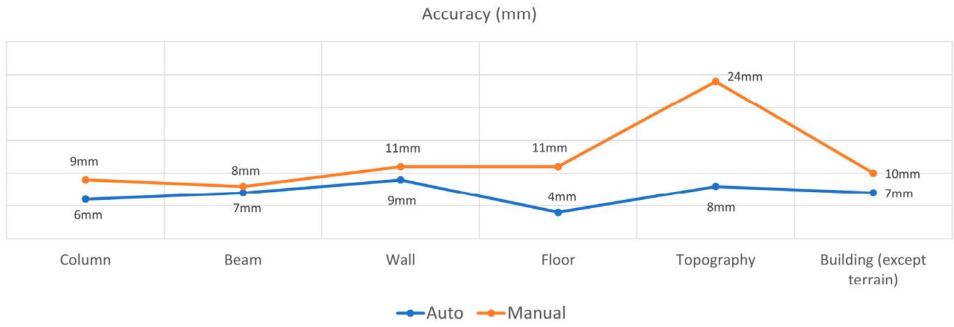
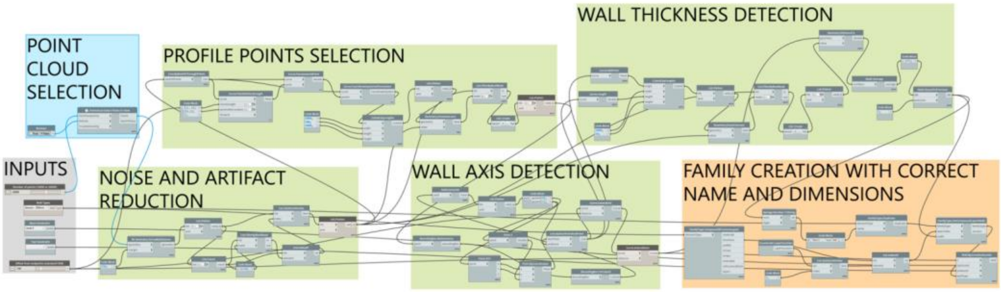


Figure 8. Average accuracy of reconstructed elements (Rocha & Mateus, 2024)



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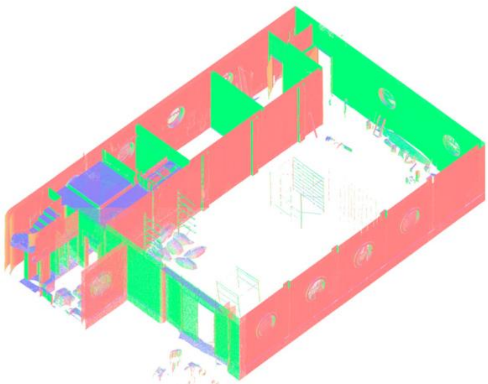

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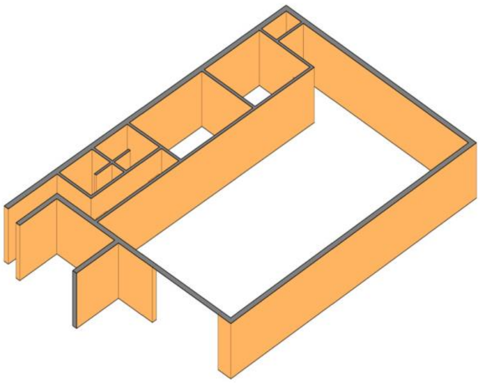

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Figure 9. a) The algorithm developed with Dynamo for automatic detection and modeling of structural beams. (b) Point cloud used. (c) BIM elements created in Revit using the Dynamo algorithm.(Rocha & Mateus, 2024)

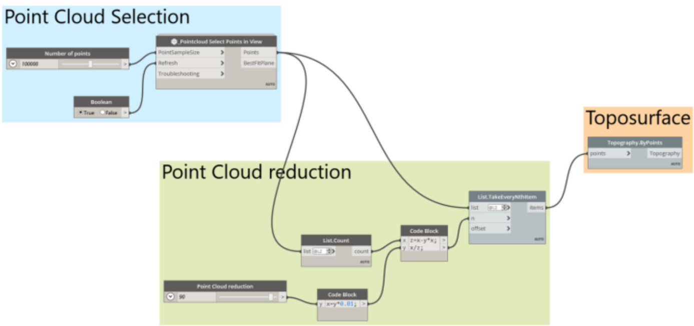


Figure 10. Dynamo's automatic topography modeling algorithm for Revit using point clouds.(Rocha & Mateus, 2024)

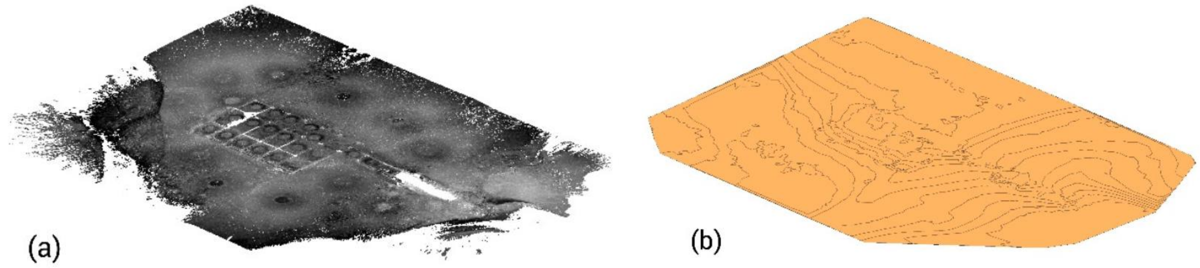
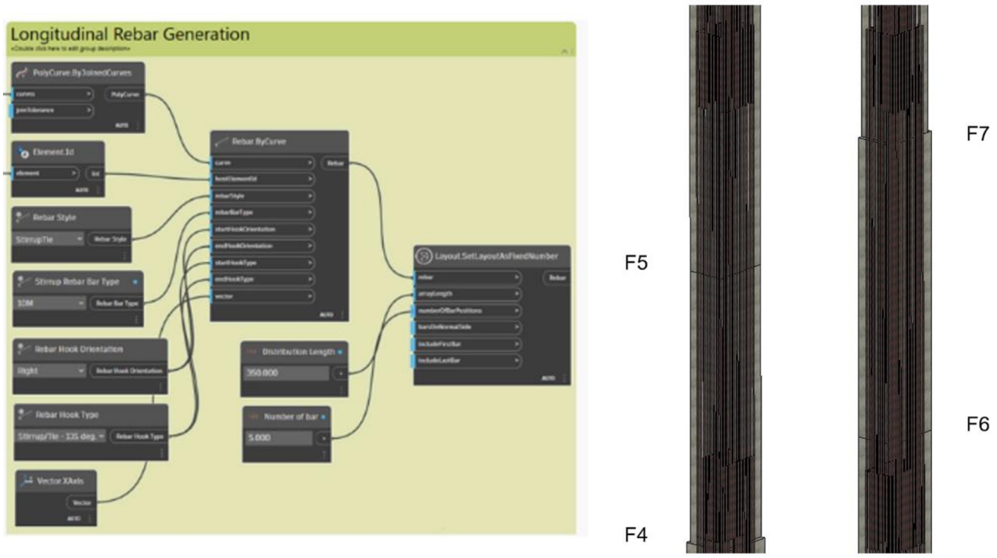


Figure 11 .a) Segmented point cloud classified with ground points, (**b**) BIM topo surface created in Revit using the algorithm developed with Dynamo(Rocha & Mateus, 2024)

Sittisom et al, developed a script to size the shallow foundation (in preliminary design phase), based on Terzaghi bearing capacity theory. In this study they imported the weight of the entire building using Excel. Unlike traditional hand calculations, the developed script offered faster and more precise results. (Sittisom et al., 2025)

Another innovative use of visual programming language in BIM was in the work of Widjaia et al, where they developed an algorithm to optimize the positioning and layout of the rebars in concrete columns. The Dynamo script enabled faster rebar generation while enhancing and improving accuracy compared to manual layout generation methods. When design changes occur, users simply update the rebar summary sheet and rerun the script to generate the rebar layout. (Widjaja et al., 2025)



B

a) Dynamo code for longitudinal rebar generation

b) Generated rebar for the column at the level F4-F6.

Figure 12.Optimizing rebar layout using dynamo code.(Widjaja et al., 2025)

Examples above were just a few of many researches conducted in the use of visual programming language in BIM. A quick search in google scholar using "dynamo" and "Revit" keywords, shows more than 1300 works from 2024. This shows and the vast potential of, visual programming within the building information modeling domain.

In geotechnical modeling, several studies used dynamo to:

- Import borehole data and create cylinders to represent boreholes.

- Build solids to represent soil layers.
- Assign soil properties as shared parameters to geometries.

Alaei in his master thesis, utilized dynamo to represent soil volume and subsurface layers in Revit. He applied BIM methodology in geotechnical engineering to integrate geotechnical data with structural data for Stockholm's metro expansion project (Västlänken Korsvägen II project). In this study, Alaei used the workflow of georeferencing borehole location and creating a spreadsheet which stores the x, y, z and ID of each borehole and then importing this data into dynamo environment to create the soil volume in Revit. Moreover, he utilized "Trimble connect" as CDE (common data environment) to "*facilitate collaborative and efficient management and visualization of geotechnical data and assets.*" (Alaei, 2023)

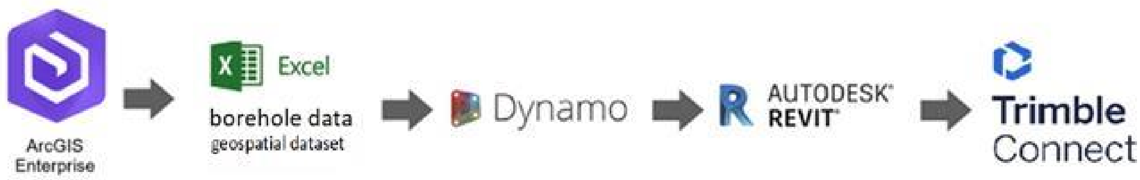


Figure 13. Performing BIM process. (Alaei, 2023)

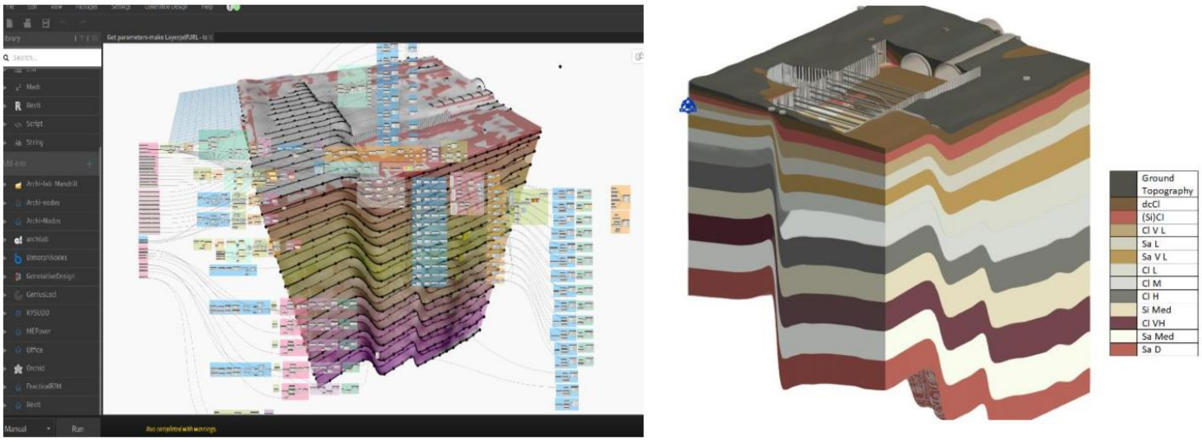
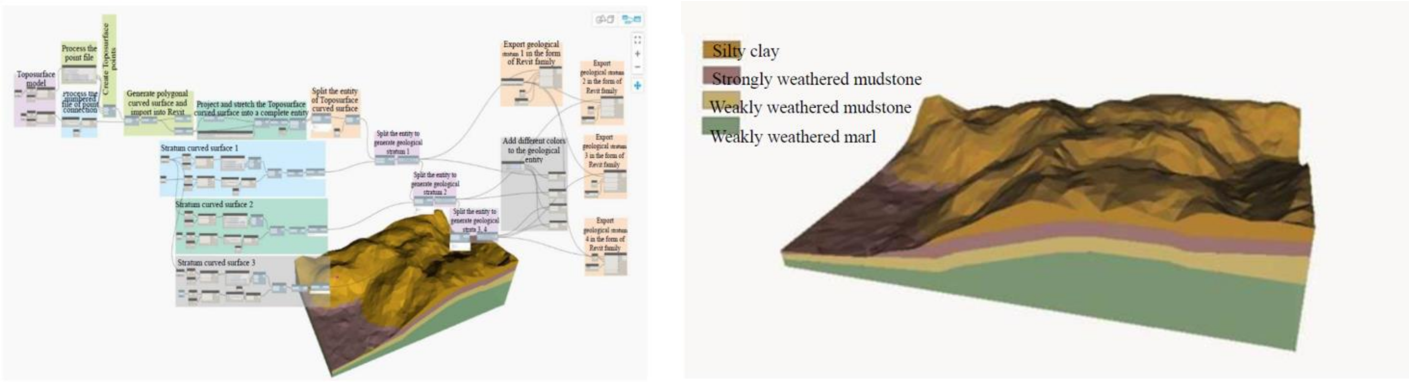


Figure 14. The layers of the project based on the boreholes in the Revit and Dynamo software.(Alaei, 2023)

In another study, dynamo script developed to create geological model that integrate with Liangshuijing Tunnel model using kriging method. Similar to previous case study, workflow started with creating a spread sheet containing borehole location data. However, based on the author acknowledgment, special geological conditions (e.g., faults, Karst caves, strata pinch-out, etc.) are not considered in the research and in this respect the layers were simplified. (Wang et al., 2022)



a) Dynamo code   b) Stratificated geological entity.

Figure 15. 3D geobody of Liangshuijjng Tunnel generated by dynamo plug-in.(Wang et al., 2022)

These efforts demonstrate the potential of GeoBIM in civil engineering but also reveal a gap: few studies offer a fully reproducible workflow applicable to real project data with automated or semi-automated logic. While the use of BIM in structural and architectural design is well-established, its application in subsurface geotechnical modeling remains limited and fragmented. Current tools often require manual data translation, lack interoperability, or provide only partial automation.

This thesis aims to fill this gap by presenting a semi-automated approach using Revit and Dynamo to visualize borehole and soil layer data in 3D.

chapter 3 Case Study: Torino's Health, Research and Innovation Park

3.1 Location

Area under study is a part of bigger re-development project in Torino, Italy; called "Parco Della Salute, Della Ricerca E Dell'innovazione di Torino". This project has been a point of interest for researchers in the fields of Civil engineering, Geotechnical engineering, urban development, building and construction and even Geology.

Figure 16. Parco della salute ortophoto(Calafiore & Leanza, 2018)

The project site was included in the requalification and urban development plan for the ex-industrial site Nizza Millefonti, located in the southeast part of Turin city. The whole area is 313.725 m2, and it is divided into three lots. The first lot (the focus of this study) will be converted into the hospital and several healthcare facilities and research centers. Lots 2 and 3 were selected for the construction of the new Headquarters of the Piedmont Region, which was officially opened on 14 October 2022. The skyscraper, which stands 205 m tall and has 42 storey, serves as the Headquarter of the Piedmont Region.(Fonsati et al., 2023)

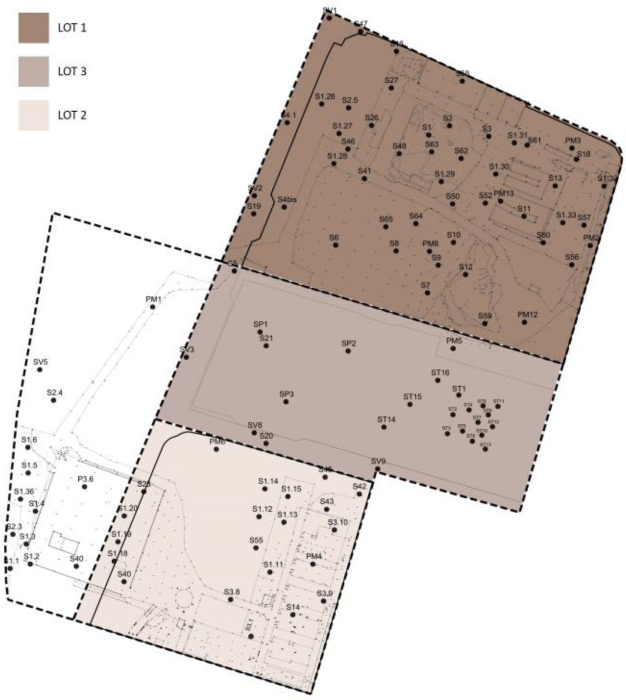


Figure 17. Divisions of parco della salute project. (Fonsati et al., 2023)

The area under study has undergone, over time, numerous transformation and reconfiguration interventions, which have led to significant changes in the soil matrix. As a result, the stratigraphy is highly variable, as is the distribution and type of pollutants present in the subsoil. The first historical evidence relating to the productive use of the area dates back to 1837-1838, with the construction of a chemical plant for the production of artificial fertilizers, which remained almost unchanged until the first half of the 20th century. Subsequently, in 1907, a building for the storage of oil and gasoline was built, owned by SIAP. (Drawing to the Future, 2025)

In the period following the Second World War, Fiat-Gestione Lubrificanti began a project to reorganize the area, dividing it into two main sectors: the "Petrolea" Zone, intended for the storage and distribution of petroleum products, and the "Lubrificants" Zone, dedicated to the management and processing of lubricants. This configuration remained substantially unchanged until 1969, when the area was again transformed with the demolition of several structures, including the buildings intended for the lubricant pumping and storage areas, the painting plants and the warehouses for the storage of tires.

In 1976, construction began on the Fiat Aviazione S.p.A. business complex, which occupied a total area of approximately 118,000 m². The area was intended for aeronautical production and included surface treatment activities on components, with processes

Since 2003, the site has been subject to intense demolition activity, which has involved the removal of numerous structures and the partial removal of surface pavements. Furthermore, based on the available historical documentation, excavation, reclamation and subsequent backfilling operations are highlighted in some areas located in the northern portion of the site.(Drawing to the Future, 2025)

This historical evolution has determined a notable heterogeneity in the composition of the soil and in the distribution of pollutants, with the presence of contaminants of different nature deriving from the various industrial activities that have occurred over time. In particular, environmental analyses have highlighted the presence of contaminants attributable to previous industrial activities, including heavy and light hydrocarbons, chlorinated organic solvents and heavy metals. Their distribution is inhomogeneous and correlated to the different phases of use of the site, with variable concentrations both on the surface and in depth, making an advanced three-dimensional characterization necessary. (Drawing to the Future, 2025)

Figure 18. Conceptual 3D view of Lot 1 and surrounding (Autodesk Infraworks).

Historical archives indicates that lot 1 was part of an industrial facility (ex- FIAT factory), 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)

3.2 Geological Information

3.2.1 Regional Geology

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.(Calafiore & Leanza, 2018; Giuseppe Luigi Ratti Guzmán, 2022)

In the area of the study presents a thickness of fill material consisting of soil mixed with fragments of bricks. 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). In the project area, the water table oscillates between 12 and 14 meters from the ground level.(Giuseppe Luigi Ratti Guzmán, 2022)

3.2.2 In-situ and Laboratory Investigation

In-situ investigation started in 2004 with Borehole testing on the study area and its surrounding. Figure 19, shows the distribution of this borehole test within the area of Lot 1.

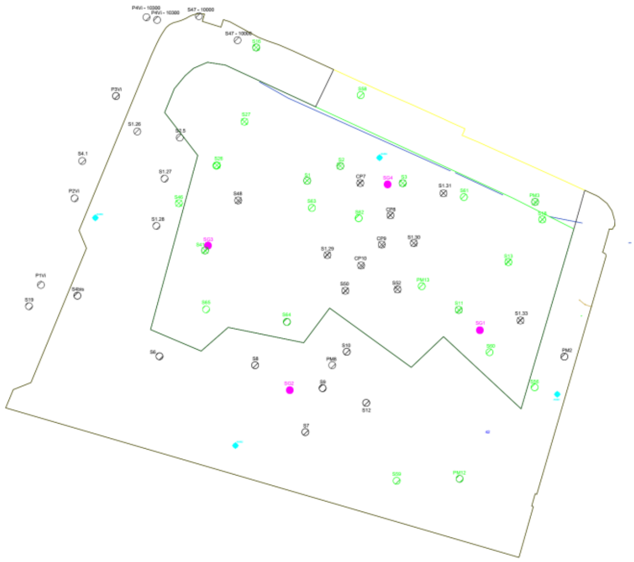


Figure 19. Distribution of boreholes in 2004 field investigation

Figure 20. shows the borehole testing in Lot 1. The device used to take borehole samples is generally called a soil sampler or borehole sampler, but more specific names depend on the sampling method:

1. Shelby tube sampler – used for undisturbed cohesive soil samples.
2. Split-spoon sampler – used in Standard Penetration Tests (SPT) to obtain disturbed soil samples.
3. Piston sampler – for very soft or loose soils, to get undisturbed samples.
4. Auger sampler – often used for disturbed samples or drilling.
5. Core barrel – used in rock coring to retrieve rock core samples.

Each is typically attached to a drilling rig or a sampling rig during a geotechnical investigation. Based on the length and type of samples were needed, different devices used during the field investigations.

Figure 20. Field Investigation and borehole testing

After drilling, samples extracted by the borehole devices stored in boxes to be transfer to laboratory for further analysis. For each borehole a unique box was used. As shown in the Figure 21, each box divided in five distinct spaces, this way for each meter that samples were extracted, a unique space can be allocated to be distinguishable. The box shown in the Figure 21 are called "S1" which denotes that this box related to borehole named "S1" and since borehole S1 investigated the soil every meter until 5-meter depth, spaces allocated accordance to each depth and the depth written in right side of the box.

Figure 21. Sample Box

Finally, after the laboratory investigation, reports created specific for each sample box, showing final depth of the borehole and type of soil for each interval. Figure 22 shows an example of this type of report for sample "S1".

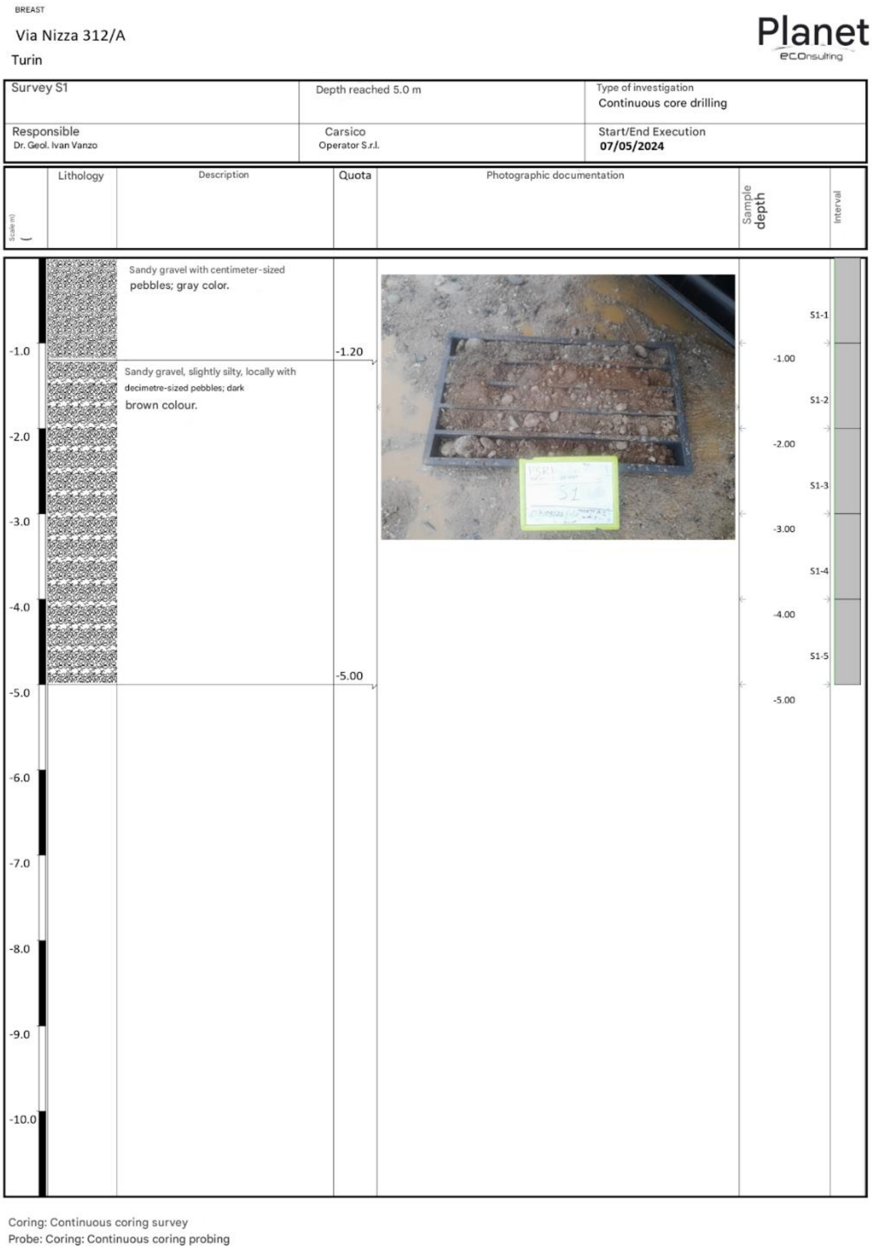


Figure 22. Laboratory report for sample “S1”

Due to complexity and importance of the project and nearby building (Regione Piemonte Skyscraper) and also collecting sample for environmental and contamination studies, additional investigation needed, therefore on 2023 additional in-situ investigation (Borehole test, geophysical test) were carried on, however, second sets of tests were focused primarily on perimeter of the Lot 1. Figure 23 shows the distribution of borehole in 2023 test.

