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Heritage-BIM Workflow for Stone Road Pavements Digital Reproduction

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Abstract: The transition from Building Information Modelling (BIM) to Heritage Building Information Modelling (H-BIM) is intended to pursue an adequate knowledge of the artefact that is to be preserved, progressively replacing the traditional methods of the restoration and structural reinforcement projects with new tools for managing both existing information and new interventions. The aim of the paper is to show the application of the H-BIM method to a stone pavement road located in the Archaeological Site of Pompeii. In detail, starting from a Laser Scanner based survey, juxtaposed by coordinated points georeferenced through a total station, points clouds were handled by means of several BIM-based tools to perform the road design process, starting from the digital elevation model (DEM) to the corridor representation. Subsequently, a visual programming application based on Python language was adopted to update corridor information by means of the object property set. As preliminary results, a tool, complete with graphical and non-graphical information, is proposed to be used in conservation, maintenance and restoration project.

Keywords: Heritage-BIM; Stone paved road; Procedural Modeling; VPL scripting; CAD; Point Cloud.

1. Introduction

Digitization and computerized processes are an effective answer to reduction costs and production times issues, and therefore BIM, defined as "a process involving the generation and management of digital representation of the physical and functional characteristics of a facility" [1], represents the best fitting result of the continuous search for new methods and approaches for increasing process efficiency in the AEC industry (Architecture, Engineering and Construction). BIM is recognized as the most appropriate methodology to undertake building and infrastructure projects [2,3] having revolutionized the field of architecture and construction for some years now [4], being both a technology and a methodology [5] and even though it remains a challenge for the AEC industry, since it requires a shift to a new way of working, there is a strong legislative endeavour to flat any differences in its adoption level among the various EU states [6].

Since the wide adoption of BIM tools in new projects design has confirmed its advantages, the same methodology has been adapted to the reproduction in BIM environment of existing civil works with historical or cultural value, taking the name of H-BIM, defined as "a new way of modeling the existing structures, generating intelligent models that can contain and manage information, and concern all components of the project, including their geometric and identification information described in detail" [7].

The experience in the architectural field is well consolidated, and many systematic approaches have been developed to be applied to historical-cultural heritage artifacts, as in the case of the Cathedral of Parma and the Ducal Palace of Mantua [8] and the Pisa

Charterhouse [9]. Other interesting case studies have been proved that H-BIM is suitable also for infrastructures, as Giorgini Bridge in Castiglione della Pescaia (Grosseto, Italy) [10] or the Carlo III Bridge of the Carolino Aqueduct in Benevento [11].

The support of cutting-edge technologies is essential to use H-BIM approach, as for the smart surveys, that rely on data acquisition techniques such as Terrestrial Laser Scanning (TLS) [12] and UAV photogrammetry that can be used, for example, to carry on intelligent survey to support the reproduction of 3D models for the H-BIM approach to archaeological excavations as happened for Hierapolis in Phrygia, Turkey [13], and Via del Vesuvio in Pompeii, Italy [14].

It is also the case of the development of virtual reality projects, in order to create digital worlds able to faithfully and accurately represent the detected reality and improve new immersive environments for Virtual Reality (VR) and Augmented Reality (AR) projects [15].

Great efforts are currently being made to automatically reconstitute the geometry of cultural heritage elements, also using Deep Learning (DL) techniques based on the Convolutional Neural Network theory that can help to recognize historical architectural elements [16], or to process analyses to automatically detect stone pavement's patterns [17-18] and retrieve precise metric data on irregular surfaces, such as the ones of historical paved roads, with a high degree of automation [19].

Most of historical urban areas in western countries are paved with stone elements [20]; in particular, the Italian road network is part of the world's greatest UNESCO heritage having the highest number of UNESCO Heritage Sites, as the case of Naples Historical Centre [21] and Pompeii's paved roads.