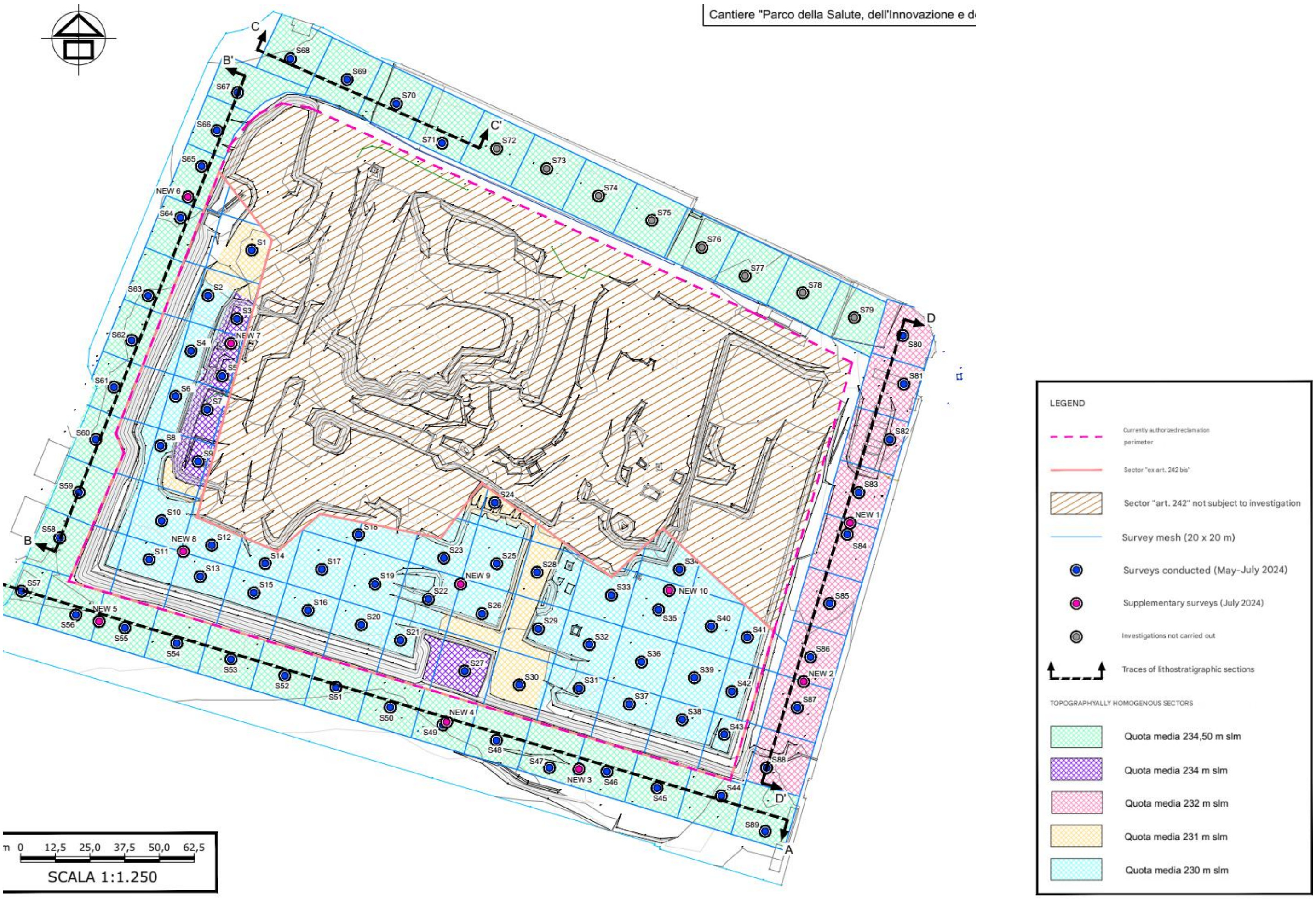
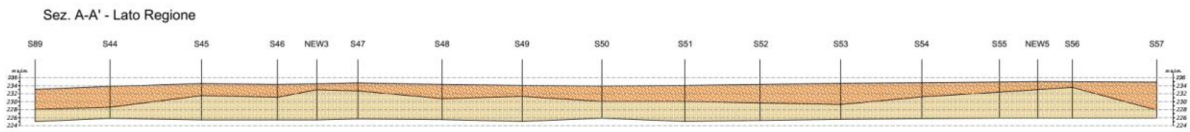
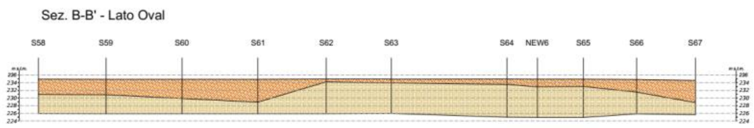


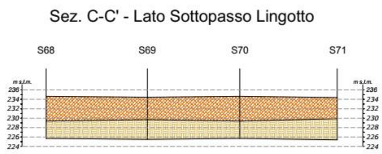
Figure 23. Distribution of borehole test in 2023 field investigation

As seen from the Figure 23, despite the fact all the tests were conducted at surface, starting depth of each borehole is different, this is because since the start of the project some phases of excavation were conducted on Lot 1. However, center portion of the field remained untouched due to the foundation of old industrial building. Borehole test on the perimeter follows a path which depicted by section lines. Data related to boreholes and soil stratigraphy can be found in appendix 1.



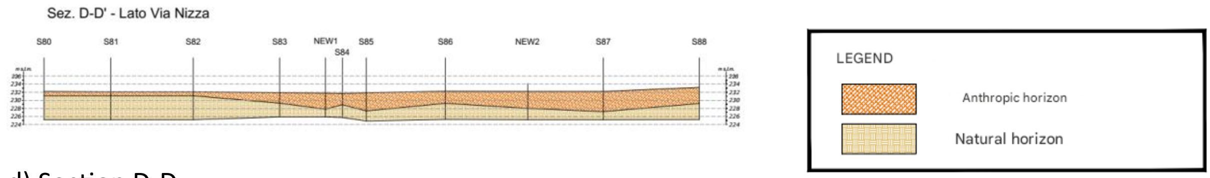
a) Section A-A





b) Section B-B

c) Section C-C



d) Section D-D

Figure 24. 2023 perimeter boreholes in four section views

Figure 24. shows a layer of anthropic sediments resulted from residue of past construction work and part of the old foundation which still exists.

Furthermore, in 2023 geophysical tests were conducted on the series of location (primarily focusing on surrounding), following the predefined line paths. Figure 25 shows the cross section of geophysical test result.

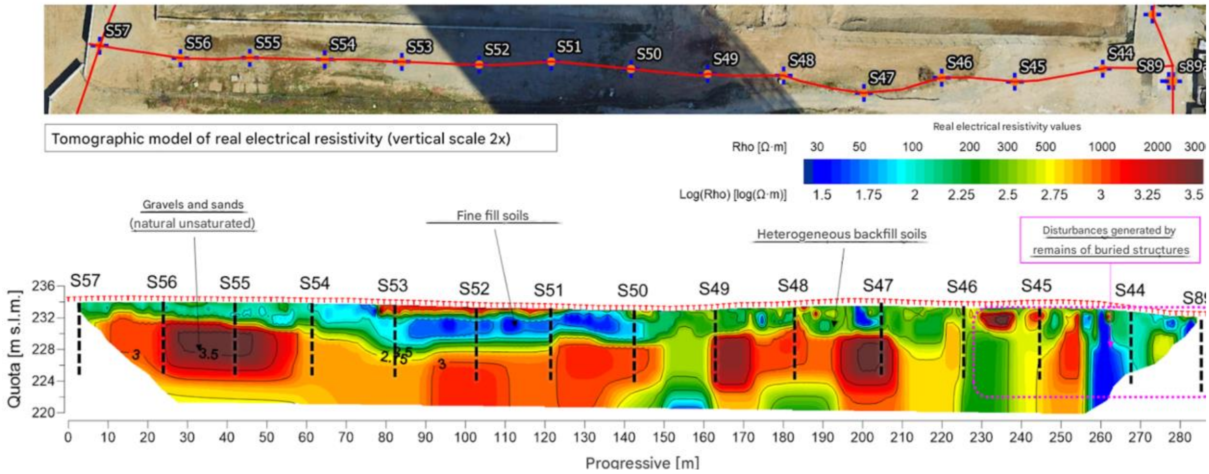


Figure 25. Geophysical tests conducted on Lot 1

Although results of geophysical investigation are not the focus of this study, however geophysical test is a useful nondestructive test which gives detailed view from field of study, although it can't be used for longer depths, however for shallow to medium depth investigation it could provide the location of underground caves resulted from degradation, existence of boulders or underground structures and pipeline paths.

The last investigation that conducted was laboratory testing on samples for contamination and concentration of heavy metals in subsurface soils. This test conducted both in 2004 and 2023, however the depth interval for each period was different. In 2004, borehole samples, randomly selected for laboratory test; in which depth interval was dependent on interval that samples were token. On the other hand, 2023 investigation conducted in a meticulously arranged manner, in such a way that perimeter of Lot 1 divided in cells and within each cell exists at least one borehole test. And finally, borehole tests themselves were conducted in 1 meter interval. This thoroughly structured field investigation resulted in highly accurate contamination and environmental data, which is necessary if the land changes from industrial use to medical use." Tecnico Lifeanalytics Torino srl", Italian company were responsible of conducting the laboratory tests. 66 parameters tested in samples which represented in following table.

Table 1. Parameters tested in laboratory sample

Parameter	
Soil Solid Characteristics	Total humidity (%)
	Skeleton (g/kg)
	Residual humidity at 105°C (g/kg)
Organic Compounds	Antimony (Sb) (mg/kg ss)
	Arsenic (As) (mg/kg ss)
	Beryllium (Be) (mg/kg ss)
	Cadmium (Cd) (mg/kg ss)
	Cobalt (Co) (mg/kg ss)
	Chromium (Cr) (mg/kg ss)
	Hexavalent chromium (Cr VI) (mg/kg ss)
	Mercury (Hg) (mg/kg ss)
	Nickel (Ni) (mg/kg ss)
	Lead (Pb) (mg/kg ss)
	Copper (Cu) (mg/kg ss)
	Tin (Sn) (mg/kg ss)
	Vanadium (V) (mg/kg ss)
	Zinc (Zn) (mg/kg ss)
Polycyclic Aromatic Hydrocarbons	Pyrene (mg/kg ss)
	Benzo(a)anthracene (mg/kg ss)
	Chrysene (mg/kg ss)
	Benzo(b)fluoranthene (mg/kg dry matter)
	Benzo(k)fluoranthene (mg/kg dry matter)
	Benzo(a)pyrene (mg/kg ss)
	Indeno(1,2,3-cd) pyrene (mg/kg dry matter)
	Dibenzo(a,h)anthracene (mg/kg dry matter)
	Benzo(g,h,i)perylene (mg/kg dry matter)
	Dibenzo(a,e)pyrene (mg/kg ss)
	Dibenzo(a,h)pyrene (mg/kg ss)
	Dibenzo(a,i)pyrene (mg/kg ss)
	Dibenzo(a,l)pyrene (mg/kg ss)
	Summatoria Polycyclic Aromatici
Carcinogenic Chlorinated Aliphatics	Chloromethane (mg/kg body weight)
	Dichloromethane (mg/kg body weight)
	Trichloromethane (Chloroform) (mg/kg body weight)
	Divinyl chloride (mg/kg body weight)
	1,2-dichloroethane (mg/kg body weight)
	1,1-dichloroethylene (mg/kg ss)
	Trichloroethylene (mg/kg body weight)
	Tetrachloroethylene (mg/kg body weight)
Non-Carcinogenic	1,1-dichloroethane (mg/kg body weight)
	1,2-dichloroethylene (cis + trans) (mg/kg ss)
	1,1,1-trichloroethane (mg/kg body weight)

Chlorinated Aliphatics	1,2-dichloropropane (mg/kg body weight)
	1,1,2-trichloroethane (mg/kg body weight)
	1,2,3-trichloropropane (mg/kg body weight)
	1,1,2,2-tetrachloroethane (mg/kg body weight)
Hydrocarbons	Hydrocarbons to be read C<12 (mg/kg ss)
	Hydrocarbons Heavy C higher than 12 (C12-C40) (mg/kg ss)
PCB	PCB (total) (mg/kg ss)
PFAS	Perfluorodecanoic acid (PFDA) (mg/kg body weight)
	N-EtFOSA (N-ethyleptadecafluorooctanesulfonamide) (mg/kg body weight)
	PFOSF (Perfluorooctanesulfonyl fluoride) (mg/kg ss)
	Perfluorooctane sulphonic acid and its derivatives (PFOS) (mg/kg ss)
	Perfluoroundecanoic acid (PFUnA) (mg/kg ss)
	Perfluorotetradecanoic acid (PFTeDA) (mg/kg ss)
	Perfluorotridecanoic acid (PFTrDA) (mg/kg ss)
	Perfluoroheptanoic acid (PFHpA) (mg/kg ss)
	Perfluorononanoic acid (PFNA) (mg/kg ss)
	Perfluorododecanoic acid (PFDoA) (mg/kg ss)
	Perfluorohexane sulfonic acid (PFHxS) and its salts (mg/kg ss)
	PFOS (Perfluorooctanesulfonic acid) and its salts (mg/kg ss)
	Perfluorobutanesulfonic acid (PFBS) (mg/kg dry weight)
	Perfluorohexanoic acid (PFHxA) (mg/kg ss)
	Perfluorooctanoic acid (PFOA) related compounds (mg/kg ss)
	Compounds related to Perfluorohexane sulfonic acid (PFHxS) (mg/kg ss)
	Perfluorooctanoic acid (PFOA) and its salts (mg/kg ss)

Laboratory, reported the results for each sample along with threshold limit introduced for each contamination in pdf format. A sample of this types of report presented in appendix 2. Although these types of reports are useful to inform stakeholders involve, however are not so useful for future application and decision-making processes. Therefore, a pre-processing procedure were introduced in chapter 4 to extract and create a spreadsheet usable for workflow.

chapter 4 Methodology

4.1 Introduction

This chapter describes the methodology adopted for collecting, pre-processing, analyzing, and modeling subsurface data. The approach integrates field investigations, laboratory test results, and environmental contamination data into a model which work as geotechnical dataset.

As a starting point a preliminary workflow was laid out, so as to better understand the processes and steps needed to: 1. Contamination model 2. Subsurface model. Figure 26 shows the workflow planned for this methodology. The procedure will involve creating a georeferenced base point for the 3D model from 2D drawings and on the other hand creating a spreadsheet that will later on feed the data into the 3D model.

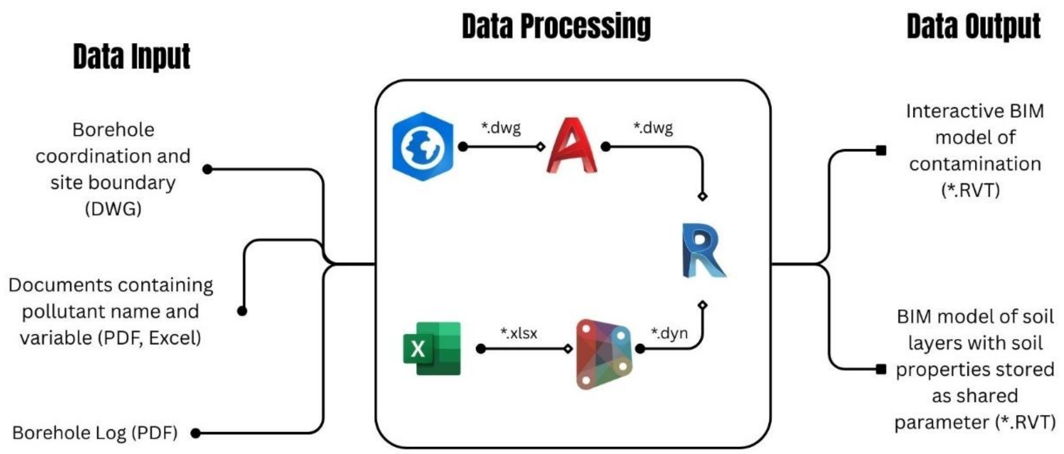


Figure 26. Developed workflow for GeoBIM modeling using Dynamo Revit

The entire workflow is divided into three main stages: Data Input, Data Processing, and Data Output.

4.1.1 Data input

This stage gathers all the essential raw data needed for modeling. It involves three primary sources:

- **Borehole Coordinates and Site Boundary**:
  CAD drawings are used to define the spatial framework. These include borehole locations and the site’s geographical boundary.
- **Documents Containing Pollutant Names and Variables**:
  This input includes laboratory test results and environmental reports identifying pollutants and their measured values across borehole depths.
- **Borehole Logs**:
  Field records or lab reports documenting the stratigraphy of each borehole which contain depth-wise descriptions of soil types and relevant geotechnical data.

4.1.2 Data Processing

In this stage all essential raw data needed for modeling are fed to Autodesk Revit directly or through dynamo for preprocessing and automation:

- **Esri ArcGIS Pro:** Used to integrate several drawings from multiple campaign and cell divisions. ArcGIS was also used for georeferencing the borehole locations.
- **Autodesk AutoCAD:**
  Used to clean and prepare DWG files.
- **Autodesk Revit**:
  Receives the processed CAD drawings and serves as the main platform for 3D modeling. Here, both contamination and soil stratigraphy will be visualized.
- **Excel**:
  Structured spreadsheets are created or refined to contain pollutant data and soil parameters. These tables are carefully formatted so they can be correctly interpreted by Dynamo scripts.
- **Dynamo**:
  Dynamo scripts are used to automate the reading of Excel data, associate it with borehole points in 3D space, and generate geometries such as soil layers or pollutant volumes. These scripts also handle the assignment of shared parameters to the resulting Revit elements for further querying and interaction.

4.1.3 Data Output

This stage results in two main deliverables, both exported as Revit models (.RVT), and both interactive and data-rich:

- **Interactive BIM Model of Contamination**:
  This output visualizes pollutant distributions at different depths and locations, allowing users to click on each zone to inspect contamination levels, types of pollutants, and regulatory exceedances.

- **BIM Model of Soil Layers with Soil Properties as Shared Parameters**:
  This model shows the stratigraphy of the subsurface, with each soil layer represented as a 3D volume. Soil properties are embedded as shared parameters within the BIM model.

4.2 Pre-processing

As mentioned, foundation of this research lies in the accurate representation of the subsurface conditions at the Parco della Salute site. Data were sourced from field investigations and laboratory tests conducted during two separate campaigns: one in 2004, covering the central part of the land, and another in 2023, focused on the surrounding area. These investigations were performed by two different geotechnical companies; however, method of report delivery of both companies was in noneditable pdf formats. Therefore, it was necessary to processes and create a spreadsheet that unifies data from both campaigns, which is useable for modeling purposes. Two main formats used for data exchange in geotechnical field. AGS (Association of Geotechnical and Geo-Environmental Specialists) or CSV (Comma Separated Variable). In this study CSV format used to store data.

The first spread sheet that created, was related to the stratigraphy and borehole data. Using Microsoft Excel 6 columns were created: first column for “Borehole ID”, the two proceeding columns, identifies “top” and “bottom” of each type of soil in which they were identified in the boreholes. For future use modeling process, it was decided that each type of soil be coded by letters; therefore, fourth column dedicated to “soil identification code” (legend code). Fifth and sixth column shows the lithography and description of the soil. Table 2 Shows a part of the spread sheet created for stratigraphy.

Table 2. Spread sheet No.1 (Including Borehole ID, Legend code, stratigraphy and soil description)

Location ID	Depth Top	Depth Base	Legend Code	Lithology	Description
S1	0	1.2	A	Sandy Gravel	Sandy gravel with centimeter-sized pebbles.
S1	1.2	5	B	Gravel and slightly silty sand	Sandy gravel, slightly silty. Locally with decimeter-sized pebbles.
S2	0	4	B	Gravel and slightly silty sand	Sandy gravel, slightly silty. Locally with decimeter-sized pebbles.
S3	0	0.5	C	Filling	Fill soil consisting of gravel and sand with concrete fragments
S3	0.5	1.5	D	Concrete	Concrete slab
S3	1.5	2.6	A	Sandy Gravel	Sandy gravel with centimeter-sized pebbles.
S3	2.6	3	F	Pebbly sand	Sand with gravel and pebbles of centimeter size
S3	3	4.2	F	Pebbly sand	Sand with gravel and pebbles of centimeter size
S3	4.2	7	B	Gravel and slightly silty sand	Gravel and slightly silty sand. with altered centimeter- to decimeter-sized pebbles.
S3	7	8	A	Sandy Gravel	Sandy gravel with centimeter-sized pebbles.
S4	0	2	B	Gravel and slightly silty sand	Gravel with slightly silty sand and altered centimeter-sized pebbles.
S4	2	4	A	Sandy Gravel	Sandy gravel with centimeter-sized pebbles.
S5	0	0.6	D	Concrete	Concrete slab

A comprehensive spreadsheet containing the full stratigraphic data, including borehole identifiers, depth intervals, soil classifications, and corresponding descriptions, is provided in Appendix 1 for reference.

From laboratory tests on extracted soil samples, 9 types of soils were identified. In order to create soil models using dynamo, it was needed to feed separate spread sheets. Therefore 9 spread sheets were created. These sheets which identified by the soil legend code are constructed as shown in table ….by borehole ID, Depths (top and base), soil legend code, coordination of the boreholes (x, y, z) and lastly top and bottom height of in which the specific soil were identified.

Table 3. Distinct spread sheet for soil model to be fed to dynamo as an input.

ID	Depth Top	Depth Base	Legend Code	X	Y	Z (Surface)	Z (Top)	Z (Bottom)
S87	3	4.5	I	394781.1	4986676	232	229	227.5
S26	0.5	2.1	I	394667.5	4986710	230	229.5	227.9
S27	0.3	1	I	394661.2	4986689	232.4	232.1	231.4
S27	1	1.5	I	394661.2	4986689	232.4	231.4	230.9
S27	1.5	3	I	394661.2	4986689	232.4	230.9	229.4
S11	1.4	2	I	394547.6	4986729	230	228.6	228
S13	0.15	0.5	I	394566	4986723	230	229.85	229.5

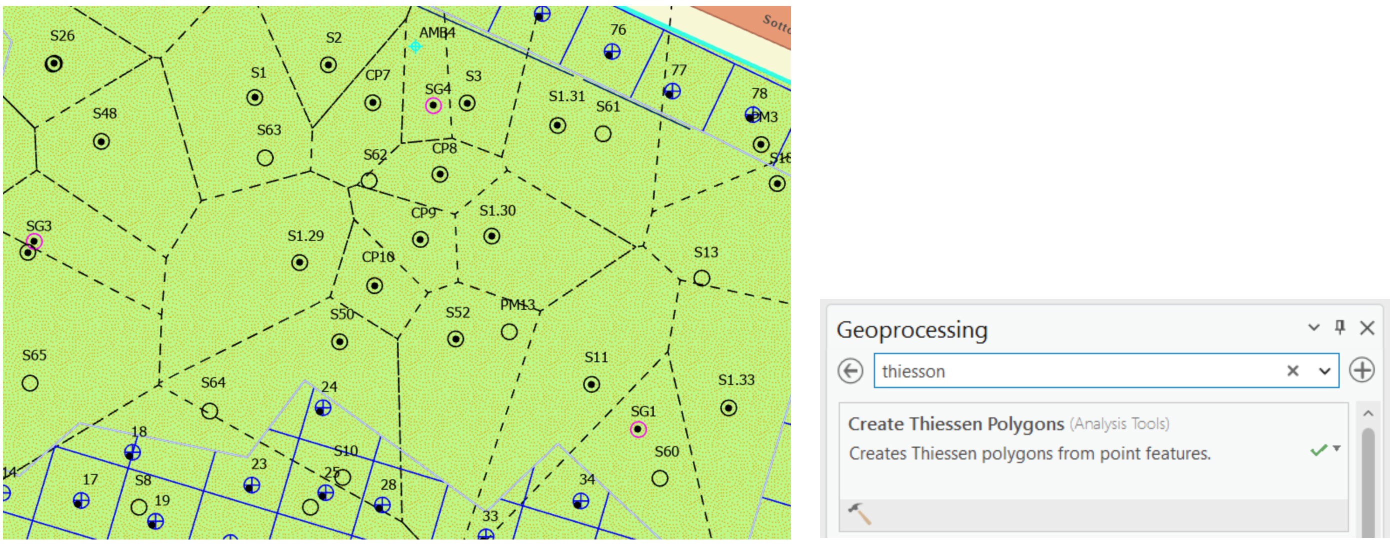
Another spread sheet needed to be created, containing environmental assessment derived from the laboratory test. Processes of creating this spread sheet involved reading and extracting all laboratory data and then merging the information from two campaigns. Final product included: 1. Data related to soil skeleton, humidity of the sample, humidity of the sample at 105° C. 2. Organic compounds and presence of heavy metals 3. Polycyclic aromatic hydrocarbons 4. Carcinogenic chlorinated aliphatic 5. Hydrocarbons 6. Polychlorinated Biphenyls (PCB) 7. Polyfluoroalkyl Substances (PFAS).

However, another step needed be integrated these data with each specific borehole. Table 4. Structure of contamination data sheet Shows the configuration of the final spreadsheet.

Table 4. Structure of contamination data sheet

Location ID	X	Y	Z	Depth Top	Depth Base	Antimony (Sb) (mg/kg s.s.)	Arsenic (As) (mg/kg s.s.)	Beryllium (Be) (mg/kg s.s.)	…	Heavy Hydrocarbons C greater than 12 (C12-C40) (mg/kg s.s.)	PCB ((mg/kg s.s.)
S1-1 (0-1m)	394584.5	4986841	230.5	0	1	0.49	1.33	0.47	…	6.3	0.0004
S1-2 (1-2m)	394584.5	4986841	229.5	1	2	0.21	1.53	0.21	…	3.8	0.0004
S1-3 (2-3m)	394584.5	4986841	228.5	2	3	0.24	1.66	0.24	…	4.2	0.0004
S1-4 (3-4m)	394584.5	4986841	227.5	3	4	0.28	1.45	0.19		3.5	0.0004
S1-5 (4-5m)	394584.5	4986841	226.5	4	5	0.22	1.86	0.21		7.6	0.0003
S2-1 (0-1m)	394568.8	4986824	229.5	0	1	0.35	3.85	0.35		5.7	0.0006

As mentioned in chapter 3, the main focus of 2004 campaign was middle portion of the Lot 1, whereas the 2023 campaign mostly focused on the boundary and perimeter of the site. Therefore, it was necessary to merge 2D model of Land-Survey data. Since 2023 model, divide the land into cells, shown in Figure 27, it was decided to keep this division and consider it as "Parent Model". Then "Thiessen", an ArcGIS geoprocessing tool were used to subdivide the middle portion of the land into cells in such a way that in each cell, at least one borehole presented from 2004 campaign.



a) b)

Figure 27. a) subdivision of middle portion of lot 1 with 2004 campaign data b) Thiessen, ArcGIS geoprocessing tool

The result was the final 2D drawing, ready to be implemented for creating contamination model.

4.3 Data Modeling Strategy

The goal of the modeling process was to generate a 3D representation of the soil layers and create a model containing contamination data.

For soil model the strategy consisted of:

- Visualizing each borehole and its layered stratigraphy in 3D
- Linking the soil type and its description to each layer

For contamination model strategy consisted of:

- Pin pointing borehole's location using adaptive points
- Visualizing borehole as a cylindrical column
- Generating the volume beneath the Lot1 geometry, according the cells division (Voxel based volume)
- Linking pollution data to cells
- Color-coding the volume for quickly identifying potentially hazardous zones, based on pollution concentration

4.4 Software Tools and Workflow

The following tools were used in the modeling process:

- **Microsoft Excel**: Excel was used to structure raw geotechnical and contamination data collected from borehole logs and laboratory reports. The data was formatted into tabular form, allowing Dynamo to read it efficiently. Excel served as the database for pollutant variables, depth intervals, and soil classification, acting as a bridge between raw site data and the parametric model.
- **Autodesk Revit**: Revit was the core platform used for subsurface modeling. The software allowed for the creation of visually descriptive elements—such as soil layers and contamination zones—while also supporting the assignment of metadata through shared parameters.
- **Dynamo**: Visual programming tool embedded in Revit, was used to automate processes in the workflow. Custom scripts were developed to read excel data, generate 3D geometries and assign shared parameters to model elements. Several Dynamo packages like Clockworks (for list manipulation) and Data-Shapes (for creating input forms) were also used.

4.5 Modeling Environment and Project Setup

The modeling was performed in Autodesk Revit, a Building Information Modeling (BIM) software widely used for architectural and structural projects. Similar to any other modeling software tool, Revit requires an initial setup before drawing. This setup involves setting up the unit, which could be metric (m, cm or mm) or imperial (ft) depending on the project. For this study, metric setting (in meter) was used as the project template.

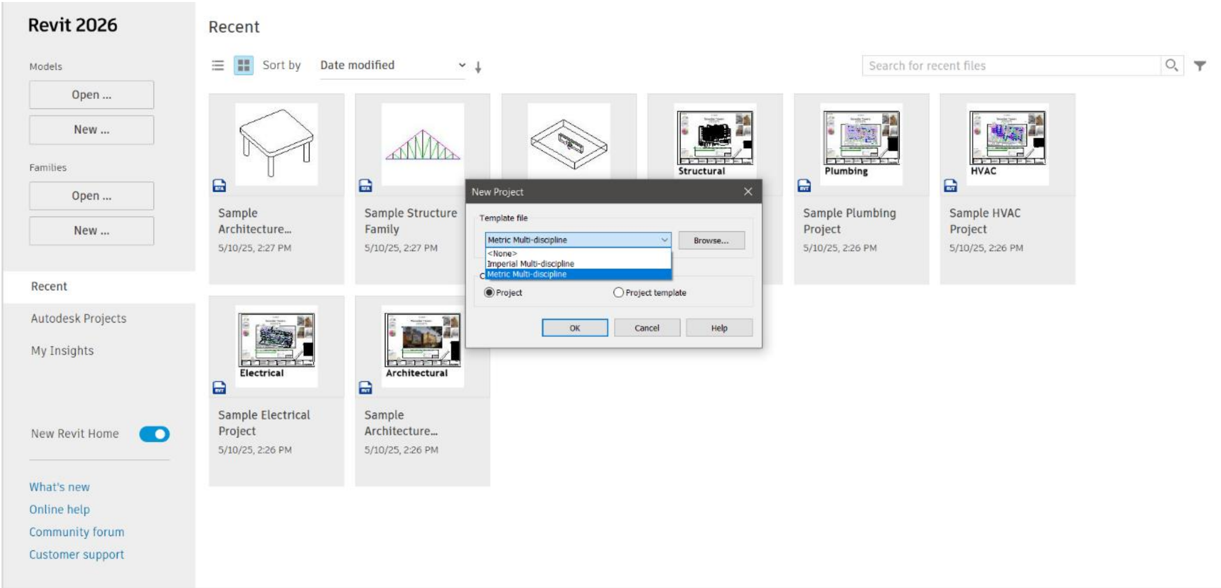


Figure 28. New project setting in Autodesk Revit

From this point, processes were divided for each model:

4.5.1 Modeling process for soil layer.

Entire procedure of soil modeling done with dynamo code. Therefore, it was necessary to set up the dynamo environment. Dynamo, could be accessed through "Manage" tab inside Revit.

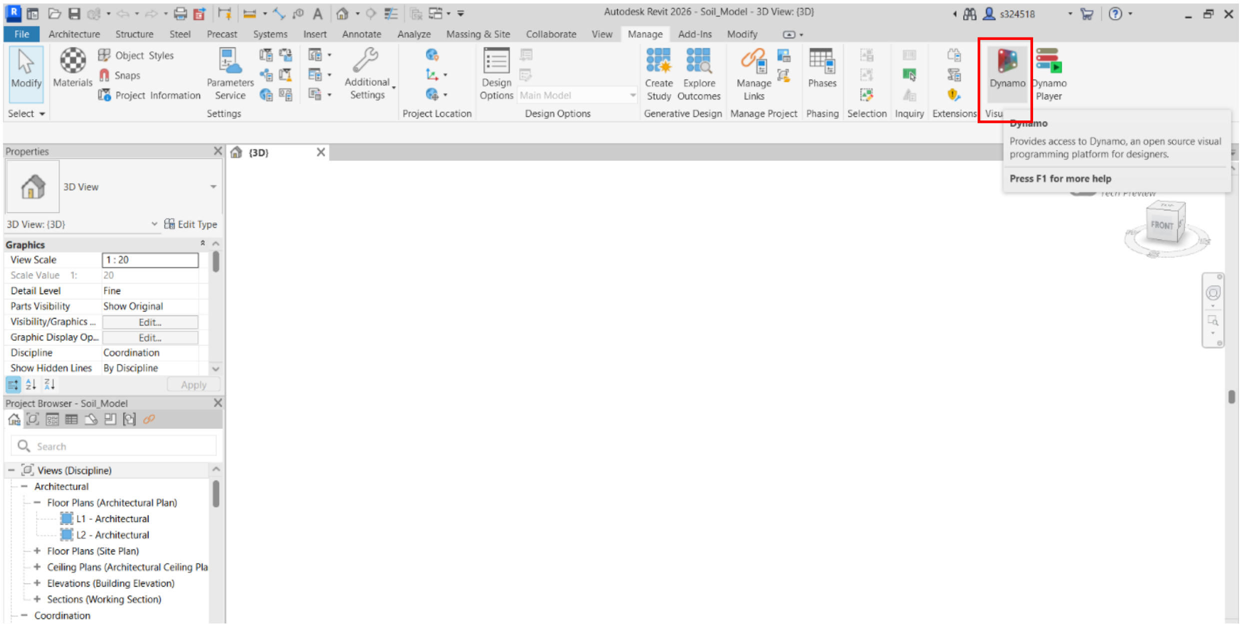


Figure 29. Dynamo environment can be accessed inside manage tab

Dynamo is an open-source component technology for visual programming. It uses visual scripts in the form of **nodes and links**, where each node or a group of nodes performs a defined function. (Weng et al., 2021). Two or more nodes connect together and via links. The links work as method of data transfer among nodes. Conventionally, nodes receive data from the left side as input, and can send the result as output. Figure 30Figure 30. A simple node in dynamo script shows a single node which receive three inputs as (x, y, z) on the left and create a point from these coordinates as an output on the right.

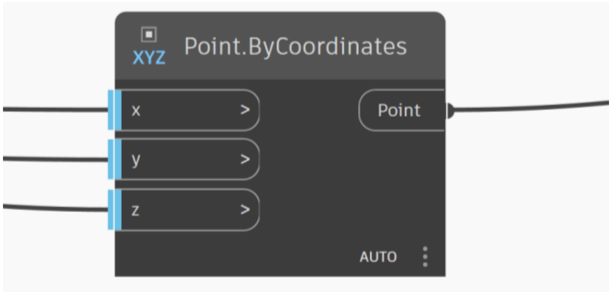
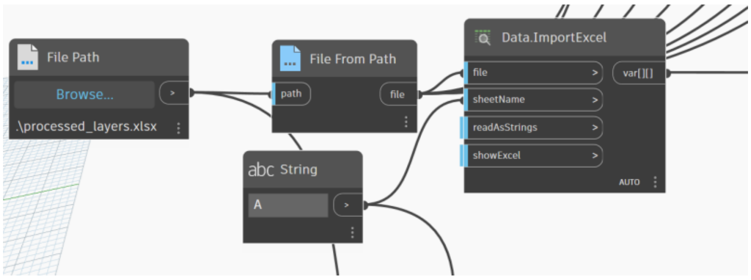
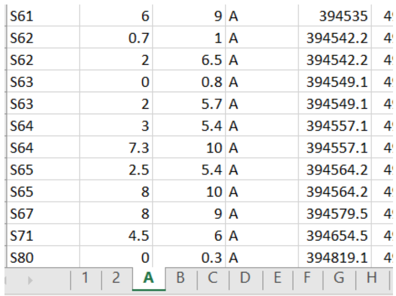


Figure 30. A simple node in dynamo script

The first step in the script was to import the excel data into dynamo environment. Using “File path” node, the directory of spreadsheet was selected. This node then has to be connected to “File from path” node, this node creates a file object from the given path. then finally latter node connected to “Data.ImportExcel” node, which able to read any specific excel sheet.





S61	6	9	A	394535	4
S62	0.7	1	A	394542.2	4
S62	2	6.5	A	394542.2	4
S63	0	0.8	A	394549.1	4
S63	2	5.7	A	394549.1	4
S64	3	5.4	A	394557.1	4
S64	7.3	10	A	394557.1	4
S65	2.5	5.4	A	394564.2	4
S65	8	10	A	394564.2	4
S67	8	9	A	394579.5	4
S71	4.5	6	A	394654.5	4
S80	0	0.3	A	394819.1	4

a) b)

Figure 31. a) Importing specific excel sheet into dynamo b) corresponding excel sheet

Second, it was necessary to clean and restructure the data in order to identify and extract the correct indices. The first row of the Excel sheet, which contains the column titles, had to be removed. This was done using the “List.RestOfItems” node, which eliminates the first item in a list. Since “Data.ImportExcel” reads the data row by row and the Excel file was organized in columns, the “List.Transpose**”** node was used to transpose the list, converting rows into columns and aligning the data properly.

Third, the top point of each borehole was identified by extracting the X, Y, and Z coordinates. This was achieved using the “List.GetItemAtIndex” node, which takes a list and a specified index as inputs and returns the corresponding data as output. This allowed the extraction of coordinate values from their respective positions in the list.

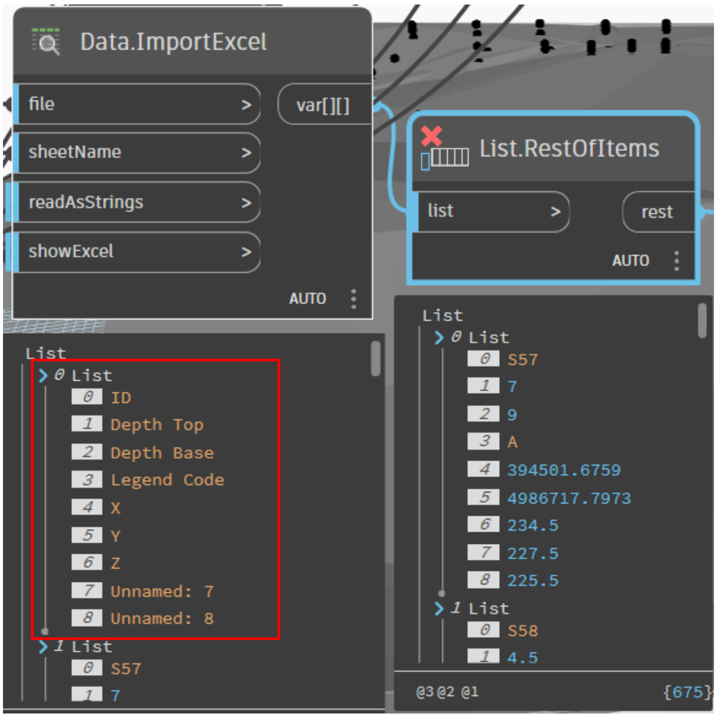


Figure 32.” List.RestOfItems” node used to remove the first index of the list

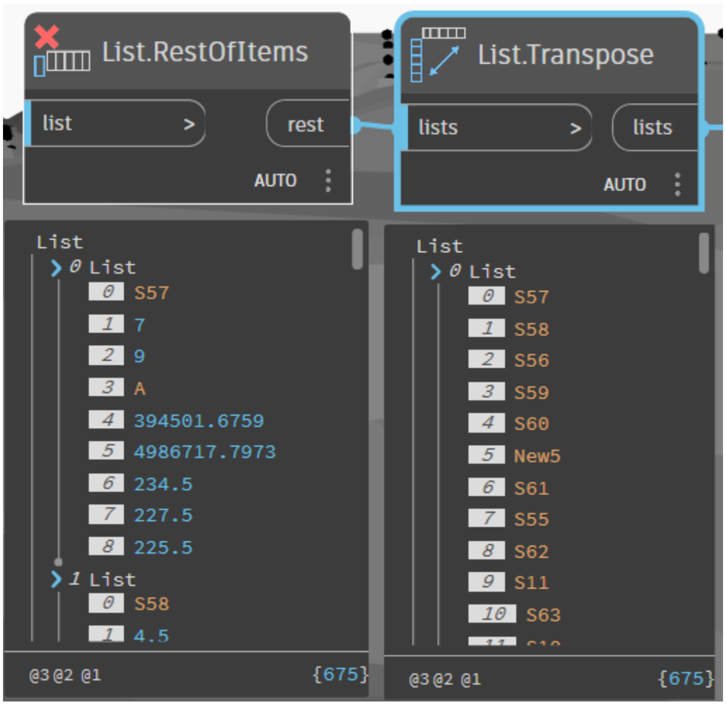
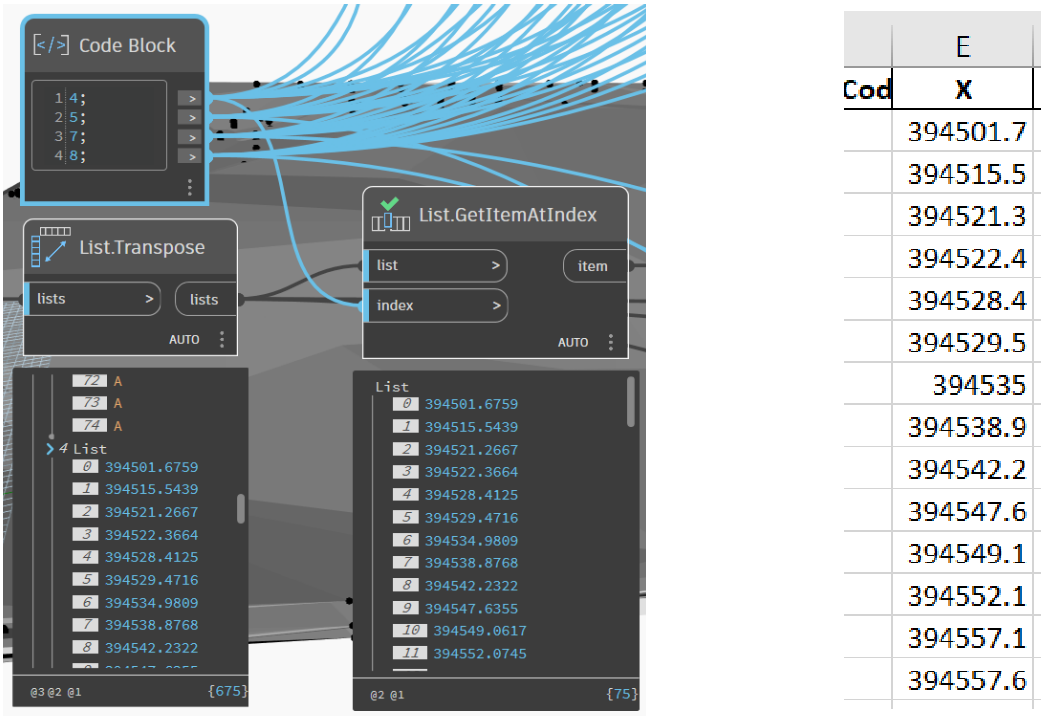


Figure 33.” List. Transpose” node used to re-arrange the list based on excel columns



a) b)

Figure 34. a)” List.GetItemAtIndex” used to retrieve the data (x value of points in this case) b) corresponding column in excel sheet

“Point.ByCoordinates” was used to create group of points from list of x, y, z coordinates. Finally, “Topography.ByPoints” used to create topo solid from created points.

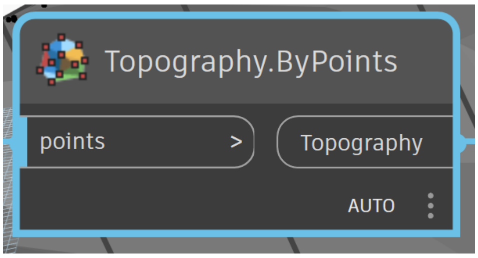


Figure 35. Topo solid created from list of points using” Topography.ByPoints”

For better distinguishing the layers, each topo solid was colored, using “Element.OverrideColorInView” node.

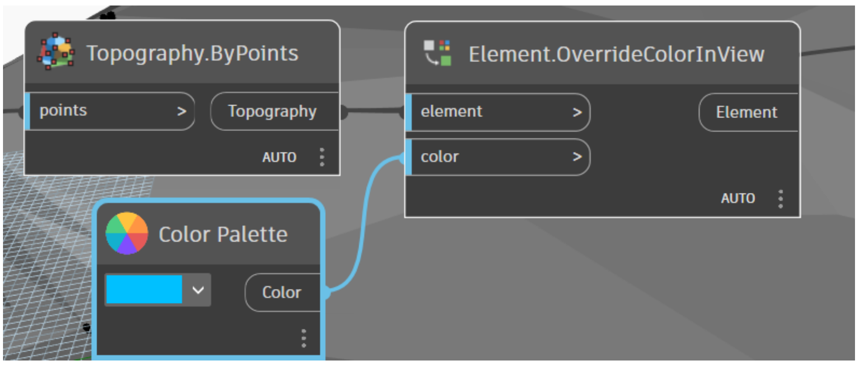


Figure 36. coloring layers using “Element.OverrideColorInView”

The result of soil modeling shown in chapter5.

4.5.2 Modeling process contamination model.

1. 2D drawings representing boreholes and cell layout were imported into Revit. In Autodesk Revit It is possible to import or link multiple file formats including DXF, DWG, FBX, through insert tab.

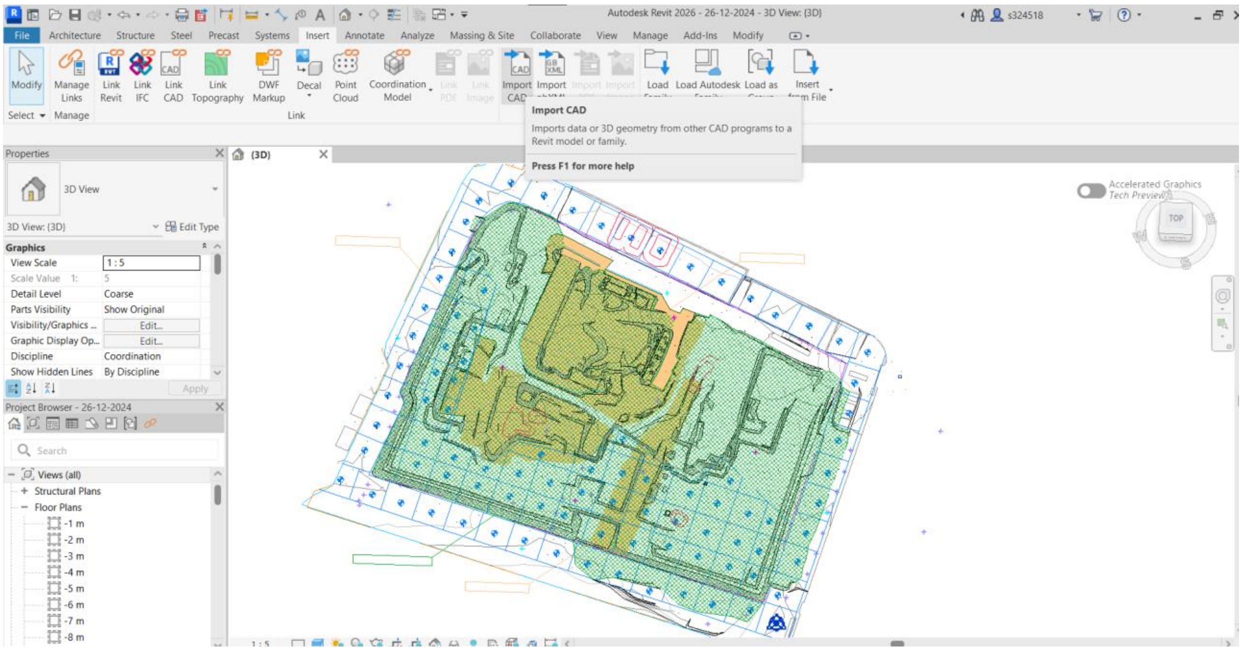


Figure 37. dwg file representing Lot 1 and boreholes were imported in Revit environment

2. Adaptive points placed on the borehole's location at the surface level, this helped to identify accurate location of the borehole in other levels.