Once a thriving and sophisticated Roman city, Pompeii was buried under meters of ash and pumice from the catastrophic eruption of Mount Vesuvius in 79 AD. Pliny the Younger, an eyewitness of the eruption from his family's villa in Miseno, described the pyroclastic mushroom as a "prodigious pine tree, here shining white, there soiled with gray from the ashes and the raised earth" [22]. Since the ashes protected the structures from the action of timed destruction, Pompeii is one of the best-preserved Roman cities. Therefore, Pompeii is one of the most important archeological sites in the world, attended by major scholars of international renown, and as the excavations continue, so there are still new discoveries, such as the Thermopolis of Regio V [23].

From the review of the literature just presented, it is noticeable the lack of practice in creating whole information models of stone paved roads, that represent even a larger gap if the scope is historical and/or archaeological heritage. Therefore, this research study aims to address this gap by defining a framework for the implementation of H-BIM methodology applied to a stretch of an archaeological road in the Site of Pompeii. The research approach is aimed at the realization of a support tool for the management of the archaeological site itself, as well as a tool for sharing information related to materials and ancient construction techniques that exert fascination despite being so old.

2. Methodology

The research study aims to define a new approach to use the H-BIM methodology for the analysis and the management processes of archeological sites focusing on the terminal part of Via Stabiana on Porta di Stabia in the Archaeological Site of Pompeii.

The pivotal methodology shown in Figure 1 is built around the so-called Scan-to-BIM workflow, that allows for the generation of a 3D BIM model from a point cloud [24], involving two main work phases: 3D surveying through Laser Scanner and processing the information surveyed with several BIM authoring software.

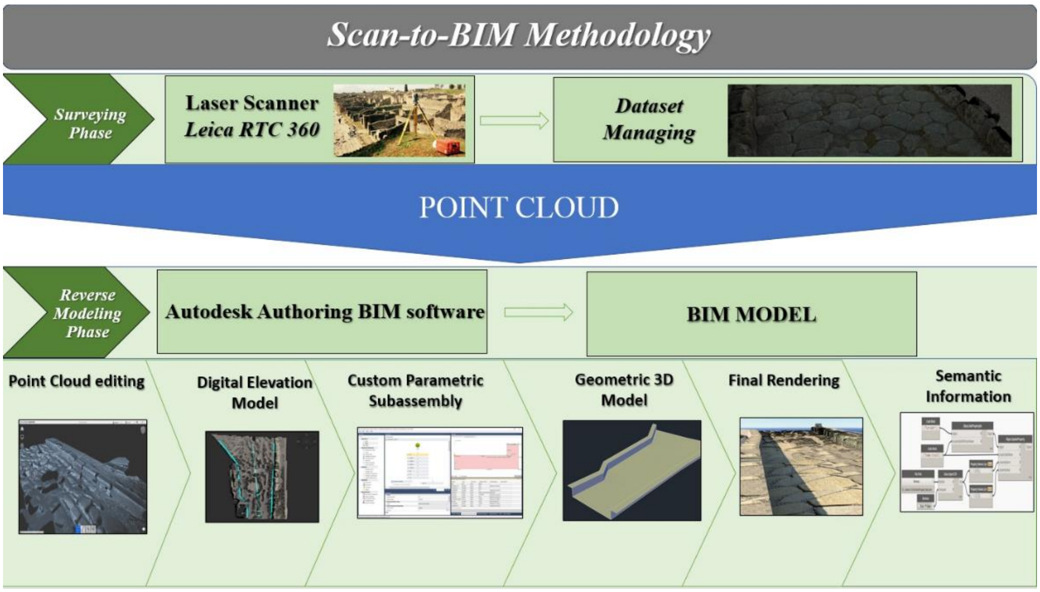

Figure 1. *Methodology Workflow.*

The surveying phase of Scan-to-BIM process relies on Laser Scanners technology, electro-optical instruments capable of survey the surface of any object by mapping points in 3D.

To obtain the H-BIM model a subsequent "reverse engineering" process was needed which consisted in creating a 3D model shaping its surfaces on the points of the point cloud. 3D surfaces are generally divided in two main categories: (i) NURBS, surfaces defined by mathematical equations, very precise and stable, used especially in the modeling of complex surfaces; (ii) MESHES, that fit the use of point clouds the best because composed by polygons whose vertices are the points of the cloud and the sides are the segments that connect them.