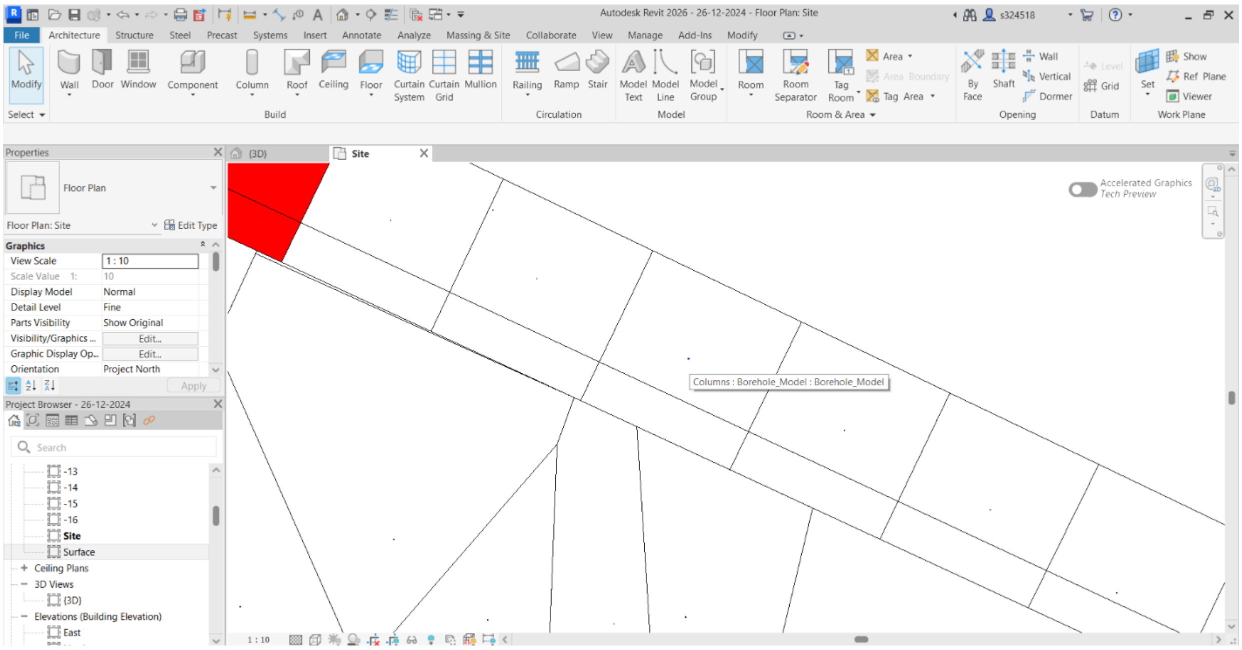
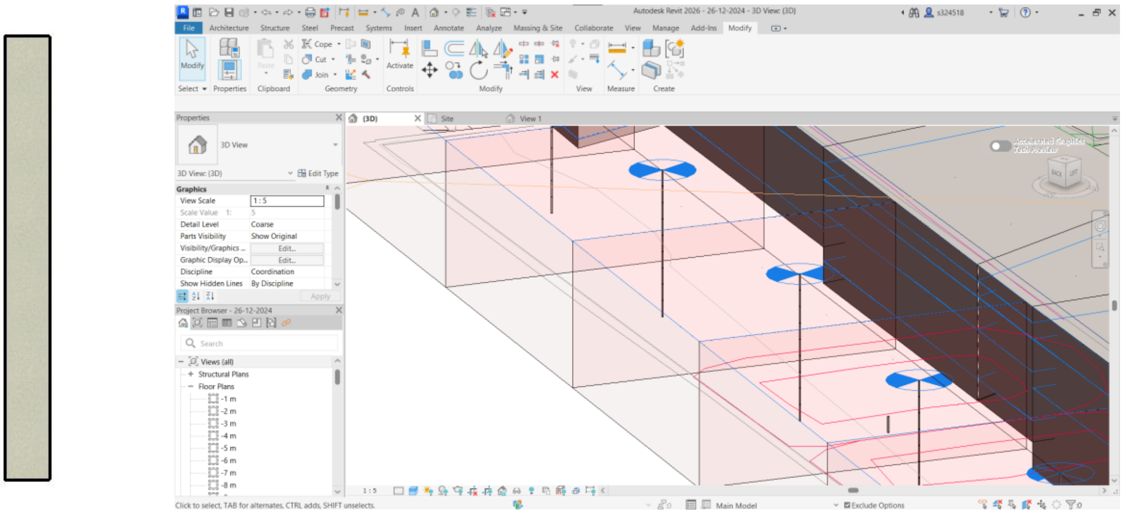


Figure 38. Adaptive points were placed to identify location of boreholes

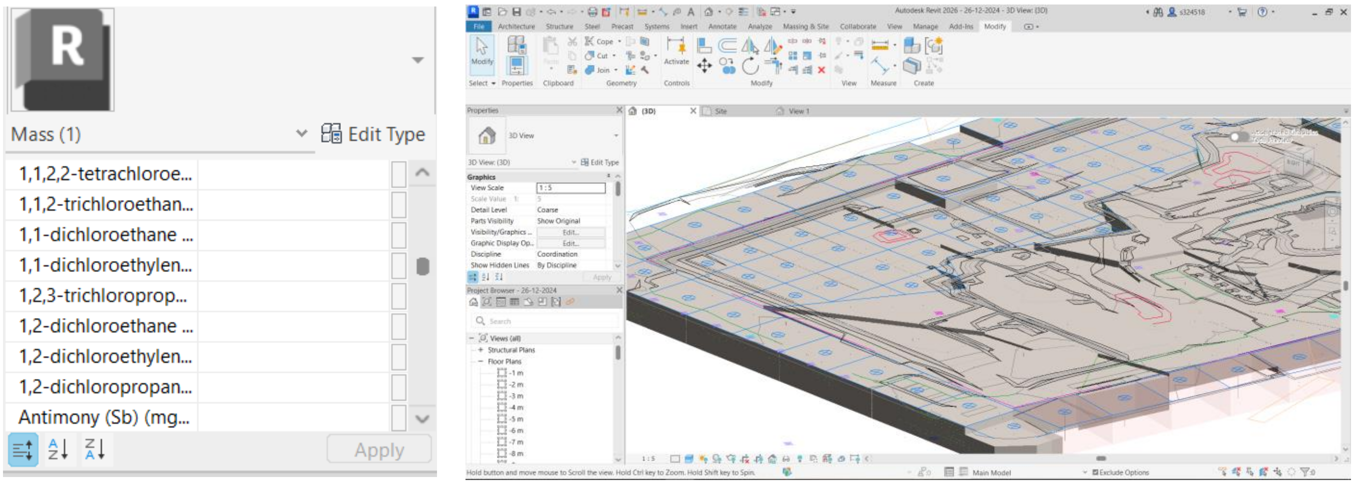
To represent the borehole itself, it was decided to use a cylindrical column by 1m height, exact length of each test interval. This column inherits the contamination data for each corresponding meter. Afterward, the cell division were re-traced to create mass. The result was masses which represent the sub surface soil volume.



a) b)

Figure 39. a) cylindrical column, representing a borehole. b) Cell division of subsurface using mass modeling

3. Final step was introducing the list of contaminations in table 1 as shared parameters. These parameters introduced to both "mass floors" and "cylindrical columns". Final result, is the voxel-based mass model representing the contamination in subsurface soil.



a) b)

Figure 40. a) Introduced shared parameter b) mass model representing the subsurface contamination

4. At this point, dynamo was used to introduce contamination values as shared parameter. This step was done similar to pervious work for creating soil layers, by reading and importing data from excel sheet to dynamo environment.

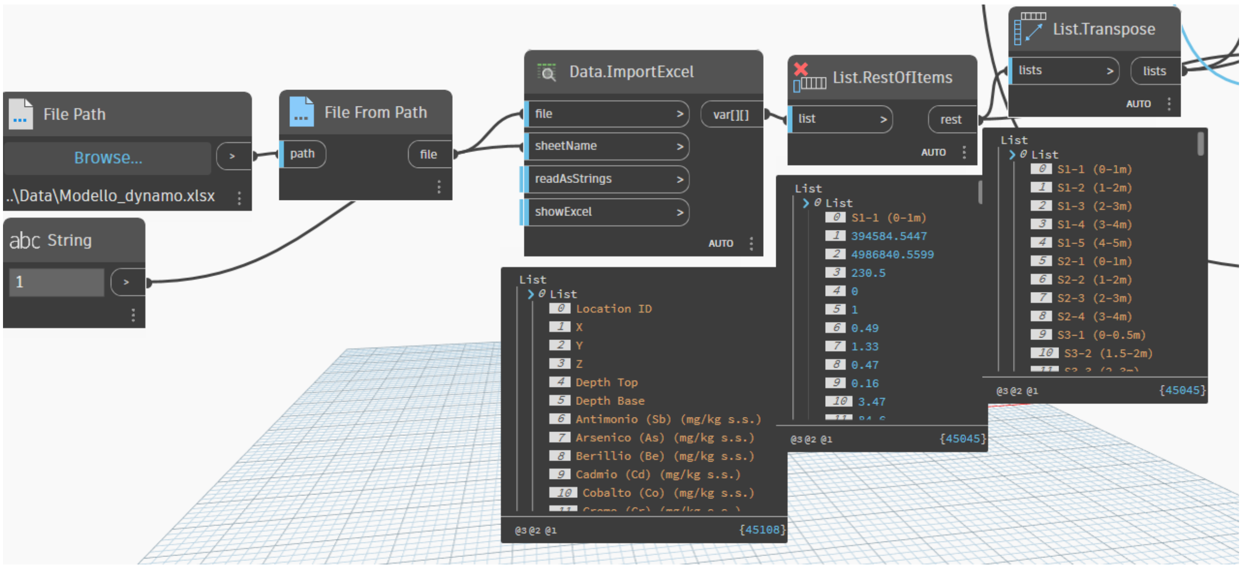
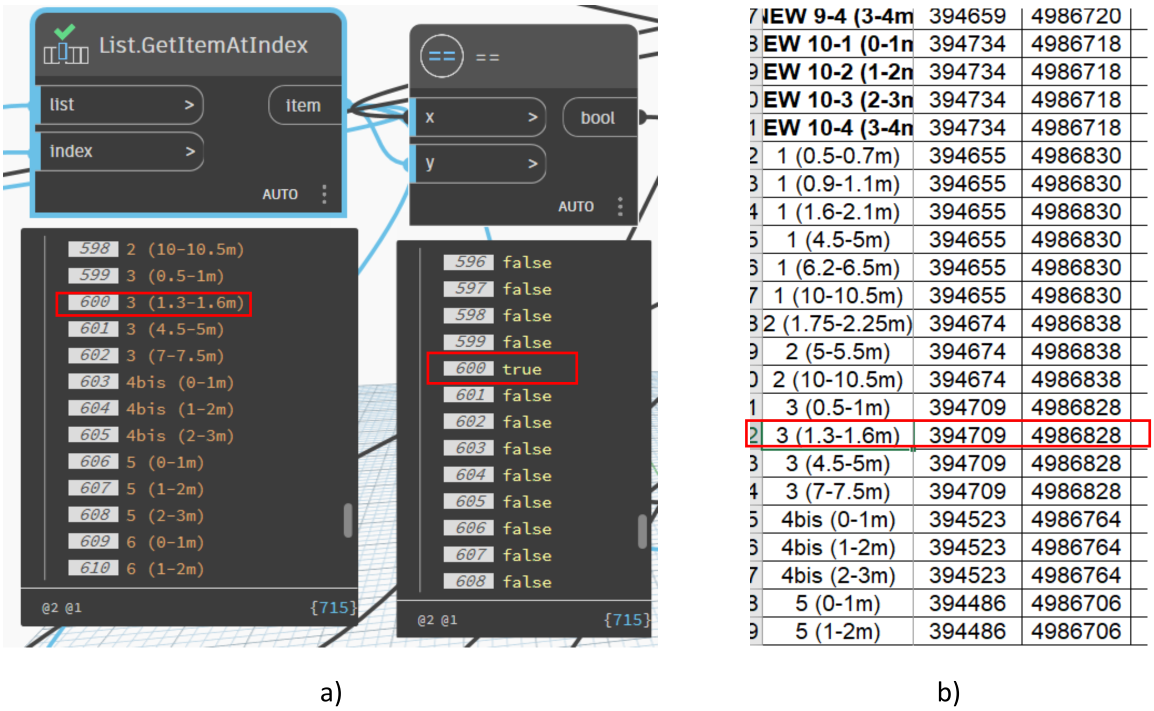


Figure 41. Reading contamination excel sheet

5. To ensure accurate assignment of contaminant data, it was necessary to check parameter name (name of the contamination) and borehole ID in excel sheet and to see if it is "contained" as shared parameter on each element. if the condition is satisfied, set the parameter value from the corresponding index. *Figure 42* shows a conditional statement which checks if there is any data available on borehole #3 from depth of 1.3 to 1.6 m. Script checks all 715 elements. If statement is wrong meaning the element "ID" is not correct and moves on to the next one.



EW 9-4 (3-4m	394659	4986720
EW 10-1 (0-1n	394734	4986718
EW 10-2 (1-2n	394734	4986718
EW 10-3 (2-3n	394734	4986718
EW 10-4 (3-4n	394734	4986718
1 (0.5-0.7m)	394655	4986830
1 (0.9-1.1m)	394655	4986830
1 (1.6-2.1m)	394655	4986830
1 (4.5-5m)	394655	4986830
1 (6.2-6.5m)	394655	4986830
1 (10-10.5m)	394655	4986830
2 (1.75-2.25m)	394674	4986838
2 (5-5.5m)	394674	4986838
2 (10-10.5m)	394674	4986838
3 (0.5-1m)	394709	4986828
3 (1.3-1.6m)	394709	4986828
3 (4.5-5m)	394709	4986828
3 (7-7.5m)	394709	4986828
4bis (0-1m)	394523	4986764
4bis (1-2m)	394523	4986764
4bis (2-3m)	394523	4986764
5 (0-1m)	394486	4986706
5 (1-2m)	394486	4986706

Figure 42. a) Checking data availability of Borehole #3 b) corresponding data on the excel sheet

6. For the selected element, corresponding shared parameter value read from the excel sheet using "List.GetItemAtIndex". following data then set to the element (in this case it was a mass floor) by

"Element.SetParameterByName". This node is an external node, from the "Rhythm" package which should be installed as a dynamo extension tool.

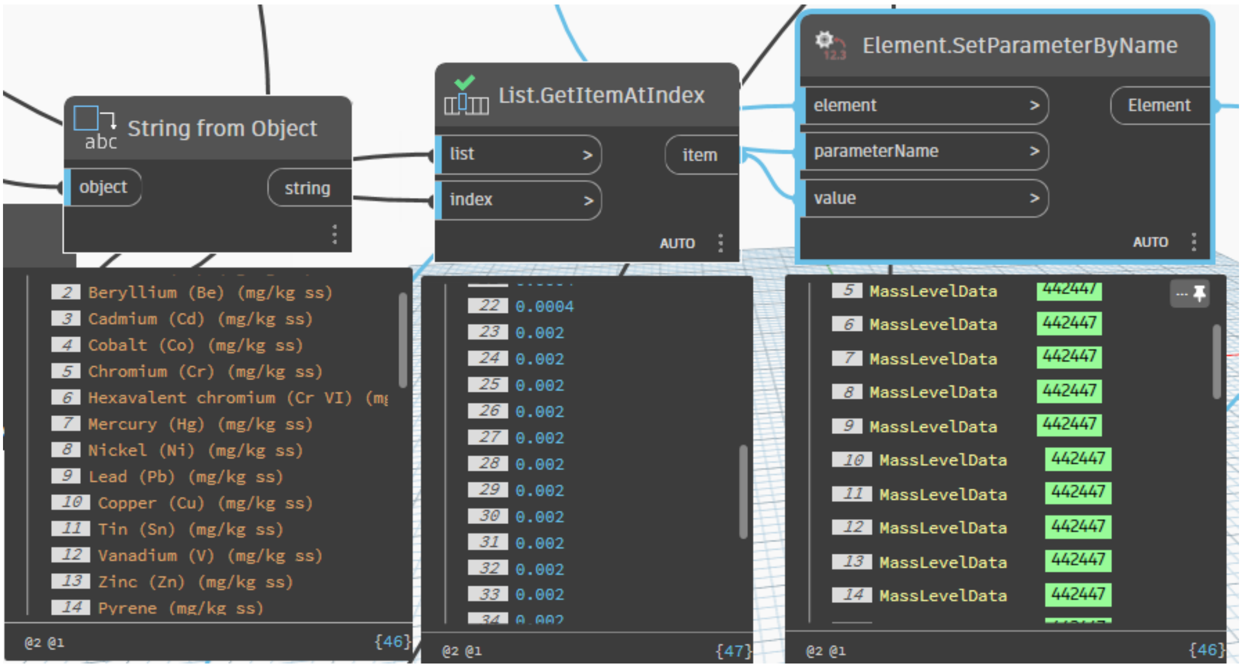


Figure 43. Setting parameter values for selected element.

7. For verification, "Paramter.ParamterByName" and "Paramter.Value" nodes used to check script worked correctly. These nodes retrieve all the shared parameters and their values that were set on an element.

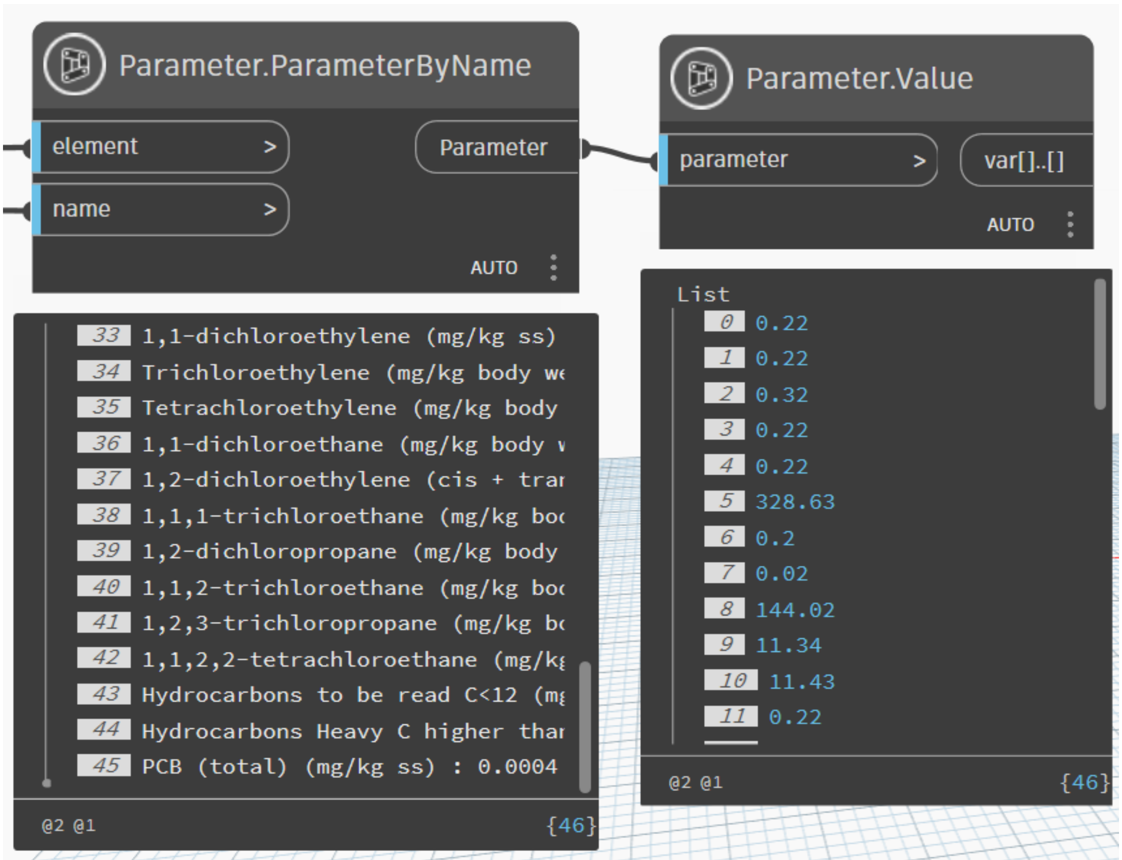
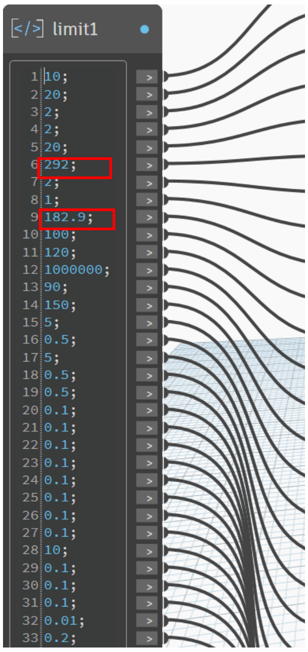


Figure 44. Retrieving elements shared parameters and their values for final verification.

As mentioned previously, contamination values should be checked to see if they're within the allowable limits set by the regulation. Therefore, an additional script created to make the model interactive, meaning the user could select a parameter name and model will color based on the value; if it's below the limit, element will change to green, if it's above the limit, element's color will change to red and finally if there are no values reported, the element's color will change to blue. For this script, "Data-Shapes" package used. "Data-shapes" itself used another package called "Dynamo Iron Python" package, "Data-shapes" uses this package to create UI nodes (like MultipleInputForm++) behind the scenes for creating Windows forms, managing inputs and handling logic.

Figure 45 shows the limitation introduced by the regulation. However, based on the particular geological characteristic and minerology of piedmont region; There high values of "chrome" and "Nickel" present in the location. Therefore, another set of limits introduced for these two heavy metals.



Parametro	D.Lgs. 152/06 Allegato 5, Parte IV, Tabella 1 e s.m.i. Colonna A	Valori di Fondo Naturale, DD n. 161 del 17/07/2020
Umidità totale (%)		
Scheletro (g/kg)		
Umidità residua a 105°C (g/kg)		
COMPOSTI ORIGANICI		
Antimonio (Sb) (mg/kg s.s.)	10	
Arsenico (As) (mg/kg s.s.)	20	
Berillio (Be) (mg/kg s.s.)	2	
Cadmio (Cd) (mg/kg s.s.)	2	
Cobalto (Co) (mg/kg s.s.)	20	
Cromo (Cr) (mg/kg s.s.)	150	292
Cromo esavalente (Cr VI) (mg/kg s.s.)	2	
Mercurio (Hg) (mg/kg s.s.)	1	
Nichel (Ni) (mg/kg s.s.)	120	182.9
Piombo (Pb) (mg/kg s.s.)	100	
Rame (Cu) (mg/kg s.s.)	120	
Stagno (Sn) (mg/kg s.s.)	-	
Vanadio (V) (mg/kg s.s.)	90	
Zinco (Zn) (mg/kg s.s.)	150	
IDROCARBURI POLICICLICI AROMATICI		
Pirene (mg/kg s.s.)	5	
Benzo(a)antracene (mg/kg s.s.)	0.5	

a) b)

Figure 45. a) contamination limit in dynamo b) limits set by regulation. Chrome and Nickel with second limit values

The "MultipleInputForm++" node is a custom Dynamo node, part of the Data-Shapes package, designed to create interactive user interfaces within Dynamo workflows. It enables users to build pop-up forms with multiple types of inputs, including text fields, dropdown menus, sliders, checkboxes, and more. This makes it possible to introduce a level of interactivity and user control that goes beyond standard Dynamo nodes, especially when workflows require human input or decision-making at runtime.

In this study, "MultipleInputForm++" was used to improve flexibility and usability of the Dynamo script by allowing user input before data processing began. A custom window form was configured to appear each time the Dynamo graph was executed. This form included a slider populated with the available Excel index (representing parameter names). The user could then choose the appropriate index that stored the specific data they wanted to assign as a parameter in Revit.

This approach made the Dynamo script adaptable to different datasets and user needs, reducing the need for constant manual changes. The script dynamically adjusts based on user selection in the form. This significantly enhanced the interoperability and repeatability of the workflow.

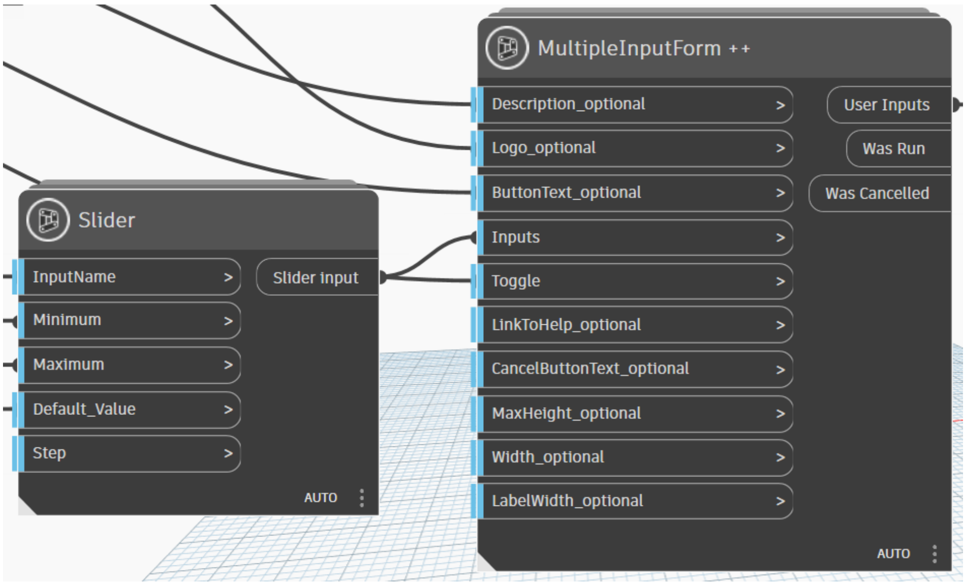


Figure 46. “MultipleInputForm++” node used to create a window form.

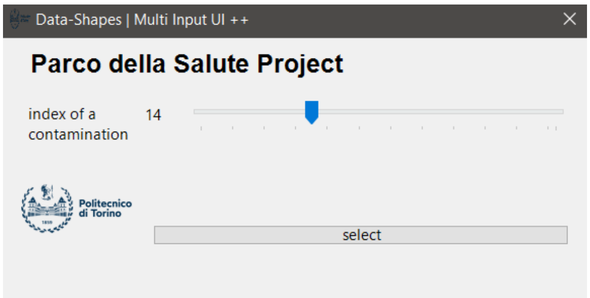


Figure 47. Window form created which receive the index of a contamination from the user

Some conditional statements were created to check and compare the selected parameter values with limit values. As shown in Figure 48 based on the result of the statement set of elements which satisfied the condition would be filtered and would be fed to next node shown in Figure 49.

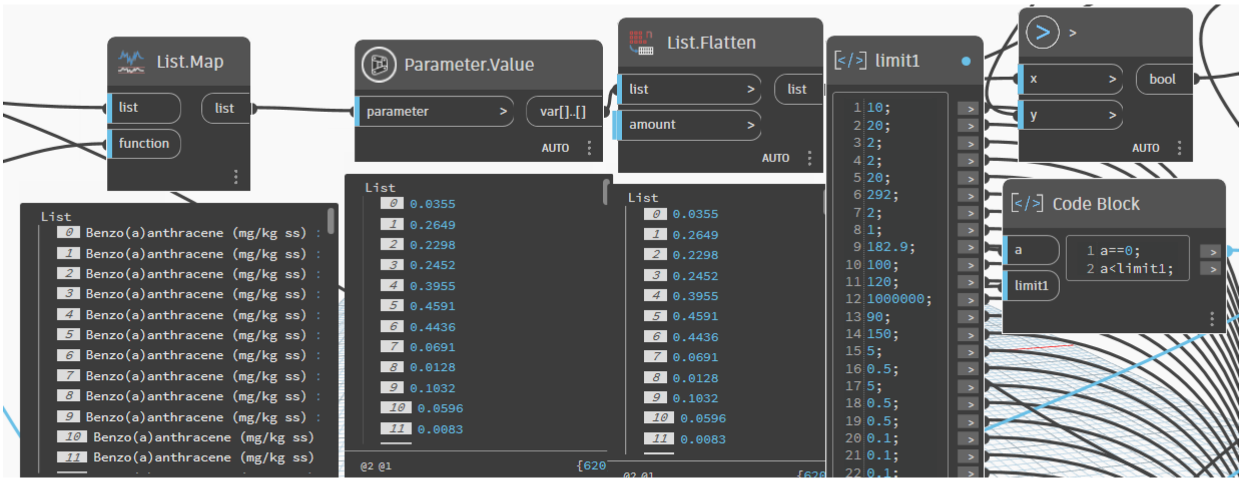


Figure 48. Checking the parameter values with limit values

“Element.OverrideColorInView” node used to change the color of the element if the conditions were satisfied.

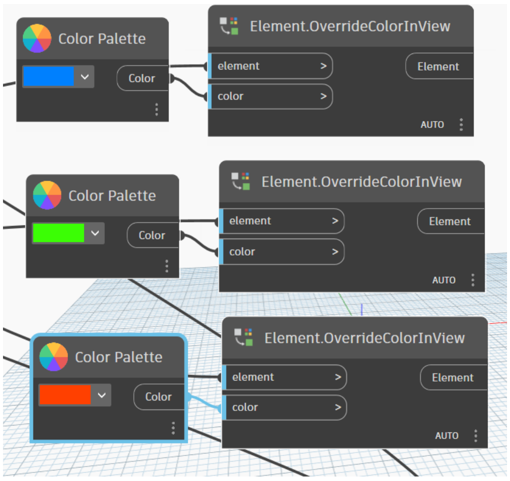
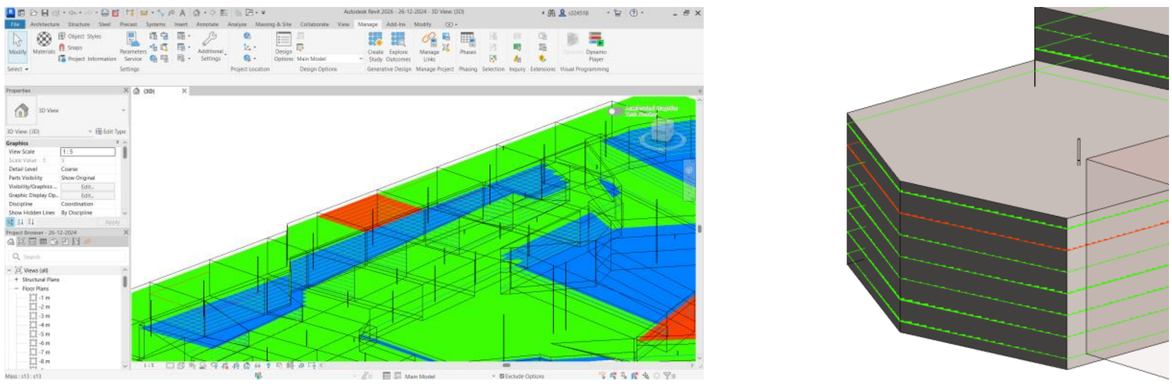


Figure 49. “Element.OverrideColorInView” would change the color of the filtered elements

The result of contamination modeling presented in chapter 5.



a) b)

Figure 50. a) colored modeled based on the selected element b) mass floors highlighted inside the cells representing soil layer

4.6 Summary and discussion

This chapter demonstrated the successful use of Revit and Dynamo for automating the modeling of geotechnical and pollution data for Parco della Salute project. The developed workflow enabled the creation of an interactive, GeoBIM model, setting a foundation for future expansion and integration with other systems or platforms.

The automated BIM modeling approach which employed in the study, shown outstanding capacities:

A. Dozens of boreholes and soil layers were generated in minutes. (Time saving and Automation)

B. Accuracy and reduced the risk of manual input errors by using structured data directly.

C. Ability to update the model by simply editing the Excel file and re-running the script. (Automation)

Despite its benefits, the workflow had some technical constraints:

A. Revit does not natively support terrain or irregular subsurface shapes; layers were modeled using idealized geometries created either by dynamo script or mass modeling.

B. Pollution data visualization was limited to one pollutant per layer due to color assignment constraints.

Several challenges were encountered during data integration and modeling:

- The time gap between the two pollution test campaigns (2004 and 2023) required careful interpretation to avoid misrepresentation and hours of manual work to merge the data from both campaigns.
- Revit's geometric modeling tools are primarily designed for buildings, making the representation of non-uniform geological features less intuitive without Dynamo scripting.

The aim of contaminant model was not to accurately represent the soil layer, but rather to create a repository for environmental data which acts as heat map, to show the stakeholders where a specific contamination surpasses the limit threshold. Although, other studies carried on to combine both soil layer and contamination data in a single map. However due to the complexity of the subsurface condition these studies were not successful yet. In another frame of study, author will continue this work to find a solution to combine 2 GeoBIM model, to create a model with high level of geometry and high level of information.

chapter 5 Analysis and Results

5.1 Introduction

In this chapter result of 3D GeoBIM subsurface and contamination modeling of Parco della Salute project were presented. Soil stratigraphy visualized and contaminated and problematic zones were identified. The findings are discussed in terms of visual interpretation and potential use.

5.2 Visualization of Soil Layers

The workflow introduced in Section 4.5.1 resulted in a 3D model that combines subsurface soil layers, represented as surface meshes, with borehole locations, represented by points. These elements were generated through a Dynamo script and later visualized both in Dynamo's preview environment and in Autodesk Revit. Figure 51 and Figure 52 illustrate the generated soil layers within Dynamo and Revit respectively, showing the consistency between the conceptual model and its integration into a BIM platform.

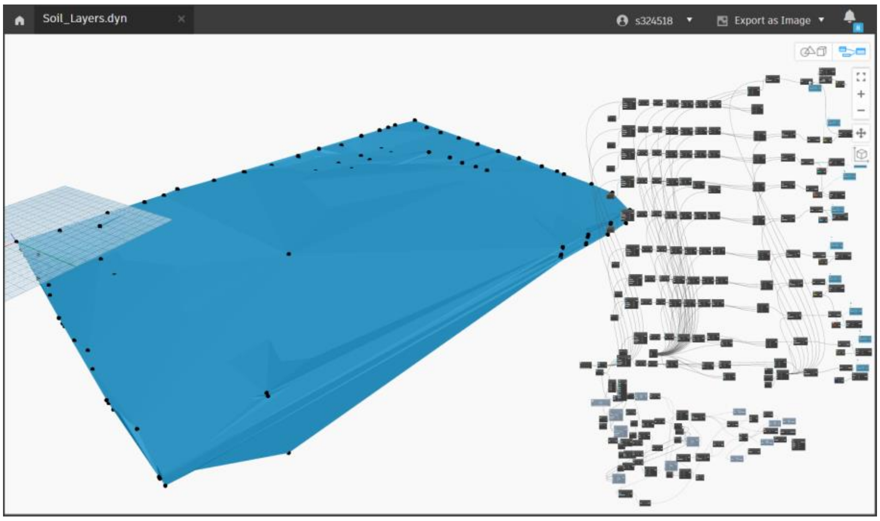


Figure 51. Created layers in dynamo

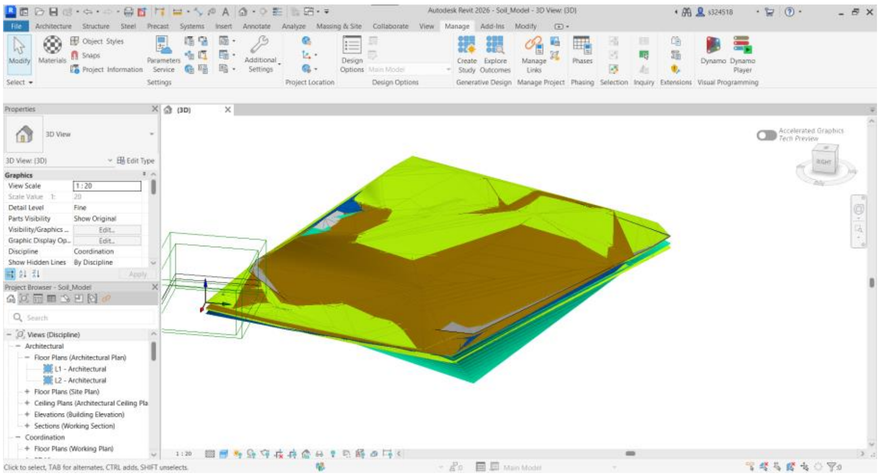


Figure 52. Created soil layers in Revit environment

Each soil layer was constructed from a set of “irregularly spaced points” representing the depth and location of stratigraphy changes across boreholes. These points were connected using TIN (Triangulated Irregular Network) surface modeling, which generates non-overlapping triangular meshes to interpolate the surface between data points. Figure 53 provides an example of these TIN surface meshes. This method is suitable for modeling irregular terrain or underground features where evenly spaced data is not available, as is often the case with geotechnical borehole data.

One of the significant challenges encountered during this phase was ensuring non-overlapping and logically ordered 3D points, especially given that the data was not co-planar and involved hundreds of nodes in some layers. Incorrect ordering could result in distorted or invalid surfaces. To address this, an AI-based sorting algorithm was implemented. This algorithm reorganized the point list in Excel to form a closed loop of vertices, minimizing overlaps and preserving the spatial relationships needed for accurate mesh generation.

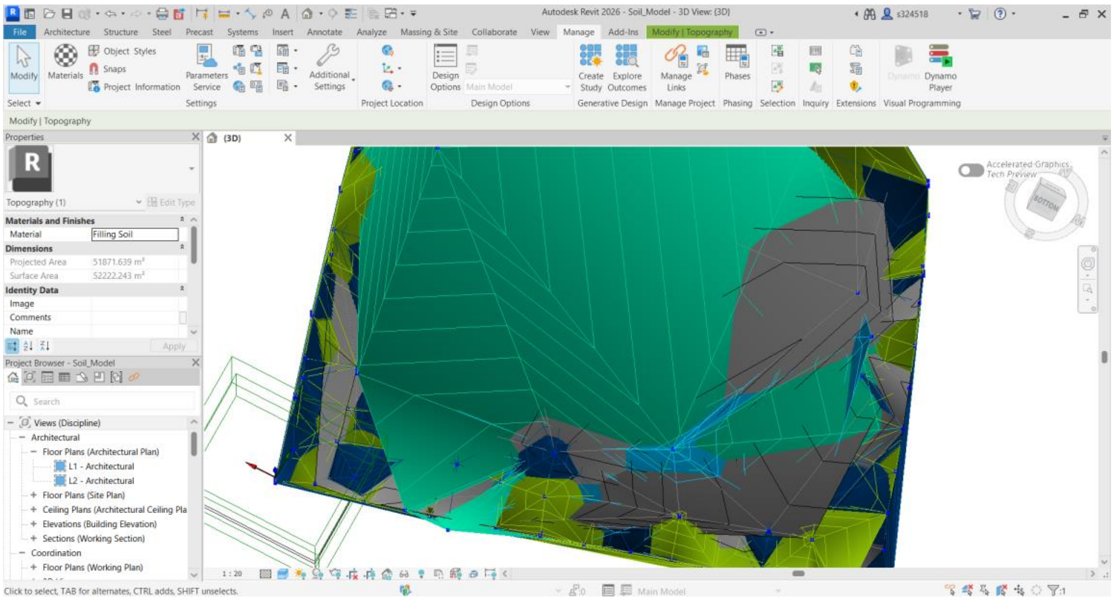


Figure 53. TIN (triangular irregular network) surface meshes

After the successful creation of these surface meshes, materials were assigned to each soil layer within Revit to enhance visual interpretation. Initially, a generic material, such as Autodesk Revit’s built-in "Sand", was used as a template. This material was duplicated and renamed according to the laboratory reports associated with each layer, such as "Gravelly Sand", "Silty Clay", or "Sandy Silt". These customized materials were then visually differentiated through changes in color and texture to match the geological descriptions and facilitate clear layer distinction in the model. Figure 54 and Figure 55 show the assigned materials and their saved metadata, such as "Material Class" and "Geological Description", embedded directly within the model properties.

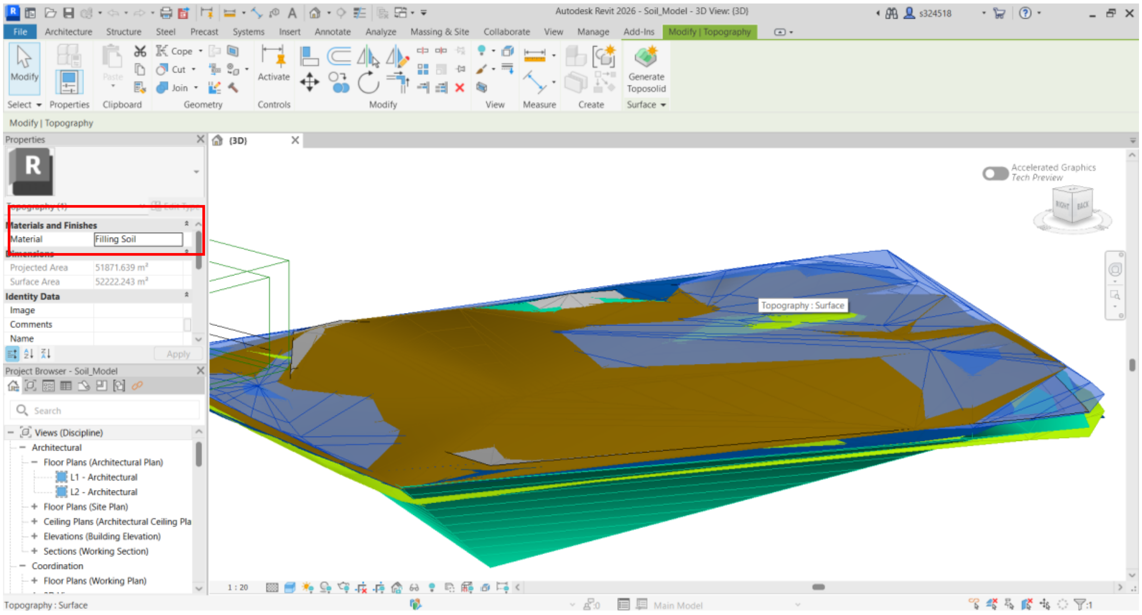


Figure 54. Assigned material to each layer based on the laboratory description

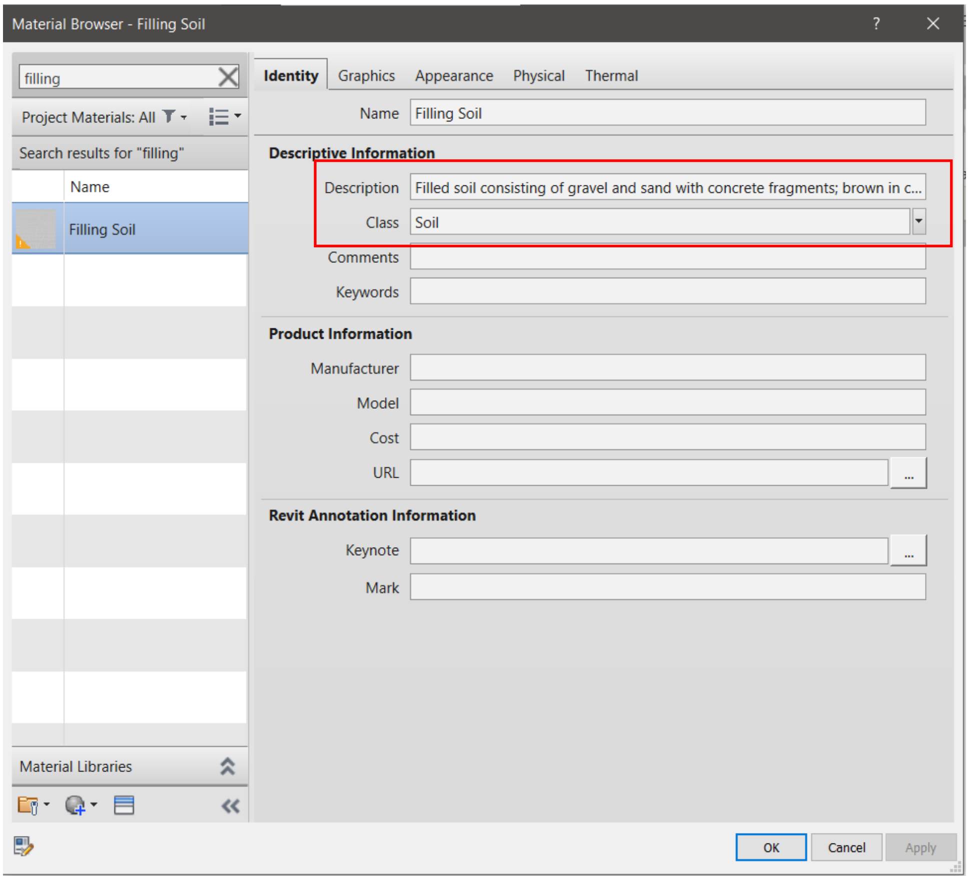


Figure 55. “Material class” and “Geological description” saved in each material

The final GeoBIM model thus comprised a set of color-coded, layered subsurface meshes and corresponding borehole references. Although the model was not intended for direct geotechnical design (as it lacks key engineering parameters like friction angle, cohesion, or permeability), it provided a strong visual and informational repository. This model aids in identifying weak zones, transition layers, or stratigraphic anomalies, offering valuable insight during the early planning and risk assessment stages.

Moreover, the digital nature of the model ensures that it can be expanded or queried by other stakeholders such as architects, urban planners, and environmental engineers. As such, it lays the groundwork for an interoperable, multidisciplinary data environment in line with GeoBIM best practices.

5.3 Representation of Pollution Zones

Result of workflow introduced in section 4.5.2 shown in Figure 56 As seen from the figure mass floors colored based on the value of a given contamination. If the values were within the limit, the mass floor highlighted in green, if they are above the limit, they turn red and if there are no values reported about the contamination, they turn blue.

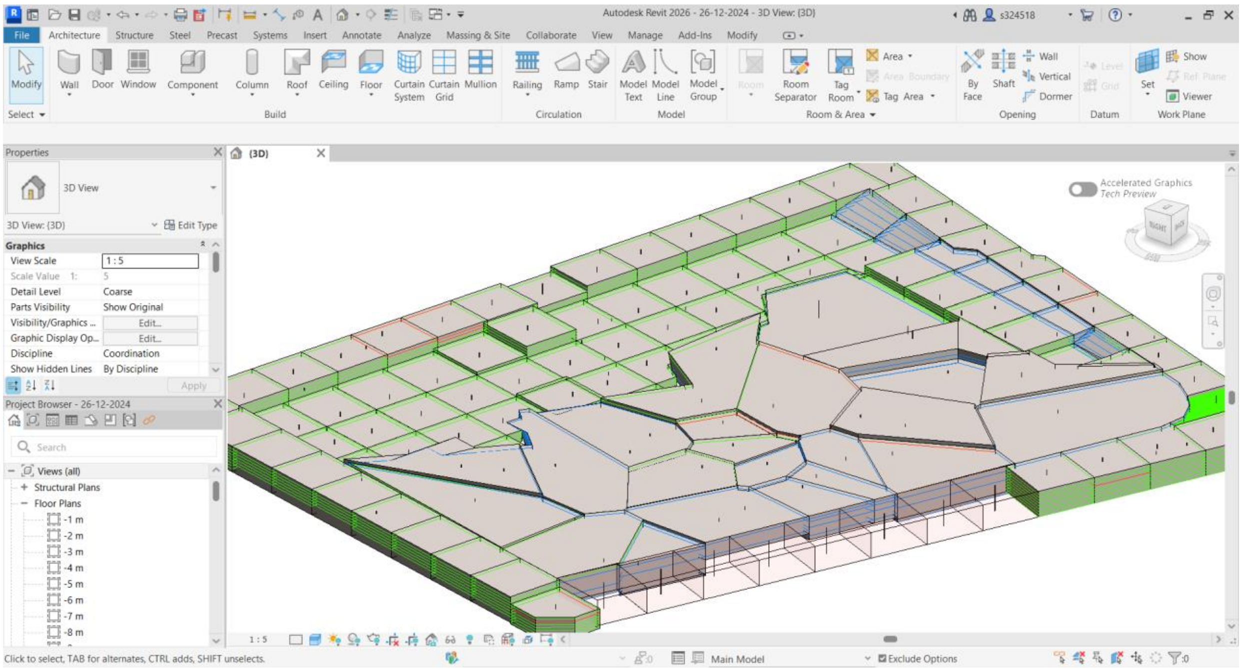


Figure 56. Contamination model created following workflow 4.5.2

Subsurface of Lot 1 was analyzed individually for each identified pollutant. Contaminated zones, based on threshold exceedance, were reported in Table 5. This table was generated by modifying the original Dynamo script with a custom subroutine that identifies and extracts the IDs of elements where pollutant concentrations exceed regulatory safety limits. Once the script is executed, it scans through all modeled elements, checks for dangerous contamination levels, and automatically saves the results in a structured .txt file. This functionality ensures traceability of the affected zones and facilitates communication with stakeholders or integration into risk management systems.

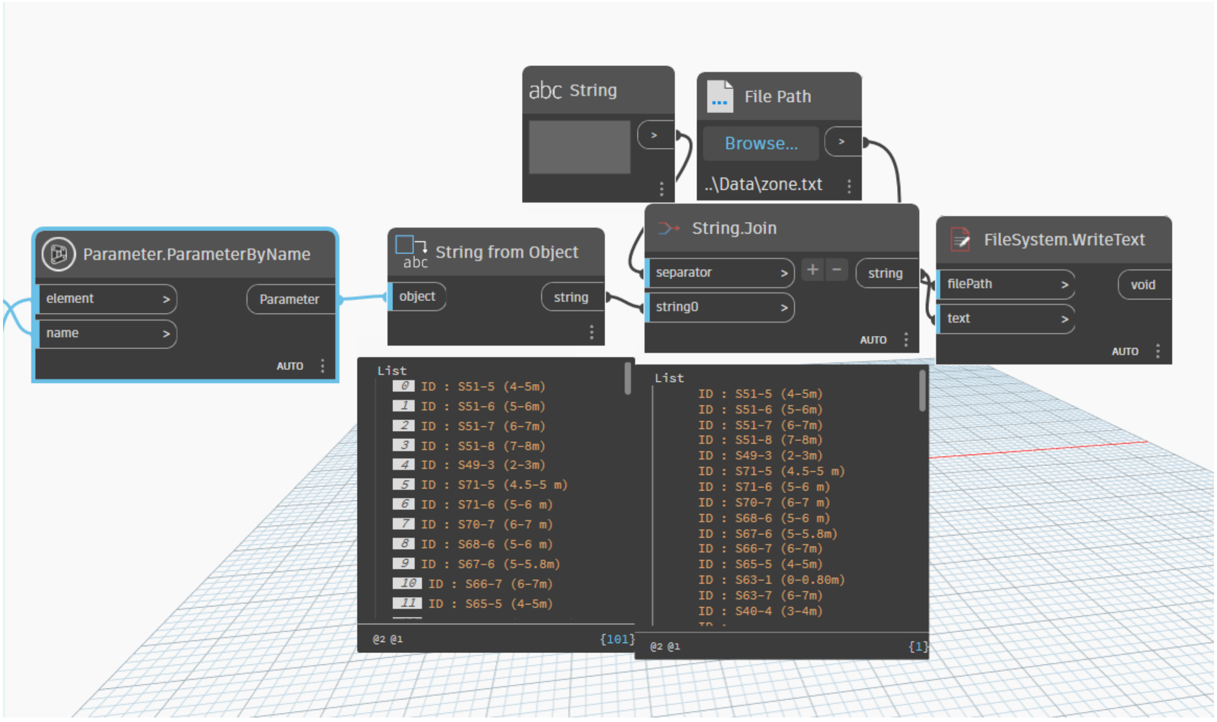
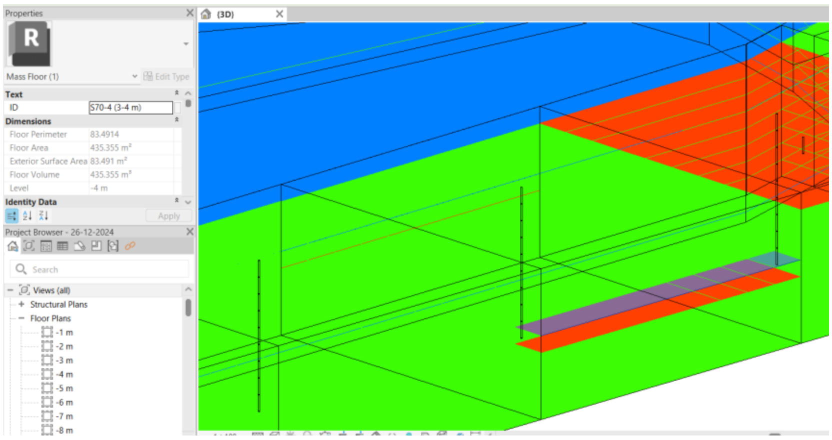
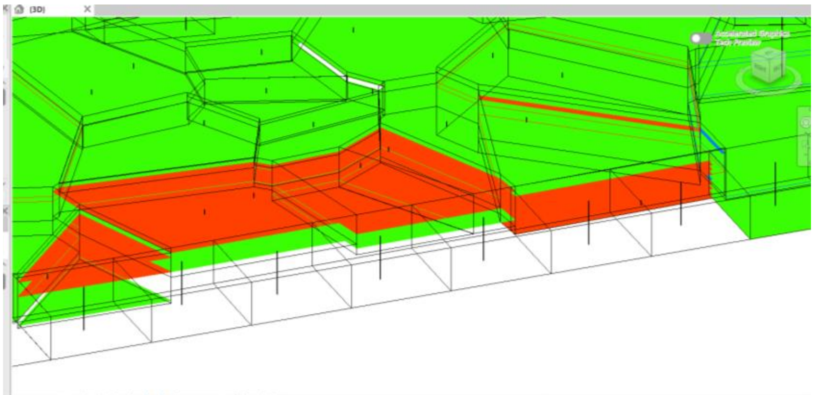


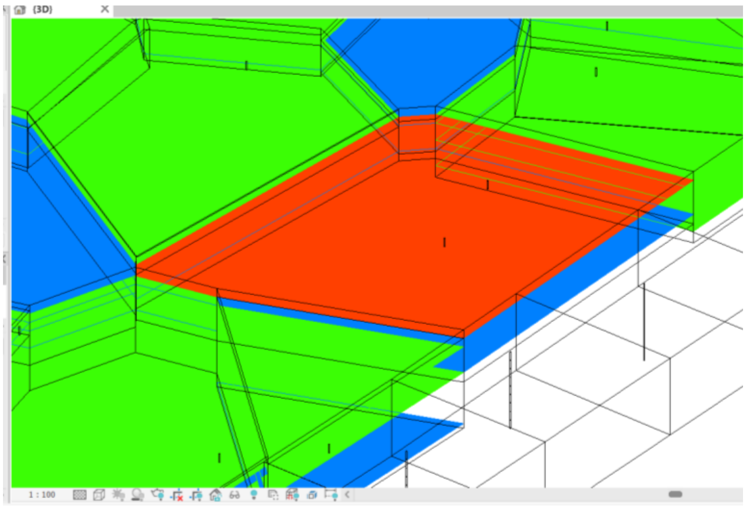
Figure 57. Script which saves the ID of the elements with dangerous concentration of pollutant.