Final step of 3D modeling was the assignment of customized textures to Mesh surfaces using as source images taken during the survey allowing for obtaining more realistic simulation. Once the model of three-dimensional surfaces has been recreated on the trace of the point cloud, it was possible to manage the information of the model itself and interrogate it using also tools able to develop semi-automatic algorithms.

Autodesk BIM-based computational codes were used as tools to ensure 100% interoperability and perfect success of the Scan-to-BIM methodology just described: (i) *Recap Pro*, for survey data managing; (ii) *Infraworks*, for BIM model creation preparation phase and final render; (iii) *Civil 3D*, to create the BIM model, for which was necessary to create from scratch a customized typological road section with its add-on *Subassembly Composer* and develop algorithms by mean of its add-on *Dynamo*.

3. Case study workflow

3.1. Pompeii case study

Since any H-BIM application should include an informed preliminary analysis of construction criteria, previous research works have been investigated in order to obtain an in-depth picture of knowledge on the case study, such as for Roman road building technologies and practices [25] and their design criteria [26]. Particularly significant is the study conducted in the archaeological site of Pompeii by Poehler and Crowther (2019) [27] on the paving techniques hypothesized from the surveys carried out.

Pompeii stands on a buttress about 40 meters high, formed by the flow of a lava flow erupted by Vesuvius in prehistoric times. The land on which the city was built is therefore considerably irregular, with a steep slope towards the south. The roads, almost all straight and crossing at right angles, are divided into main arteries, corresponding to the cardines

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with direction from North to South and to the decumans with direction from West to East, and in secondary arteries, of variable width; they are flanked by more or less high sidewalks, made with construction waste and paved by private individuals [14].

The H-BIM workflow was applied to the terminal part of Via Stabiana on Porta di Stabia in the Archaeological Site of Pompeii. It is a road stretch 12 meters long with a 5.20% average slope that guarantees the outflow of the water into an underground canal on the right side (North-South direction) and then outside the walls thanks to a change of the road's cross slope.

3.2. Surveying phase

A Leica RTC360 model Laser Scanner has been used which operates by emitting a laser pulse and calculating the distance from the object detected by measuring the round-trip time of the laser pulse itself. After setting the resolution parameter, connected to precision and scanning speed, a single 360° scan is performed in one minute and 50 seconds obtaining a point cloud composed by 2 million of points whose position is identified by coordinates [X,Y,Z] defined by the distance of the point from the instrument, the inclination angle formed by the conjunction of the point and the instrument with respect to the vertical axis of the instrument itself and the azimuth angle formed by the conjunction of the point and the instrument with respect to a horizontal axis taken as reference.

Terrestrial Laser Scanner survey process should be supported by multiple scans, to survey the same object from different perspectives, in order to cover every shadow zone. Performing several scans of the same object produced as result overlapping data that have been manipulated with a dedicated software, Leica Cyclone, in order to view and check every scan, coordinate several scans in one, georeference the project in Gauss-Boaga system and export the project in a common format file to ensure interoperability.

Since the area subject of this study is not too wide, the satisfactory number of scans needed was three. It is always a good practice to perform at least three scans, forming a triangle in which the vertices are the subsequent positions of the Laser Scanner.

3.3. Database managing and Point Cloud editing

The management of the scanned point cloud database was carried out with Leica Cyclone tool according to workflow shown in Figure 2. When finished, a single point cloud derived from coordinating the three scans performed was exported to a PTX format file for import into Autodesk Recap Pro. The latter was then leveraged to clean up the cloud and export it to RCP format files so that it could be used by Autodesk Infraworks.