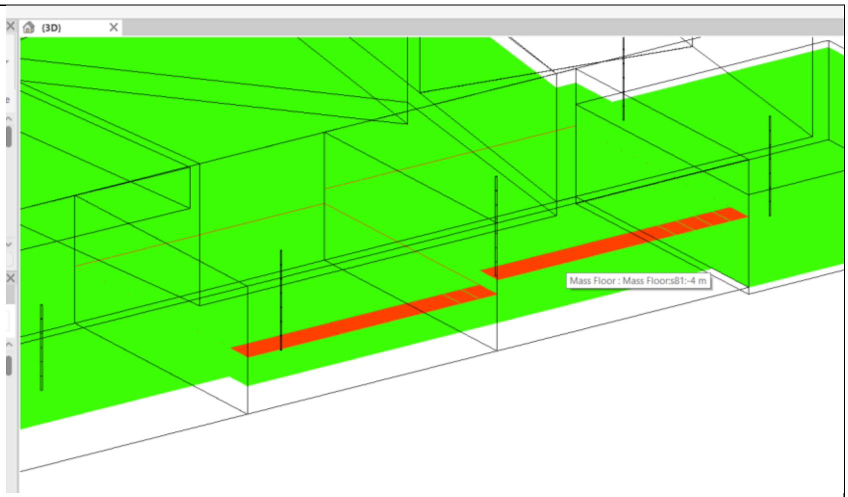
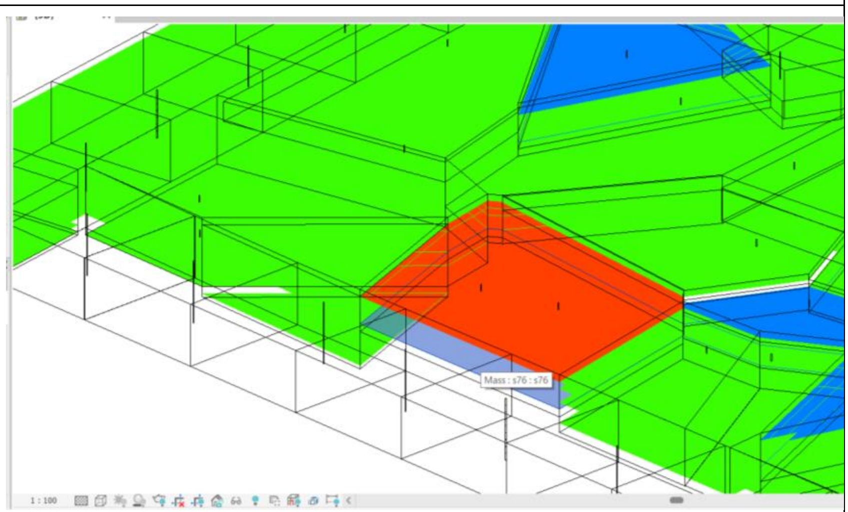
Table 5. Contaminant zones in Lot 1

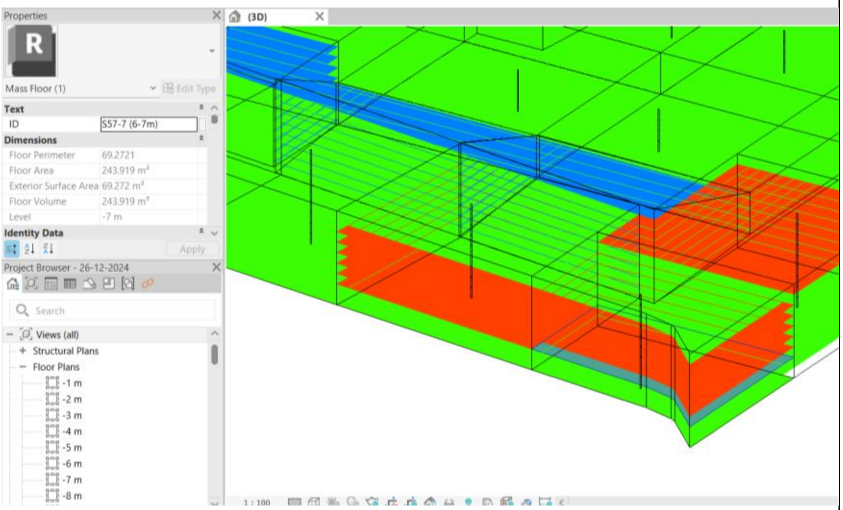
Pollutant	Depth and borehole ID in which contaminant with dangerous concentration was found	Example from the model
Antimony (Sb) (mg/kg ss)	ID: S88-5 (4-5m) ID: S70-4 (3-4 m) ID: S70-5 (4-5 m) ID: S69-1 (0.6-1 m) ID: 2 (1.75-2.25m) ID: 2 (5-5.5m) ID: 27 (1-1.5m) ID: 27 (3.9-4.4m) ID: 27 (10-10.5m) ID: 26 (1-1.5m) ID: 26 (2.1-2.5m) ID: 46 (5-6m)	 Borehole #S70 At depth of 3-4 m

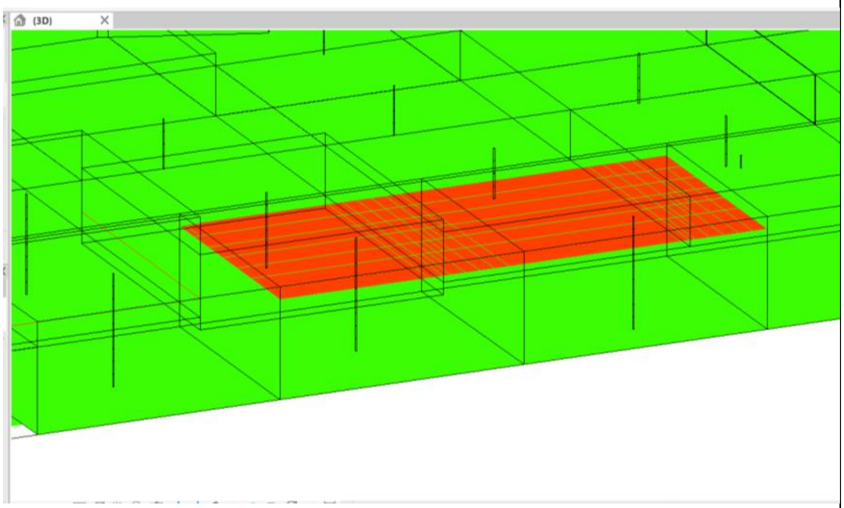
	ID: 46 (10-10.5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 3 (7-7.5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 3 (7-7.5m) ID: 11 (0.5-1m) ID: 11 (1.5-2m) ID: 11 (2-2.5m) ID: 13 (2-2.5m) ID: 13 (10-10.5m) ID: PM3 (1.8-2.3m) ID: PM3 (5-5.5m) ID: 61 (0.5-1.5m) ID: 2 (10-10.5m) ID: 41 (10-10.5m) ID: 1 (0.5-0.7m) ID: 1 (0.9-1.1m) ID: 1 (1.6-2.1m) ID: 1 (4.5-5m) ID: 1 (6.2-6.5m) ID: 62 (1-2m)	

Arsenic (As) (mg/kg ss)	ID: 2 (5-5.5m) ID: 27 (3.9-4.4m) ID: 27 (10-10.5m) ID: 26 (2.1-2.5m) ID: 46 (10-10.5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 11 (1.5-2m) ID: 11 (2-2.5m) ID: PM3 (1.8-2.3m) ID: PM3 (5-5.5m) ID: 61 (0.5-1.5m) ID: 2 (10-10.5m) ID: 1 (0.9-1.1m) ID: 1 (1.6-2.1m)	 Borehole #2 At depth of 5-5.5

Beryllium (Be) (mg/kg ss)	ID: S49-7 (6-7m) ID: 65 (5-5.5m) ID: 27 (1-1.5m) ID: 27 (3.9-4.4m) ID: 26 (1-1.5m) ID: 26 (2.1-2.5m) ID: 26 (5-5.5m) ID: 46 (1.3-1.5m) ID: 46 (5-6m) ID: 46 (10-10.5m) ID: 64 (5-5m) ID: 11 (0.5-1m) ID: 11 (1.5-2m) ID: 11 (2-2.5m) ID: 11 (5-5.5m) ID: 60 (0.8-1.5m) ID: 60 (5-5.5m) ID: 13 (2-2.5m) ID: PM3 (10.2-10.7) ID: 61 (0.5-1.5m) ID: 61 (5-5.5m) ID: 41 (1.7-2.2m) ID: 41 (5-5.5m) ID: 41 (10-10.5m) ID: 62 (1-2m) ID: 62 (5-5.5m) ID: 62 (5-5.5m)	 Borehole #61 At depth of 0.5-1.5 m

Chromium (Cr) (mg/kg ss)	ID: S82-5 (4-5m) ID: S81-4 (3-4m) ID: 46 (10-10.5m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 3 (4.5-5m) ID: 11 (5-5.5m) ID: PM3 (1.8-2.3m) ID: 1 (1.6-2.1m)	 Borehole #81 At depth of 3-4 m * Due to the specific geological characteristics of the Piedmont region, a secondary threshold limit of 292 mg/kg dry substance was introduced for Chromium.
Hexavalent chromium (Cr VI) (mg/kg ss)	ID: 65 (5-5.5m) ID: 46 (2.5-3m) ID: 46 (5-6m) ID: 46 (10-10.5m) ID: 64 (5-5m) ID: 60 (0.8-1.5m) ID: 60 (5-5.5m) ID: 61 (0.5-1.5m) ID: 61 (5-5.5m) ID: 62 (1-2m) ID: 62 (5-5.5m)	 Borehole #61 At depth of 5-5.5 m

Nickel (Ni) (mg/kg ss)	ID: S57-2 (1-2m) ID: S57-3 (2-3m) ID: S57-4 (3-4m) ID: S57-5 (4-5m) ID: S57-6 (5-6m) ID: S57-7 (6-7m) ID: S56-1 (0-1m) ID: S54-2 (1-2m) ID: S52-6 (5-6m) ID: S49-7 (6-7m) ID: S48-7 (6-7m) ID: S48-8 (7-8m) ID: S47-1 (0-1m) ID: S82-6 (5-6m) ID: S81-4 (3-4m) ID: S81-7 (6-7m) ID: S69-2 (1-2 m) ID: S68-3 (2-3 m) ID: S67-1 (0-1m) ID: S63-2 (1-2m) ID: S57-2 (1-2m) ID: S57-3 (2-3m) ID: S57-4 (3-4m) ID: S57-5 (4-5m) ID: S57-6 (5-6m) ID: S57-7 (6-7m) ID: 2 (1.75-2.25m) ID: 2 (5-5.5m) ID: 27 (3.9-4.4m) ID: 26 (2.1-2.5m)	 Borehole #S57 At depth of 6-7 m * Due to particular geological characteristic of piedmont region; a secondary threshold limit of 292 mg/kg dry substance was introduced for Nickel.

	ID: 26 (5-5.5m) ID: 46 (10-10.5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 52 (2-2.5m) ID: 11 (1.5-2m) ID: 11 (2-2.5m) ID: PM3 (1.8-2.3m) ID: 61 (0.5-1.5m) ID: 2 (10-10.5m) ID: 1 (0.5-0.7m) ID: 1 (0.9-1.1m) ID: 1 (1.6-2.1m) ID: 52 (2-2.5m)	
Copper (Cu) (mg/kg ss)	ID: S48-1 (0.4-1m) ID: S47-1 (0-1m) ID: S70-4 (3-4 m) ID: S70-5 (4-5 m) ID: S69-1 (0.6-1 m) ID: S69-2 (1-2 m) ID: S69-3 (2-3 m) ID: S69-4 (3-4 m) ID: S69-5 (4-4.8 m) ID: S68-5 (4-5 m) ID: S67-1 (0-1m) ID: S62-1 (0-0.5m) ID: S15-3 (2-3m) ID: S27-7 (6-7m) ID: 2 (5-5.5m)	 Borehole #S48 At depth of 0.4-1 m

	ID: 27 (3.9-4.4m) ID: 26 (2.1-2.5m) ID: 46 (10-10.5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 3 (0.5-1m) ID: 3 (1.3-1.6m) ID: 3 (4.5-5m) ID: 11 (1.5-2m) ID: 11 (2-2.5m) ID: 13 (0.9-1.3m) ID: 61 (0.5-1.5m) ID: 2 (10-10.5m) ID: 1 (0.5-0.7m) ID: 1 (0.9-1.1m) ID: 1 (1.6-2.1m) ID: 62 (1-2m)	

GeoBIM model was successfully able to identify the zones with high concentration of pollutant, which aids in future planning and targeted remediation and managing the contamination.

One of the most significant advantages of the GeoBIM model was its interactivity. Users could click on any soil layer or borehole to access embedded data. Moreover, they could change the visual representation of the model based on the pollutant and its concentration.

5.4 Summary and discussion

The results of the Revit Dynamo model showed that GeoBIM offers a powerful way to represent and analyze geotechnical and environmental data. The model improved clarity, supported planning decisions, and opened pathways for future integrations with infrastructure workflows. However, being an innovative method, the work was not without challenges; lack of continues data for pollutants meant all data were presented in flat mass floor rather than in gradient, compatible to soil layer itself. Moreover, the visualization of multi data model still a challenge. In this work, to visual model based on contaminant it meant that the user has to run window form each time, which was time consuming task. It shows the necessity for having a dashboard interface which allows the user to select and any parameter seamlessly. The latter will be pursued in the future work with the aim of developing a “Revit API” program capable of doing so.

chapter 6 Comparison

6.1 Introduction

In this chapter, the results of the modeling were compared with models created using other software in precision and accuracy, automation of workflow, modeling time and then software itself were compared in interoperability and data loss to see the capability of the model for future use in other disciplines.

Finally, two methods were introduced to develop a GeoBIM repository, integrating subsurface model and Building models for facility management and decision-making purposes.

6.2 Model Comparison

6.2.1 Soil Model

Prior to this work, Autodesk Civil 3D and Bentley Leap frog Geo were used to create subsurface soil models.

In the study of Guzman, Civil 3D with “Geotechnical Module Extension” utilized to insert borehole location and create TIN layer of the soils. Figure 58 the surface layers created in Civil 3D. Similar workflow was established to create the model. The work started by reading excel data (borehole number and location, type of soil at each depth), afterwards the module created cylindrical columns that represent the boreholes. Finally similar soil types were connected together to create a triangular irregular network. For this, at least 3 points should be identified in order to develop a surface. (Giuseppe Luigi Ratti Guzmán, 2022)

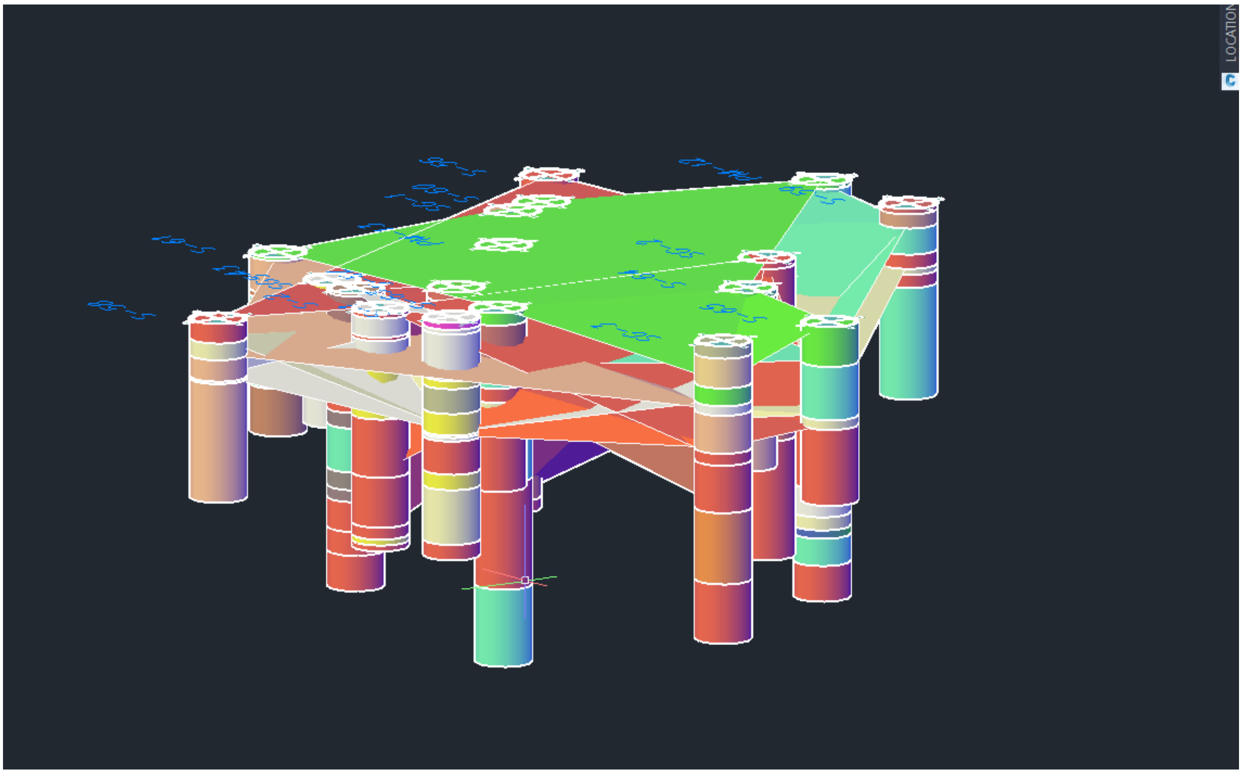


Figure 58. Boreholes and Surfaces created in Civil 3D using geotechnical module extension(Giuseppe Luigi Ratti Guzmán, 2022)

Although, the modeling time were moderately fast, and with the aid of the extension the procedure was automatized, however in this work, some clashes were reported in the intermediate levels and it was solved by simplifying the layers.

In second work, Bentley Leap Frog software were used. Leap frog is a powerful software for geological studies and representing sublayer conditions of earth. The workflow in this software involves introducing the type of layers and sorting them based on the age of sediments from old to new layer by importing the excel data. Figure 59. Soil layer created in Leapfrogshows the model created in Leapfrog software.

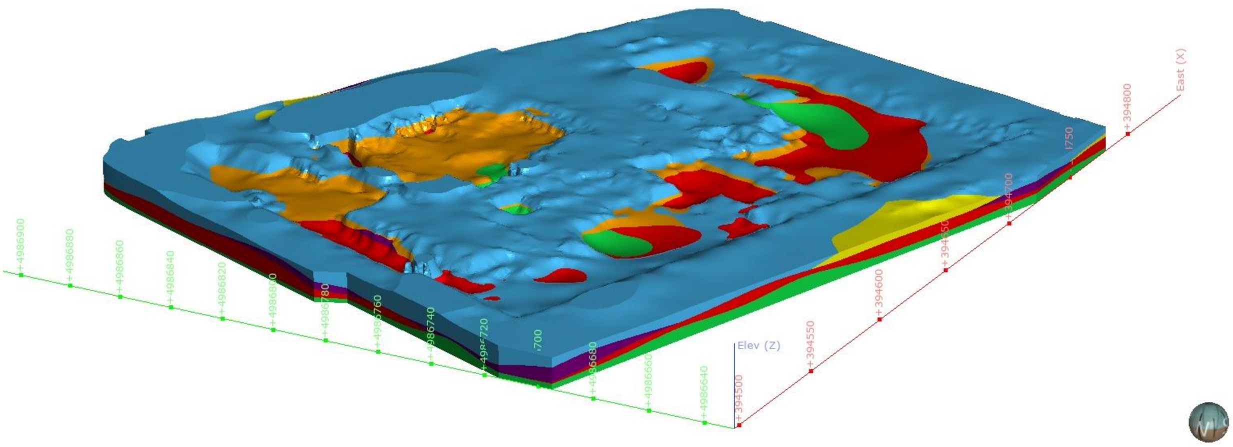


Figure 59. Soil layer created in Leapfrog

Model created in Leapfrog showed, high level of accuracy. The software enables filtering and slicing through the model to view intermediate layers. Moreover, it is possible to export the 3D, georeferenced layer (single layer or the entire model) in FBX format. However, the attribute data saved inside each layer were lost during data exchange.

6.2.2 Contamination Model

Alternative to Revit and Dynamo, Esri ArcGIS pro were used to represent the contamination model. Each contaminant was introduced into ArcGIS environment by reading the excel data and in result, 3D voxel-based model was created for each contaminant using Kriging method. It is possible to slice the model and filter, based on each contaminant. Final result is a 3D-colored map, showing the distribution and concentration of pollutant which represented in Figure 60.

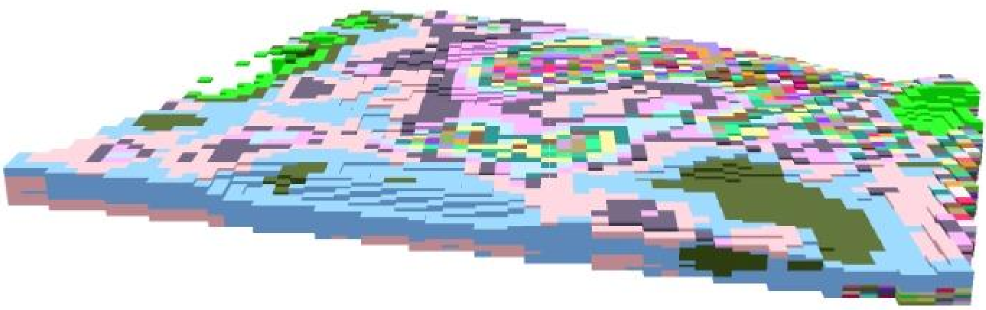


Figure 60. Voxel-based 3D contamination model in ArcGIS pro.

Despite the Accuracy of the model, the model is saved in NetCDF format which makes it difficult to share and exchange the data with BIM software and it only possible to upload the model inside ESRI repository for online viewing.

6.2.3 Key performance Indicator

Key Performance Indicators (KPIs) are measurable values which are used to evaluate how effective a tool or method is performing to obtain specific objectives. In this study, KPIs serve to compare different methodologies based on their performance in essential areas related to interoperability and modeling. The following indicators were contemplated: model reliability, user friendliness, automation, information content share, data exchange, modelling time and cost. Each indicator was then broken down into different factors which help better evaluate each methodology, as seen in *Table 6*.

Table 6. KPIs breakdown structure

Criteria	**Factors considered**	
Model Reliability (%)	Location Accuracy	
	Reality Representation	
	Data Accuracy	point accuracy
		spatial continuity
User Friendliness (%)	Ease of navigation	
	Learning curve	
	Graphical User Interface	
	Templates	
	Version sensitiveness	
	Automatic Backup	
Automation (%)	Automated Process from Data to 3D Model	geometry
		shared parameters
	Parallel Modeling	
	Scripting Environment	
	Customizable Annotation and Detailing	
	Templates	
	Plugins and Extensions	
Information content share (%) (Reciprocal to Data loss)	Metadata (Shared parameters, attributes…)	
	Geometry/location	
	Coordination	
	Annotation	
	Unit	
Data Exchange (%)	Raster Data	
	Vector Data	
	Conversion when exported to InfraWorks	
	IFC Export	
Modeling Time (h)	Total hours of time spent developing the model. with the exclusion of data pre-processing	
Cost (euro)	The yearly cost of commercial license	

Model reliability represents the degree to which a model consistently produces accurate and dependable results, reflecting its validity and robustness in representing real world systems (IEEE Standard Computer Dictionary). It is an important KPI because it considers the consistency and trustworthiness of the outputs generated in the methodologies. Some criteria were considered to measure reliability within the procedures.
For instance, location accuracy was the first criterion, which evaluates whether if software lets to work the model in the proper location and coordination system; geometry, that evaluates how well do the generated models respect reality (input data regarding log studies and surveys); data accuracy, which contemplates the point accuracy and the spatial continuity concerning the created model.

User friendliness of operating each methodology can be equated with usability, which refers to t*he extent to which a system, product or service can be used by specified users to achieve goals with effectiveness, efficiency and satisfaction in a specified context of use* (ISO 9241-11:2018).
For evaluating this indicator, some factors were considered, such as the ease of navigation across the whole employed platforms; the learning curve associated to each methodology; the graphic user interface; the fact whether if platforms allow ready-made templates; the version sensitiveness which assesses if older software version outputs can be used in newer versions; and the ability of software to make work automatic backups. These aspects were measured specially through satisfaction scores which at last provided an overall understanding of how user friendly each applied methodology is.

Automation is an important indicator when evaluating the modelling workflows as it reflects the degree to which a tool can perform tasks with minimal human intervention, improving efficiency and reducing manual errors(Parasuraman et al., 2000). Therefore, higher automation allows faster data processing, model updating, and integration across platforms. The factors that were contemplated to assess the methodologies consisted of: specially passing from data to 3D models parametric design automation, considering both geometry and shared parameters; possibility to perform several models parallelly; scripting environment present on the platform that allows to automate modelling processes; presence of customizable annotations, detailing and symbology; possibility of templates use when modelling; and if the platform enables the employment of plugins or extensions which facilitates the modelling.

IEEE standard computer dictionary defines interoperability as “the ability of two or more systems or elements to exchange information and to use the information that has been exchanged” (IEEE Standard Computer Dictionary)

According to Levine et al, Interoperability is:
“The ability of a collection of communicating entities to
1. Share specified information and
2. operate on that information according to a shared operational semantics
3. to achieve a specified purpose in each context.” (Levine et al., 2003)

Therefore, software interoperability could be broken down into two KPIs;
1. The ability to share specified information (Data exchange (%)).
2. Operates on shared information (Information content share (%)).

These KPIs described as follows:
Information content share, or inversely, data loss is a relevant indicator when evaluating interoperability among modelling tools. It indicates the percentage of relevant successfully transferring from one platform to another. On some occasions, even with standardized exchange formats such as IFC, partial data may occur. Therefore, this indicator is of great importance when integrating software from different domains, like GIS to BIM. The factors which were evaluated to define this indicator were the following ones: metadata, model geometry, reference systems coordination, and systems unit. InfraWorks was selected as benchmark to evaluate interoperability within all methodologies as well as data loss,

occurring when sharing models. It was chosen due to its user friendliness, capability of integration of BIM and GIS data, ability to read vast quantity of formats and ability to link data bases to model.

Data exchange measures how effectively data is transferred between systems. In the present research, the selected factors regarding this indicator were the export format: whether if it consists of vector or raster data; if the outcome format needs a transformation in order to be opened and viewed in InfraWorks and if the platform allows IFC file export.

The required modelling time represents a quantitative indicator that comprehends the effort to complete a model with given tools or platforms. Many factors influenced modeling time. It does not only highlight the technicalities of software, but the interface design and the user learning curve. In this study, the time was recorded from the initial input data set on each platform until the model conclusion. excluding the data pre-processing time, the procedure to create the model effected by; the authors proficiency on the software, hardware and operating system in which the software was installed on and help of scripting (even though creating the code itself was a time-consuming task). The total time spent on modeling could be divided into; 1. Software setup (setting the coordinate system, unit...) 2. Drawing (time spent on pure drawing works, i.e.; creating adaptive points, boreholes, masses, mass floors….) 3. Scripting/ Attributes (creating the code for extracting excel data such as borehole coordination and contamination data) 4. Interpolation (creating TIN, kriging, multidimensional voxel layers….).
Overall, a shorter modelling time indicates higher productivity and, thus, a good indicator value.
Cost was considered as a KPI by the authors as it represents the total investment required to operate each software. This includes license fees, plugin purchases, etc. Cost sometimes can directly influence tools' adoption, especially in projects or studies with limited budgets or small teams. In the following study, the cost indicator was set as cost per year, as the licenses' prices are yearly renewable.
For the first 5 indicators previously described: model reliability, user friendliness, automation, data loss and data exchange, it was assigned to each factor a maximum score that contributes a total sum of 1 for each indicator. This ensures that all factors belonging to the same indicator are proportionally weighted. This normalization permits consistent aggregation and allows a logical comparison within all 4 studied methodologies. Nonetheless, regarding the purely quantitative indicators cost and modelling time, these do not contemplate factors within each indicator, but its real value instead. Then, combining the first group of qualitative indicators with these last two is valid inside AHP framework, so that after a proper normalization, all criteria can be compared and, thus, all methodologies can be evaluated and ranked.
Following table, summarized the result of the KPI comparison for four softwares including Revit as a tool for GeoBIM modeling.

Table 7. KPI comparison of modeling softwares as GeoBIM tool

Criteria	Methodology			
	Civil 3D	Leapfrog	ArcGIS pro	Revit + Dynamo
Model Reliability (%)	60	97	86	71
User Friendliness (%)	80	60	62	70
Automation (%)	58	51	100	83
Information content share (%)	60	60	40	61
Data Exchange (%)	70	50	50	75
Modeling Time (h)	10	16	24	8
Yearly Cost (euro)	3,267	1,000	100	3,425

As evident from the table, ArcGIS, showed high potential in modeling automation, however in other aspects showed mediocre functionality, same results were observed for leapfrog in model reliability however the results were low for other criterions. Figure 61. shows the result of this comparison in a multi criterion graph. Autodesk Revit, showed moderately high capabilities in regards to KPI factors.

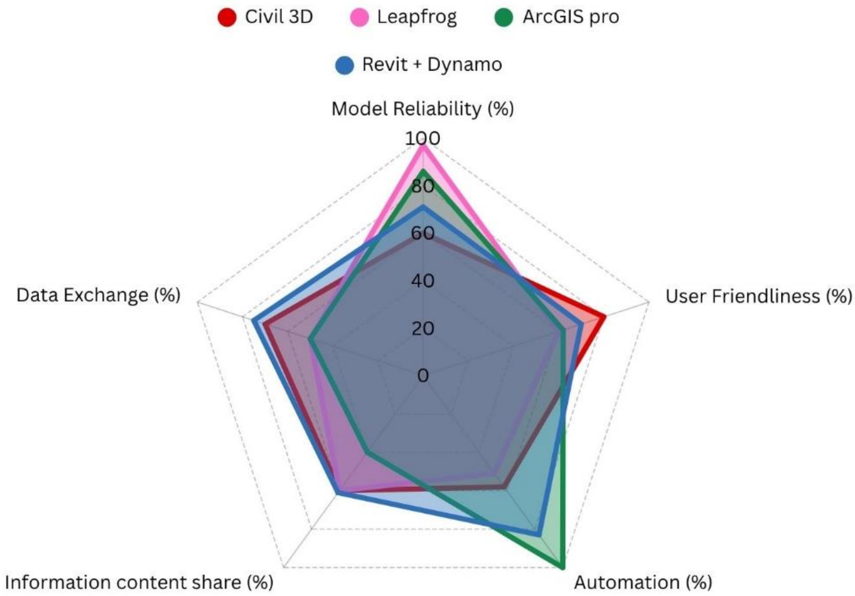


Figure 61. Result of KPI comparison

6.3 GeoBIM Repository for Facility Management

To integrate GeoBIM data and building model and also a data base for facility management use, it was decided to develop a repository for subsurface models. Two approaches were followed; one to develop an online data base for GeoBIM contamination model and the second to develop an integrated and aggregated model within the BIM environment. These approaches were introduced in the following sections.

6.3.1 Fusion Autodesk Manager

Upon developing a BIM model, it should be anticipated that model will be used by stakeholders from multiple disciplines. Some of these stakeholders may not familiar with using BIM software tools. therefore, it was necessary to have an online model independent of any software and accessible through a public URL. For this reason, "Fusion Autodesk Manager" was used. Fusion[1] is a power database which can acts both as database for centralized BIM model so all stakeholder could access and modify as they seem fit and also as viewing tool for all Autodesk BIM based models.

GeoBIM model was uploaded inside this online database. Then a QRcode was created for ease of access through stakeholders use. Figure 62. Online based contamination model. shows the contamination model inside this environment.

[1] There is a software called "Autodesk Fusion" available in Autodesk software house, which it should not be confused with the Autodesk manager tool called Fusion. The latter was used in this study.

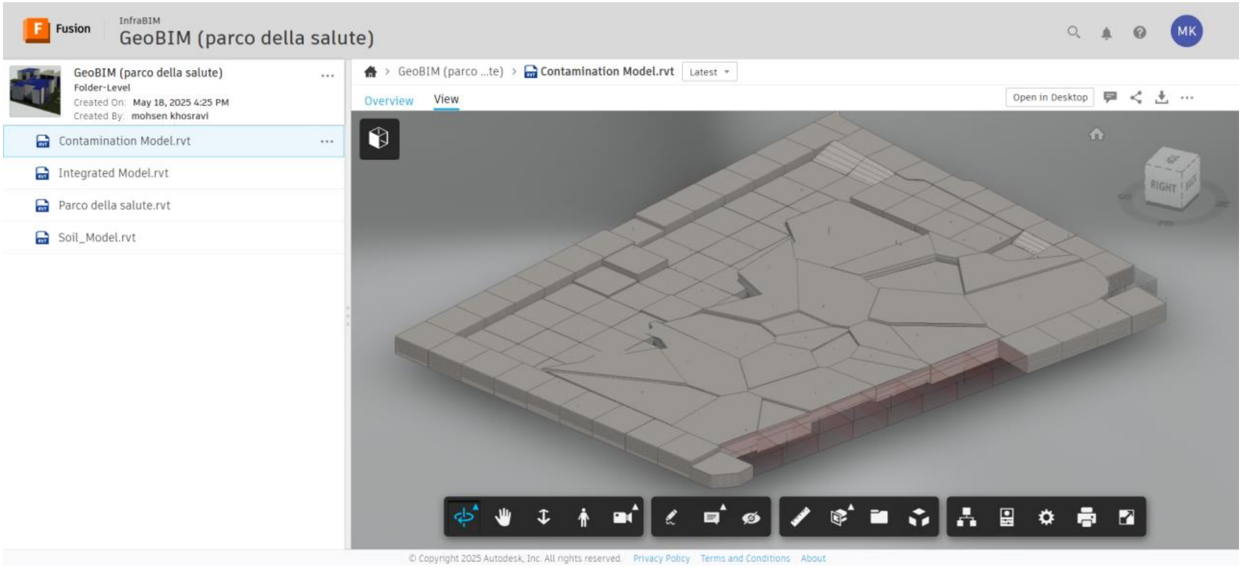


Figure 62. Online based contamination model.

Within this environment, the stakeholder can have a walkthrough view and interact with any part of the model, explode it to see the intermediate layers. Moreover, it enables to see any attribute that are saved inside the model. Figure 63 shows the exploded view of the model, which by selecting a portion the attribute data will be visible.

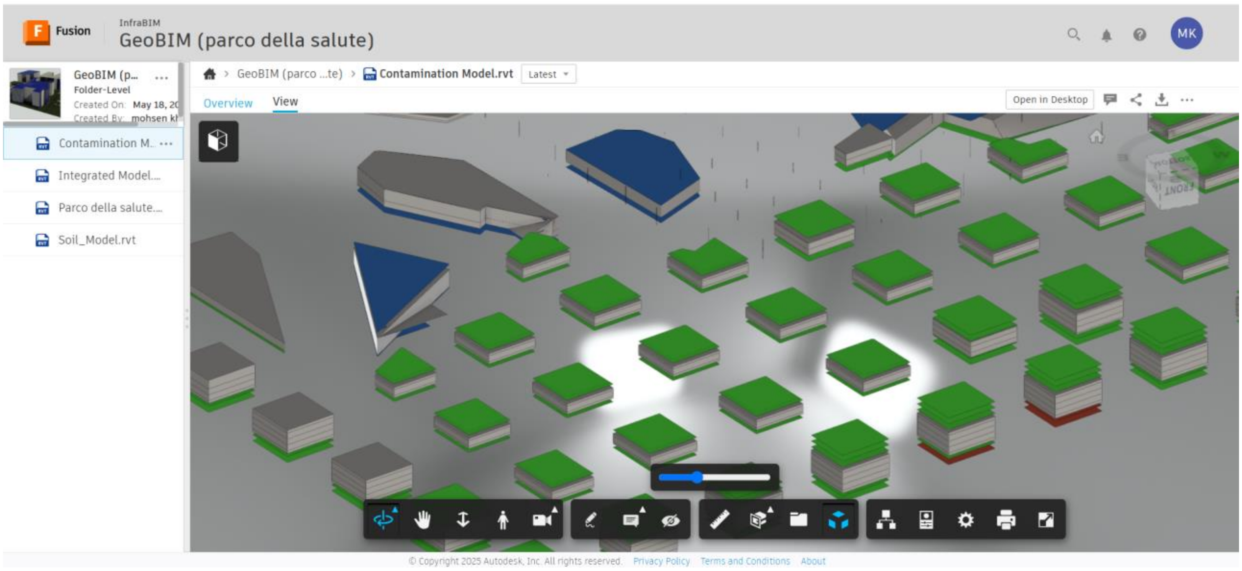


Figure 63. Exploded view of the contaminated model

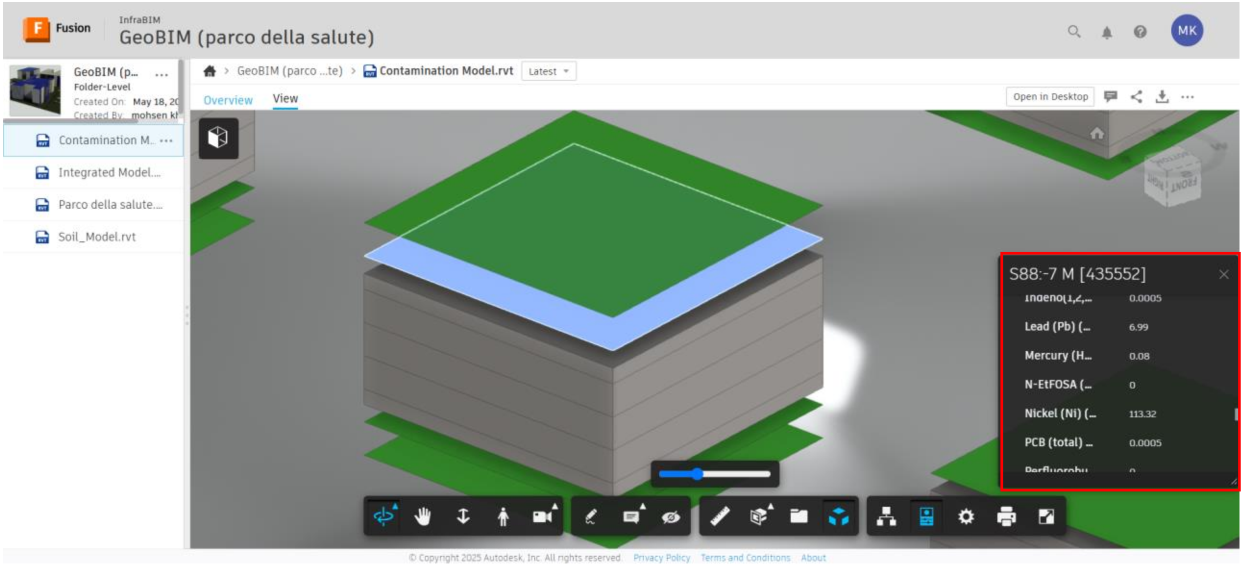


Figure 64. A layer of model and its related properties.

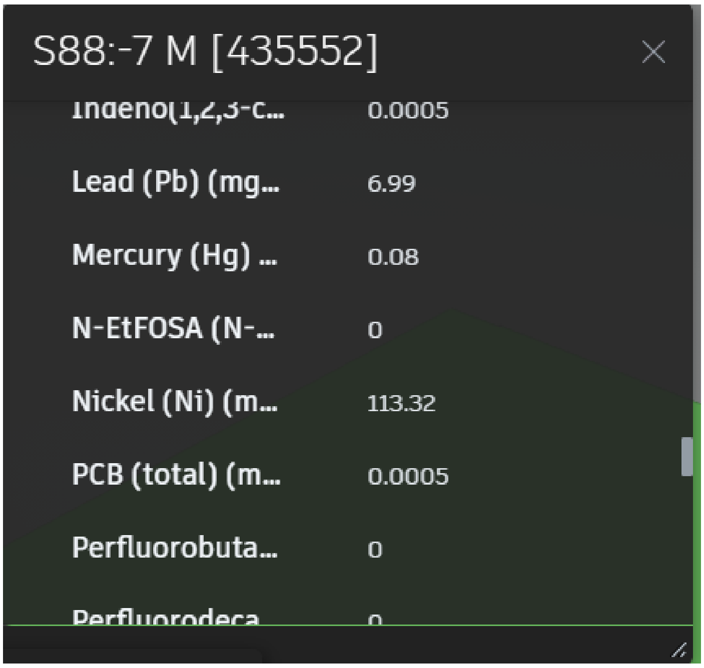


Figure 65. Information related to contamination saved as attribute inside the model.

This online model will help stakeholders involve to easily access and extract data by simply scanning a QRcode. Although the online GeoBIM model has all the information which was inside the Revit model, however, the model lost its intractability, and represented in static manner.

6.3.2 Autodesk Infraworks

In further work, the subsurface layers and conceptual model of the hospital were uploaded to "Autodesk Infraworks" environment. Infraworks is a multi-disciplinary BIM software, which enables to integrate large georeferenced infrastructure data (road, land, piping and water network…) with highly detailed oriented data (buildings and tunnels and metro stations….).

Figure 66. Integrated soil and conceptual model of parco della salute project

Infraworks enables to view the models from different disciplines one single federated models. This could help to see the possible clashes and predict infrastructures pathway under the structure and within the subsurface layers.

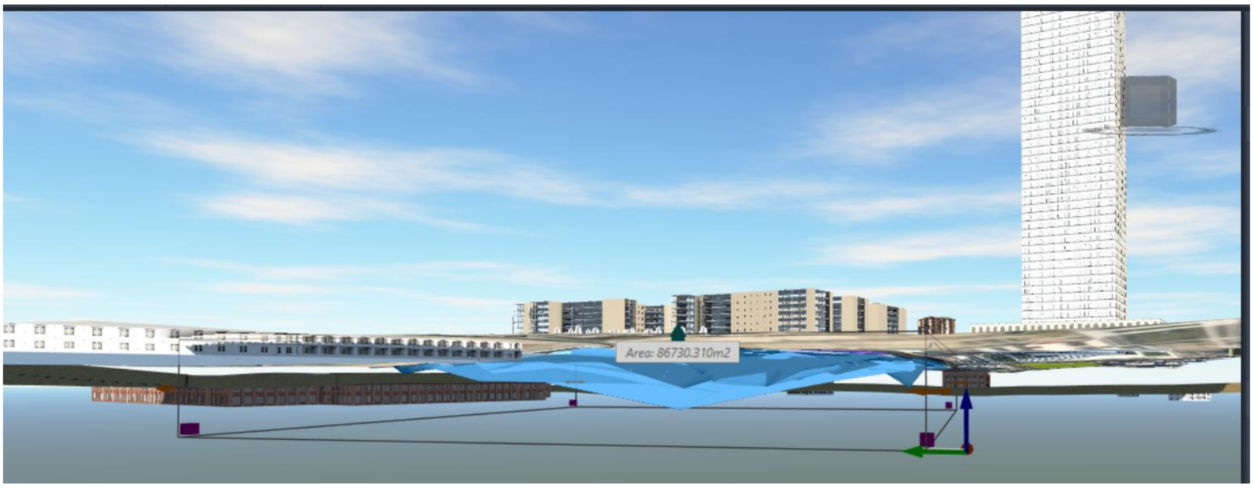


Figure 67. Integrated soil and conceptual model of parco della salute project

chapter 7 Conclusions and Future developments

This study showed the high potential of using visual programming tools like dynamo in GeoBIM modeling. Processes of reading laboratory and field data, extracting information and then representing this information so far have been in manners that was time consuming and not so interoperable with other disciplines. Subsurface situations have been bound to simplification. Recent software like leapfrog, civil 3d with aid of the extension, were able to represent underground geological situations but they were not able to save data within the model despite their accuracy in representation. ArcGIS pro was also another software which was considered for GeoBIM modeling. ArcGIS pro model was highly accurate and rich with attribute data; however, the final model was not usable in third party BIM software.

Autodesk Revit with Dynamo scripting were used as BIM tool for GeoBIM modeling. The final result showed that Revit's GeoBIM model has high accuracy in representation high level of detail. Developed models were capable for facility management and decision-making use. Moreover, the model could be exported in IFC format to integrate with other disciplines in any BIM platform.

As final work, GeoBIM repository was developed both to provide easier accesses to information for stakeholders involved and integration of GeoBIM model with other models.

Building on the outcomes of this study, several directions for future research and development are proposed:

1. Assessment of GEO5 and Novapoint for GeoBIM Applications

   While this study utilized Autodesk Revit and Dynamo as the platform for GeoBIM modeling, future research could explore the use of software tools such as GEO5 and Novapoint. These platforms could be evaluated in terms of:

   - Modeling precision and reliability in representing subsurface conditions,
   - Workflow integration with civil and architectural disciplines.
   - User interface and ease of use for both geotechnical and non-geotechnical users,
   - Level of interoperability with BIM and GIS environments (Ability to import/export to IFC, LandXML, …),
   - Data retention and loss during model exchange,

2. Feasibility of a Real-Time GeoBIM Online Repository

   Another direction is the development of a cloud-based GeoBIM repository capable of connecting to real-time monitoring systems. For example, integrating data from on-site piezometric devices to record groundwater pressure at predefined intervals, directly into the BIM model could allow for:

   - Continuous monitoring of subsurface conditions,
   - Risk analysis in real time (for slope stability or flooding),
   - Alert systems based on threshold exceedance.

Such a repository could be structured using APIs or IoT platforms that feed time-series data into shared parameters within the BIM environment. This would mark a significant shift from static representations to dynamic GeoBIM systems capable of evolving with site conditions.

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Appendix 1 Soil Stratigraphy*

Location ID	Depth Top	Depth Base	Legend Code	Lithology	Description
S1	0	1.2	A	Sandy Gravel	Sandy Gravel con ciottoli di dimensioni centimetriche. colore grigio.
S1	1.2	5	B	Slightly silty gravel and sand	Ghiaia sabbiosa debolmente limosa. localmente con ciottoli di dimensioni decimetriche. colore marroncino scuro.
S2	0	4	B	Slightly silty gravel and sand	Ghiaia sabbiosa debolmente limosa. con ciottoli di dimensioni da centimetriche a decimetriche alterati. colore marroncino scuro.
S3	0	0.5	C	Fill	Terreno di Fill costtuito da ghiaia e sabbia con frammenti di calcestruzzo. colore marrone.
S3	0.5	1.5	D	Concrete	Soletta in Concrete.
S3	1.5	2.6	A	Sandy Gravel	Sandy Gravel con ciottoli di dimensioni centimetriche. colore grigio-beige.
S3	2.6	3	F	Pebbly sand	Pebbly sand. colore grigio-beige.
S3	3	4.2	F	Pebbly sand	Sabbia con ghiaia e ciottoli di dimensioni centimetriche. colore grigio-beige.
S3	4.2	7	B	Slightly silty gravel and sand	Ghiaia esabbia debolmente limosa. con ciottoli di dimensioni da centimetriche a decimetriche alterati. colore marroncino scuro.
S3	7	8	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni decimetriche. colore grigio-marrone.
S4	0	2	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche alterati. colore marroncino scuro.
S4	2	4	A	Sandy Gravel	Ghiaia con sabbia e ciottoli di dimensioni centimetriche. colore grigio-beige.
S5	0	0.6	D	Concrete	Soletta in Concrete.
S5	0.6	1.5	C	Fill	Terreno di Fill costituito da ghiaia e sabbia con frammenti in calcestruzzo. colore marroncino.
S5	1.5	1.9	E	Compacted Clayey silt	Limo argilloso. con presenza di contaminazione da idrocarburi. colore da marroncino scuro a nerastro.
S5	1.9	2.5	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. con contaminazione da idrocarburi. colore nero.
S5	2.5	3.3	A	Sandy Gravel	Ghiaia e sabbia con odore da idrocarburo. colore marroncino scuro.
S5	3.3	4.5	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-beige.
S5	4.5	8	B	Slightly silty gravel and sand	Slightly silty gravel and sand. con ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S6	0	4	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S7	0	1	C	Fill	Terreno di Fill costituito da ghiaia e sabbia debolmente limosa con frammenti in calcestruzzo. colore marroncino.
S7	1	1.5	A	Sandy Gravel	Ghiaia e sabbia. con contaminazione da idrocarburi. colore nero.
S7	1.5	5.6	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-beige.

S7	5.6	6.5	B	Slightly silty gravel and sand	Slightly silty gravel and sand. con ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S7	6.5	9	A	Sandy Gravel	Ghiaia e sabbia. con ciottoli di dimensioni decimetriche e presenza di so:li livelli conglomeratici. colore grigio.
S8	0	4	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. colore marroncino scuro.
S9	0	0.8	B	Slightly silty gravel and sand	Ghiaia limosa. colore marrone scuro.
S9	0.8	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S9	4	4.5	B	Slightly silty gravel and sand	Slightly silty gravel and sand. con ciottoli di dimensioni centimetriche. colore marroncino scuro.
S9	4.5	8	A	Sandy Gravel	Ghiaia e sabbia. con ciottoli di dimensioni decimetriche e presenza di sottili livelli conglomeratici. colore grigio-beige.
S10	0	2.5	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. colore marroncino scuro.
S10	2.5	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S11	0	2.5	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. parzialmente alterati. colore marroncino scuro.
S11	2.5	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio-marrone.
S12	0	2.5	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. colore marroncino scuro.
S12	2.5	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S13	0	1.5	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. alterati. colore marroncino scuro.
S13	1.5	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio-marrone.
S14	0	2	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. colore marroncino scuro.
S14	2	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio-marrone.
S15	0	1.5	C	Fill	Terreno di Fill ghiaioso sabbioso con presenza di elementi in calcestruzzo concentrati alla base dello strato. colore grigio-marrone.
S15	1.5	4	A	Sandy Gravel	Ghiaia e sabbia a tratti debolmente limosa con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S16	0	4	C	Fill	Terreno di Fill costituito da ghiaia limosa e ghiaia sabbiosa con presenza di elementi in laterizi . colore marrone.
S17	0	1.4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con sporadici ciottoli di dimensioni centimetriche. colore marroncino scuro.
S17	1.4	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S18	0	4	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S19	0	1.2	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni centimetriche. colore marroncino scuro.