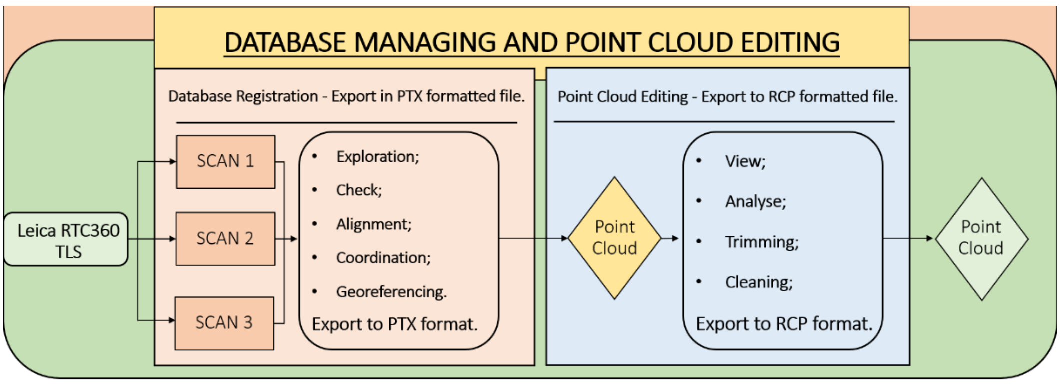


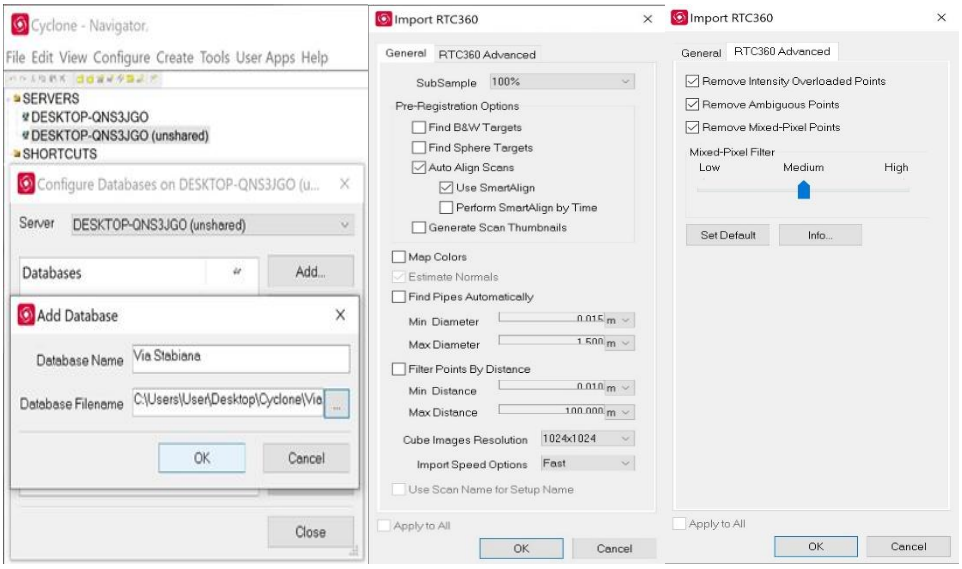
Figure 2. Database managing and Point Cloud Editing Workflow.

3.3.1. Leica Cyclone database managing

Cyclone user interface presents itself clear and friendly: data are organized in a *Navigator* menu on the left side of the screen in a hierarchical tree. The head of the hierarchy is the folder *Servers*. A Database was configured within the local server by right-clicking on its folder and then using the command *Databases*. The following dialogue window enables to add a Database, creating it from scratch giving it a name and a file path, or importing an already existing one (Figure 3.a).

Once the database is configurated, it is possible to add data, by right-clicking on the Database and using the command *Import RTC360 Data* and then *Import RTC360 Project.*

Once the folder containing the scans is selected, within the general settings was possible to *Auto Align* the different scans trough the *SmartAlign* mode (Figure 3.b), while Ambigous Points, Mixed-Pixel Points and Overloaded Points were removed within the advanced settings (Figure 3.c).



(a) (b) (c)

Figure 3. Import settings in Cyclone: (a) Importing Database; (b) Auto-Align mode; (c) Remove points options.

Once the import process is complete, under the Database a *project folder* is located, containing all the scans. At this level, each scan is called a *scanworld*. Each scanworld has a *control space* that contains the constraint objects, thus targets can be viewed and managed, and other three folders: *model space* – where is it possible to view, edit and work with the point cloud; *scans* – where the single scans are listed; *images* – where the images elaborated from the pictures taken withing the survey are contained, and that are attached to the point cloud to colorize it.

The SmartAlign option aligns automatically the three scans made on field in a unique *registration.*

By double-clicking on the name of any scanworld, it is possible to view the point cloud attached, but there will be only one point of view matching the local origin of the scan, i.e. the position of the scanner in the field. To view and navigate the point cloud more freely, it is necessary to open the ModelSpace of the scanworld of interest: in this case, it is possible to overfly the scan, rotate the view, zooming in and out and interrogate points data, (ctrl+s+left-click).

To add the georepherence to the project, a *Control file* was used. It is a text file in which some of the points surveyed are identified by their ID and their coordinates (latitude, longitude, altitude). To import the Control file, right-click the dataset folder, *import* command and then select the Control file in its folder. The imported file is processed as a scanworld. To georepherence all several scans, it is necessary to set the Control file as *home scanworld* by right-clicking on it and then select the command *set as home scanworld*. Now it is possible to proceed with the final registration.

Eventually, the project was exported in PTX formatted file, by right-clicking on the project folder and pin the *export* option, and after having chosen the directory folder, the PTX type was set.

3.3.2. Autodesk Recap Pro point cloud editing

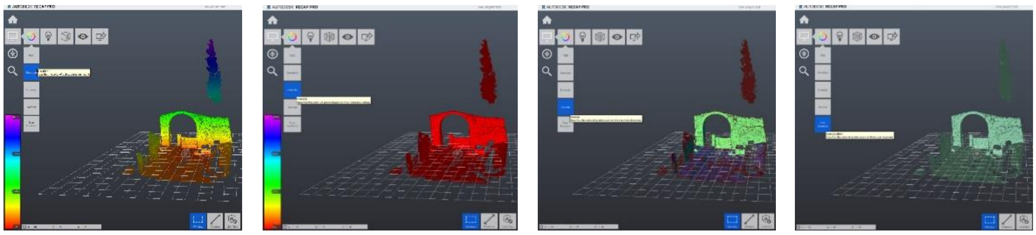
Recap Pro, similarly to Cyclone, allows to manage the point cloud, that is, it makes possible 3D visualization of the survey and point cloud modification. The interface of Recap Pro is user-friendly and intuitive, also providing some training content.

Once the file to import has been selected, a filter has been applied to adjust density and range; moreover, the geographical coordinate system was specified among hundreds of options available, but the operation was eased by the automatic detection performed by the software itself. Then, decimation grid was set, which is a parameter that imposes the minimum points mutual distance. In Cyclone, points scanned were at a mutual distance of the order of 1 mm, and the dimension of the points was set at 0.5 mm radium, thus points were perfectly covering the space on surfaces giving to human eye the exact perception of the objects surveyed. This level of detail is not needed anymore in the modelling phase, so the decimation grid was set at 5 mm, obtaining a lighter database.

Recap Pro has several tools, allowing for changing background color and simulate illumination, but two are the tools that were mainly used for this study:

- The Color Setting to change points color according to different characteristics, as: Elevation (Figure 4.a) – to underline heights and hollows; Intensity (Figure 4.b) – to show different density of points; RGB (Red, Green, Blue) – that shows the true colors of objects surveyed as sum of three fundamentals that are red, green and blue; Normal Direction (Figure 4.c) – the same color is associated to points that are on the same plane; Scan Location (Figure 4.d)– to discriminate points based on different origin scan files (it is possible to obtain one point cloud by different scans);
- The Selection Tools to define a point selection by means of a rectangular window, a closed polygon, a plane or a limit box.

These tools were used to identify the area strictly necessary to the modeling process, to cut the superfluous and making the model even more streamlined, optimizing at the same time the performance of the machine and the graphic rendering.