S19	1.2	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio.
S20	0	4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni da centimetriche a decimetriche. colore marroncino scuro.
S21	0	1.3	A	Sandy Gravel	Sandy Gravel. colore marroncino scuro. Alla base dello strato è presente la rete di alerta arancione.
S21	1.3	4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni da centimetriche a decimetriche. alterati. marroncino scuro.
S22	0	4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S23	0	2.6	B	Slightly silty gravel and sand	Slightly silty gravel and sand con sporadici ciottoli di dimensioni centimetriche. alterati. colore marroncino scuro.
S23	2.6	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. color grigio marrone.
S24	0	1.2	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio.
S24	1.2	3	B	Slightly silty gravel and sand	Slightly silty gravel and sand con sporadici ciottoli di dimensioni centimetriche. alterati. colore marroncino scuro.
S24	3	5	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S25	0	1.4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni centimetriche. alterati. colore marroncino scuro.
S25	1.4	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. color grigio marrone.
S26	0	4	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni da centimetriche a decimetriche. alterati. colore marroncino scuro.
S27	0	0.7	B	Slightly silty gravel and sand	Ghiaia con limo. colore marrone rossiccio.
S27	0.7	1.5	A	Sandy Gravel	Ghiaia e sabbia debolmente ciottolosa (ciottoli di dimensioni centimetriche). colore marrone rossiccio.
S27	1.5	3.4	A	Sandy Gravel	Ghiaia e sabbia debolmente ciottolosa (ciottoli di dimensioni centimetriche). colore marrone chiaro.
S27	3.4	4	F	Pebbly sand	Sabbia debolmente ciottolosa (ciottoli di dimensioni centimetriche). colore marrone.

S27	4	8	A	Sandy Gravel	Ghiaia e sabbia. con ciottoli di dimensioni decimetriche e presenza di sottli livelli conglomeratici. colore grigio-beige.
S28	0	1.6	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio.
S28	1.6	4.2	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni da centimetriche a centimetriche. localmente molto alterati. colore marroncino scuro.
S28	4.2	5	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. colore grigio-marrone.
S29	0	1.5	B	Slightly silty gravel and sand	Slightly silty gravel and sand con ciottoli di dimensioni centimetriche. localmente alterati. colore marroncino scuro.
S29	1.5	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimetriche. color grigio marrone.
S30	0	2.4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni da centimetriche a decimentriche. colore marrone-grigio.
S30	2.4	4	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni da centimetriche a centimetriche. colore marroncino scuro.
S30	4	5	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore marrone.
S30	5	6	B	Slightly silty gravel and sand	Ghiaia e sabbia limosa con ciottoli di dimensioni centrimetriche. molto alterati. colore marroncino scuro.
S31	0	3	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni da centimetriche a decimetriche. localmente alterati. colore marroncino scuro.
S31	3	4	A	Sandy Gravel	Ghiaia e sabbia con ciottoli di dimensioni centimetriche. colore grigio-marrone.
S32	0	1	F	Pebbly sand	Sabbia con ghiaia e ciottoli di dimensioni da centimetriche a decimetriche. colore marrone-grigio.
S32	1	4	B	Slightly silty gravel and sand	Ghiaia con sabbia debolmente limosa e ciottoli di dimensioni centimetriche. localmente alterati. colore marroncino scuro.

*A complete version of the table is available upon request to the author.

Appendix 2 Soil Contamination*

Location ID	X	Y	Z	Depth Top	Depth Base	Antimonio (Sb) (mg/kg s.s.)	Arsenico (As) (mg/kg s.s.)	Berillio (Be) (mg/kg s.s.)	Cadmio (Cd) (mg/kg s.s.)	Cobalto (Co) (mg/kg s.s.)	Cromo (Cr) (mg/kg s.s.)	Cromo esavalente (Cr VI) (mg/kg s.s.)	Mercurio (Hg) (mg/kg s.s.)	Nichel (Ni) (mg/kg s.s.)	Piombo (Pb) (mg/kg s.s.)	Rame (Cu) (mg/kg s.s.)	Stagno (Sn) (mg/kg s.s.)	Vanadio (V) (mg/kg s.s.)	Zinco (Zn) (mg/kg s.s.)
1	394584.5	4986841	230.5	0	1	0.49	1.33	0.47	0.16	3.47	84.6	0.2	0.08	56.89	3.88	6.15	0.51	7.01	12.85
1	394584.5	4986841	229.5	1	2	0.21	1.53	0.21	0.21	3.02	55.07	0.2	0.05	53.98	3.87	4.89	0.21	5.67	17.67
1	394584.5	4986841	228.5	2	3	0.24	1.66	0.24	0.24	3.51	90.49	0.2	0.04	84.74	5.4	6.14	0.61	9.29	18.24
1	394584.5	4986841	227.5	3	4	0.28	1.45	0.19	0.17	3.26	75.77	0.2	0.04	73.68	4.66	6.35	0.49	5.91	13.34
1	394584.5	4986841	226.5	4	5	0.22	1.86	0.21	0.2	3.73	78.36	0.2	0.06	71.96	6.49	7.02	0.36	8.54	22.48
2	394568.8	4986824	229.5	0	1	0.35	3.85	0.35	0.35	6.96	100.84	0.2	0.06	133.1	9.72	11.24	0.35	11.39	49.18
2	394568.8	4986824	228.5	1	2	0.27	4.51	0.58	0.27	6	86.88	0.2	0.05	115.55	10.12	11.33	1.31	12.96	36.49
2	394568.8	4986824	227.5	2	3	0.31	4.2	0.5	0.22	5.27	56.4	0.2	0.09	94.11	11.16	10.88	0.76	9.15	33.35
2	394568.8	4986824	226.5	3	4	0.21	2.02	0.21	0.21	3.79	37.19	0.2	0.05	57.23	7.53	7.36	0.21	6.49	26.36
3	394579.2	4986816	233.75	0	0.5	0.43	2.58	0.26	0.26	3.73	92.56	0.2	0.31	73.73	18.42	14.44	2.36	10.56	60
3	394579.2	4986816	232.25	1.5	2	0.17	1.53	0.17	0.17	3.99	70.23	0.2	0.03	69.99	6.13	22.24	1.21	7.54	24.14
3	394579.2	4986816	231.5	2	3	0.17	1.8	0.17	0.17	2.99	72.95	0.2	0.06	54.22	3.77	7.98	0.17	8.51	16.43
3	394579.2	4986816	230.5	3	4	0.13	1.03	0.13	0.13	2.46	65.37	0.2	0.03	53.94	2.59	7.71	0.13	4.72	11.21
3	394579.2	4986816	229.5	4	5	0.17	2.66	0.19	0.17	10.24	78.6	0.2	0.03	87.38	5.51	10.37	0.17	8.91	18.04
3	394579.2	4986816	228.5	5	6	0.3	3.09	0.3	0.3	7.6	184.38	0.2	0.11	140.99	7.21	11.25	0.3	11.71	24.08
3	394579.2	4986816	227.5	6	7	0.18	2.78	0.18	0.18	11.24	122.5	0.2	0.13	128.75	7.41	23.95	0.18	9.84	28.27
3	394579.2	4986816	226.5	7	8	0.23	2.54	0.23	0.23	7.75	68.81	0.2	0.04	91.56	8.97	18.63	0.23	9.73	25.74
4	394562.7	4986804	229.5	0	1	0.26	2.89	0.36	0.26	6.53	55.98	0.2	0.07	121.3	6.81	7.26	0.3	8.45	20.5
4	394562.7	4986804	228.5	1	2	0.25	3.13	0.81	0.25	5.13	107.91	0.2	0.51	116.43	10.61	7.77	0.72	10.67	18.38
4	394562.7	4986804	227.5	2	3	0.2	1.33	0.2	0.2	2.33	101.85	0.2	0.07	65.05	4.42	4.77	0.2	6.17	4.99
4	394562.7	4986804	226.5	3	4	0.23	0.92	0.23	0.23	3.53	40.37	0.2	0.13	54.14	5.85	5.73	0.23	4.36	11.92
5	394573.9	4986795	233	0.5	1.5	0.64	4.54	0.25	0.43	3.97	121.92	0.2	0.52	86.07	146.3	55.62	72.74	15.04	105.66
5	394573.9	4986795	232	1.5	2.5	0.22	4.16	0.39	0.22	8.61	104.93	0.2	0.2	118.25	16.11	26.46	0.84	22.53	54.51
5	394573.9	4986795	231.1	2.5	3.3	0.19	1.24	0.31	0.19	2.75	67.93	0.2	0.04	60.85	3.78	10.22	0.19	6.38	20.02
5	394573.9	4986795	230.35	3.3	4	0.21	1.9	0.21	0.21	3.98	107.89	0.2	0.03	73.95	7.35	10.09	0.21	8.75	19.12
5	394573.9	4986795	229.5	4	5	0.27	3.36	0.39	0.27	7.39	136.88	0.2	0.02	126	8.46	20.05	0.27	14.88	31.18

5	394573.9	4986795	228.5	5	6	0.23	3.68	0.28	0.23	9.47	168.14	0.2	0.04	175.47	9.29	19.12	0.23	13.20	30.14
5	394573.9	4986795	227.5	6	7	0.25	4.26	0.42	0.25	6.82	159.2	0.2	0.03	143.57	9.17	17.3	0.25	15.12	30.55
5	394573.9	4986795	226.5	7	8	0.39	3.54	0.45	0.3	6.17	93.6	0.2	0.03	121.79	9.3	26.84	0.3	14.50	34.56
6	394557.2	4986788	229.5	0	1	0.27	1.25	0.27	0.27	5.2	43.95	0.2	0.11	44.96	5.09	7.11	0.27	5.08	12.48
6	394557.2	4986788	228.5	1	2	0.26	1.11	0.3	0.26	25.91	114.01	0.2	0.14	61.73	5.3	10.8	0.58	8.83	10.78
6	394557.2	4986788	227.5	2	3	0.19	1.24	0.29	0.19	5.71	49.34	0.2	0.26	63	6.11	4.55	0.55	6.57	10.89
6	394557.2	4986788	226.5	3	4	0.14	1.1	0.17	0.14	4.2	31.73	0.2	0.27	45.26	4.43	4.44	0.37	4.22	8.2
7	394568.5	4986783	233.5	0	1	0.72	5.63	0.18	0.2	5.14	112.33	0.2	0.13	101.64	24.01	50.87	3.04	11.14	76.5
7	394568.5	4986783	232.75	1	1.5	0.24	3.02	0.19	0.19	4.95	109	0.2	0.1	98.56	24.94	16.24	0.19	12.57	44.17
7	394568.5	4986783	232.25	1.5	2	0.24	1.93	0.16	0.16	22.17	86.23	0.2	0.31	99.85	8.26	11.42	0.16	7.79	22.41
7	394568.5	4986783	231.5	2	3	0.32	2.03	0.17	0.17	26.39	105.71	0.2	0.05	83.84	4.21	8.27	0.17	8.83	19.39
7	394568.5	4986783	230.5	3	4	0.23	3.91	0.23	0.23	6.6	174.53	0.2	0.04	134.85	7.27	17.47	0.23	15.29	32.67
7	394568.5	4986783	229.5	4	5	0.17	2.2	0.17	0.17	3.34	141.75	0.2	0.07	88.72	3.79	9.26	0.17	10.12	17.07
7	394568.5	4986783	228.5	5	6	0.43	2.92	0.24	0.24	4.14	98.31	0.2	0.11	69.65	3.82	8.14	0.24	6.70	14.56
7	394568.5	4986783	227.5	6	7	0.23	1.58	0.23	0.23	1.94	42.46	0.2	0.1	36.75	1.66	4.12	0.23	3.61	6.9
7	394568.5	4986783	226.5	7	8	0.48	2.02	0.26	0.26	12.53	100	0.2	0.1	84.48	6.11	18.57	0.26	9.72	24.11
7	394568.5	4986783	225.5	8	9	1.59	2.98	0.27	0.27	85.18	84.64	0.2	0.06	83.84	6.12	145.63	0.27	11.60	97.09
8	394551.8	4986770	229.5	0	1	0.2	1.89	0.24	0.2	4.09	60.56	0.2	0.06	82.25	5.91	7.53	0.4	6.59	12.54
8	394551.8	4986770	228.5	1	2	0.2	1.5	0.23	0.2	3.86	66.3	0.2	0.15	63.03	4.93	4.69	0.37	6.91	7.96
8	394551.8	4986770	227.5	2	3	0.16	0.91	0.16	0.16	3.96	40.49	0.2	0.15	44.32	4.13	5.12	0.16	3.84	7.06
8	394551.8	4986770	226.5	3	4	**0.2**	1.35	0.3	0.2	6.14	65.61	0.2	0.17	56.21	5.04	4.98	0.2	7.48	8.99
9	394565.3	4986764	233.5	0	1	0.29	3.26	0.19	0.19	5.05	100.03	0.2	0.05	112.42	20.08	14.64	0.19	10.74	263.1
9	394565.3	4986764	232.5	1	2	0.17	1.63	0.17	0.17	3.62	62.6	0.2	0.02	67.98	4.63	5.35	0.17	5.82	108.84
9	394565.3	4986764	231.5	2	3	0.18	1.75	0.18	0.18	4.67	66.2	0.2	0.01	69.55	4.23	4.95	0.18	5.44	36.17
9	394565.3	4986764	230.5	3	4	0.25	3.19	0.25	0.25	3.55	135.05	0.2	0.11	89.4	4.09	8.62	0.25	8.50	20.42
9	394565.3	4986764	229.5	4	5	0.32	3.29	0.25	0.25	6.41	110.73	0.2	0.03	142.69	5.89	10.68	0.25	10.57	19.24
9	394565.3	4986764	228.5	5	6	0.48	2	0.21	0.21	19.93	107.11	0.2	0.03	70.69	5.49	25.66	0.21	8.07	24.64
9	394565.3	4986764	227.5	6	7	0.22	3.32	0.61	0.22	4.08	93.64	0.2	0.03	94.37	6.58	9.23	0.22	10.42	20.75
9	394565.3	4986764	226.5	7	8	0.37	2.55	0.47	0.19	7.78	80.34	0.2	0.17	60.34	4.51	19.52	0.19	6.68	21.45
10	394552.1	4986743	229.5	0	1	0.24	2.13	0.35	0.24	3.94	67.63	0.2	0.07	77.48	6.57	8.72	0.24	6.94	13.44
10	394552.1	4986743	228.5	1	2	0.23	2.12	0.34	0.23	4.1	101.1	0.2	0.16	89.03	6.46	8.48	0.54	9.60	11.91
10	394552.1	4986743	227.5	2	3	0.18	1.38	0.29	0.18	3.05	114.06	0.2	0.05	77.07	4.38	6.35	0.57	8.91	5.24

10	394552.1	4986743	226.5	3	4	0.15	1.51	0.19	0.15	11.8	66.83	0.2	0.11	58.09	10.59	12.2	0.31	7.53	14.16
11	394547.6	4986729	229.5	0	1	0.24	2.85	0.3	0.24	4.9	112.46	0.2	0.1	114.62	8.1	10	0.39	9.18	24.07
11	394547.6	4986729	228.5	1	2	0.22	2.52	0.37	0.22	4.43	55.84	0.2	0.39	92.17	8.85	9.78	0.33	6.68	20.92
11	394547.6	4986729	227.5	2	3	0.22	2.08	0.22	0.22	3.43	56.56	0.2	0.16	64.2	9.72	8.86	0.22	7.09	18
11	394547.6	4986729	226.5	3	4	0.25	1.53	0.25	0.25	4.53	70.17	0.2	0.07	76.03	7	10.28	0.25	6.50	18.7
12	394570.2	4986734	229.5	0	1	0.14	2.03	0.14	0.14	3.85	62.58	0.2	0.13	67.3	7.79	4.62	0.14	5.94	8.88
12	394570.2	4986734	228.5	1	2	0.2	2.49	0.32	0.2	4.07	118.71	0.2	0.17	108.84	6.49	5.78	0.47	10.75	8.1
12	394570.2	4986734	227.5	2	3	0.24	1.28	0.24	0.24	5.44	66.25	0.2	0.55	60.07	6.17	11.88	0.3	9.18	14.27
12	394570.2	4986734	226.5	3	4	0.2	1.13	0.2	0.2	3.26	58.58	0.2	0.07	50.58	5.57	10.41	0.2	7.53	11.35
13	394566	4986723	229.5	0	1	0.26	2.53	0.3	0.26	4.6	81.16	0.2	0.15	90.75	8.28	16.32	0.26	7.65	23.49
13	394566	4986723	228.5	1	2	0.31	2.33	0.5	0.31	4.78	122.85	0.2	0.24	94.64	7.86	18.32	0.49	10.86	28.55
13	394566	4986723	227.5	2	3	0.22	1.06	0.22	0.22	9.28	99.83	0.2	0.01	92.79	6.11	9.17	0.22	6.08	16.08
13	394566	4986723	226.5	3	4	0.23	1.44	0.23	0.23	4.39	47.04	0.2	0.01	49.87	6.69	9.54	0.23	8.03	16.15
14	394589.5	4986728	229.5	0	1	0.22	2.53	0.33	0.22	4.56	88.99	0.2	0.01	105.04	10.67	12.14	0.73	9.63	23.32
14	394589.5	4986728	228.5	1	2	0.24	3.44	0.31	0.24	4.46	103.27	0.2	0.02	100.63	9.29	14.34	0.24	9.71	24.93
14	394589.5	4986728	227.5	2	3	0.2	1.7	0.28	0.2	1.06	135.53	0.2	0.05	68.35	5.05	20.9	0.2	7.27	25.76
14	394589.5	4986728	226.5	3	4	0.2	1.21	0.2	0.2	3.97	50.39	0.2	0.12	58.37	4.86	9.98	0.32	5.73	14.64
15	394585.3	4986717	229.5	0	1	0.22	2.27	0.22	0.22	4.12	80.97	0.2	0.1	88.46	13.56	17.94	0.94	7.57	23.34
15	394585.3	4986717	228.5	1	2	0.28	1.77	0.28	0.28	15.8	76.25	0.2	0.08	84.85	7.76	70.71	0.54	7.35	54.11
15	394585.3	4986717	227.5	2	3	0.22	1.53	0.22	0.22	11.38	111.53	0.2	0.17	100.76	5.89	152.82	0.32	7.14	50.25
15	394585.3	4986717	226.5	3	4	0.24	1.47	0.24	0.24	3.82	55.98	0.2	0.08	61.51	8.88	24.15	0.54	7.64	31.1
16	394604.9	4986711	229.5	0	1	0.24	2.01	0.24	0.24	3.45	81.46	0.2	0.07	65.69	8.54	20.12	0.89	8.86	22.65
16	394604.9	4986711	228.5	1	2	0.23	2.82	0.26	0.23	4.63	75	0.2	0.1	80.03	8.26	14.33	0.54	8.78	23.27
16	394604.9	4986711	227.5	2	3	0.26	2.97	0.27	0.26	9.84	118.49	0.2	0.08	107.4	22.28	24.25	3.1	12.42	110.09
16	394604.9	4986711	226.5	3	4	0.25	3.36	0.32	0.25	6.06	97.82	0.2	0.22	89.82	53.38	28.31	11.97	15.30	55.99
17	394609.8	4986726	229.5	0	1	0.29	3.79	1.24	0.29	6.1	104.31	0.2	0.11	111.31	9.55	6.88	1.1	9.52	31.34
17	394609.8	4986726	228.5	1	2	0.24	2.65	0.33	0.24	4.58	68.02	0.2	0.07	83.58	11.43	9.67	1.17	9.08	31.93
17	394609.8	4986726	227.5	2	3	0.28	1.51	0.28	0.28	5.71	106.44	0.2	0.16	97.75	5.34	5.16	0.28	6.84	25.22
17	394609.8	4986726	226.5	3	4	0.22	2.06	0.22	0.22	3.3	60.7	0.2	0.1	64.67	5.33	3.95	0.22	5.71	26.95
18	394623	4986738	229.5	0	1	0.27	2.46	0.29	0.27	4.12	77.61	0.2	0.26	91.33	10.23	5.48	0.6	8.37	34.92
18	394623	4986738	228.5	1	2	0.21	2.05	0.27	0.21	4.78	78.39	0.2	0.16	102.88	9.58	3.21	0.36	7.58	23.44
18	394623	4986738	227.5	2	3	0.25	3.06	0.34	0.25	6	83.03	0.2	0.01	123.77	10.8	8.45	0.27	9.07	35.93

18	394623	4986738	226.5	3	4	0.24	2.31	0.24	0.24	4.11	53.01	0.2	0.07	69.04	7.82	5.8	0.24	6.65	21.19
19	394628.9	4986720	229.5	0	1	0.29	2.6	0.36	0.29	5.28	48.45	0.2	0.15	91.36	12.74	3.4	0.36	8.67	35.25
19	394628.9	4986720	228.5	1	2	0.2	2.31	0.2	0.2	3.31	61.58	0.2	0.09	68.73	6.1	2.83	0.22	7.27	20.15
19	394628.9	4986720	227.5	2	3	0.22	2.15	0.36	0.22	4.46	106.96	0.2	0.05	92.03	6.47	4.27	0.22	8.83	19.03
19	394628.9	4986720	226.5	3	4	0.25	1.84	0.25	0.25	4.75	70.47	0.2	0.05	70.22	5.5	1.73	0.25	7.75	14.01
20	394624	4986706	229.5	0	1	0.25	1.99	0.25	0.25	6.25	97.67	0.2	0.03	104.15	8.41	11.99	0.44	8.42	34.95
20	394624	4986706	228.5	1	2	0.15	2.09	0.16	0.15	8.49	100.21	0.2	0.05	110.07	6.52	11.48	0.25	7.54	22.81
20	394624	4986706	227.5	2	3	0.17	2.06	0.21	0.17	4.48	105.68	0.2	0.05	93.07	7.56	16.71	0.5	10.22	20.47
20	394624	4986706	226.5	3	4	0.28	3.35	0.28	0.28	6.36	85.14	0.2	0.05	115.28	14.97	10.1	0.75	14.35	40.11
21	394638.1	4986700	229.5	0	1	0.21	3.99	0.22	0.21	4.79	51.9	0.2	0.05	75.09	12.27	7.55	0.71	9.42	27.92
21	394638.1	4986700	228.5	1	2	0.27	5.03	0.35	0.27	6.39	93.51	0.2	0.04	116.45	16.45	10.66	0.54	14.17	40.74
21	394638.1	4986700	227.5	2	3	0.26	4.55	0.29	0.26	5.79	145.81	0.2	0.06	126.11	13.74	10.24	0.4	14.41	38.36
21	394638.1	4986700	226.5	3	4	0.25	3.71	0.36	0.25	5.19	59.68	0.2	0.04	91.62	10.71	6.41	0.4	9.23	23.72
22	394648.3	4986715	229.5	0	1	0.25	3.95	0.5	0.25	5.47	65.63	0.2	0.1	98.87	9.2	6.55	0.39	9.63	28.51
22	394648.3	4986715	228.5	1	2	0.29	2.56	0.4	0.29	6.37	42.71	0.2	0.12	80.36	7.62	3.99	0.35	6.66	20.64
22	394648.3	4986715	227.5	2	3	0.29	3.27	0.35	0.29	4.97	127.05	0.2	0.19	123.16	9.02	5.26	0.46	11.96	27.78
22	394648.3	4986715	226.5	3	4	0.25	3.49	0.44	0.25	7.44	103.1	0.2	0.07	106.03	11.24	6.55	0.66	13.60	32.47
23	394653.8	4986730	229.5	0	1	0.22	2.12	0.29	0.22	4.07	62.02	0.2	0.16	92.07	8.14	4.84	0.22	6.58	19.06
23	394653.8	4986730	228.5	1	2	0.31	2.04	0.36	0.31	9.12	113.73	0.2	0.05	122.6	8.05	7.65	0.45	9.83	23.76
23	394653.8	4986730	227.5	2	3	0.23	1.36	0.23	0.23	10.36	48.04	0.2	0.07	51.46	4.63	5.74	0.64	4.67	13.64
23	394653.8	4986730	226.5	3	4	0.27	1.59	0.27	0.27	30.55	42.8	0.2	0.16	57.31	6.7	9.68	0.27	6.02	18.96
24	394672.1	4986750	230.5	0	1	0.27	1.34	0.27	0.27	3.88	75.91	0.2	0.08	73.5	5.03	3.02	0.27	6.10	15.47
24	394672.1	4986750	229.5	1	2	0.25	1.96	0.26	0.25	4.42	74.65	0.2	0.01	86.82	11.38	3.87	0.25	7.99	16.71
24	394672.1	4986750	228.5	2	3	0.27	2.36	0.57	0.27	5.31	84.39	0.2	0.1	93.41	8.54	4.98	0.3	8.01	18.17
24	394672.1	4986750	227.5	3	4	0.24	1.52	0.24	0.24	3.95	51.92	0.2	0.08	60.27	6.47	2.54	0.24	5.20	12.88
24	394672.1	4986750	226.5	4	5	0.19	1.42	0.19	0.19	3.28	53.71	0.2	0.1	60.77	4.88	3.09	0.19	5.02	13.43

*A complete version of the table is available upon request to the author.