(**a**) (**b**) (**c**) (**d**)

Figure 4. Colorization options: (a) Elevation; (b) Intensity; (c) Normal; (d) Scan Location.

3.4. H-BIM modeling

H-BIM modeling was accomplished through a series of Autodesk codes, used in a synergistic and versatile way to optimize resources and results as shown in Figure 5.

The output point cloud of the Recap process was imported into Infraworks to make the mesh of an Digital Elevation Model (DEM). The output of this part of the process is represented by some three-dimensional polylines, which trace the DEM, i.e., the very heterogeneous road surface under study. These polylines have been transformed into Feature lines in Civil 3D, used as Baselines of the Corridor. At the same time, through Subassembly Composer, an extension of Civil 3D, a parametric section corresponding to that of the ancient Roman roads has been created. The association of this subassembly with the baselines has led to the production of the Corridor in Civil 3D, on which a 3D surface with custom material has been modeled. To the geometric model thus obtained, a series of information was added, a semantic content using Dynamo, another Civil 3D extension, which works through scripts in VPL-Visual Programming Language.

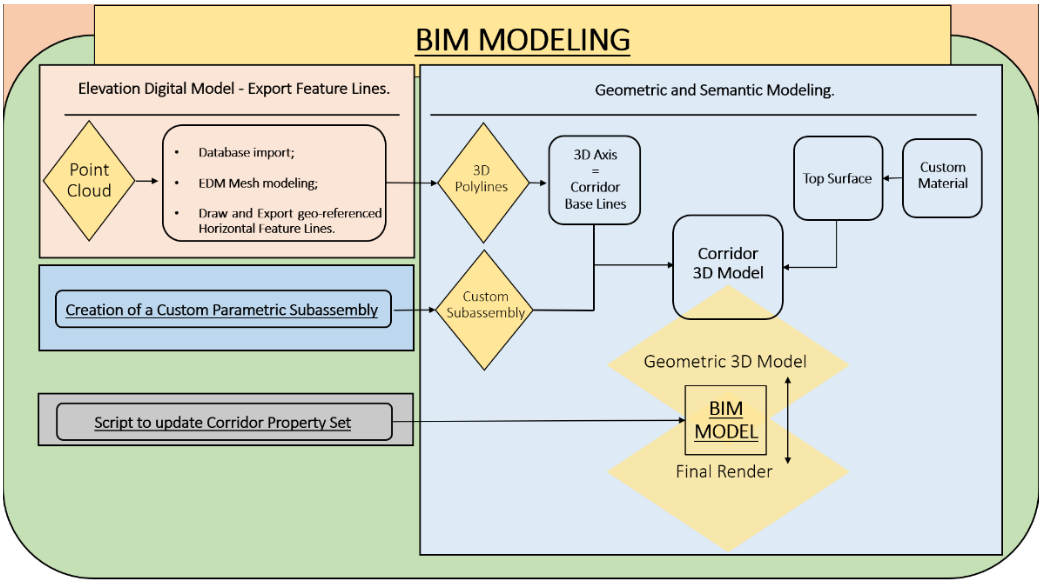


Figure 5. BIM Modeling Workflow.

3.4.1. Infraworks DEM creation

Recap Pro was also fundamental to ensure interoperability with other software used; indeed, it was used to convert the original file with PTX extension to a file with RCP extension, in order to import it in Autodesk Infraworks, a civil infrastructure design software that enables AEC professionals to model, analyze and visualize their projects in a real-world context of the built and natural environment, improving decision-making and project outcomes.

To start a new project within Infraworks, the geographical coordinate system must be set and, to work properly, it must be the same used in the georeferencing phase of the data surveyed. Infraworks allows Point Clouds import among several other file types, as AutoCAD dwg, 3D models, Revit file, etc. (Figure c). The dataset configuration consists in assigning a name, a description and again a geographical coordinate system: if the dataset is already georeferenced, the system will be automatically detected and suggested.

After the import process has been completed, Infraworks was used for the creation of an DEM. Usually, the concept of DEM can be overlapped to the concept of Digital Terrain Model (DTM), since a common procedure within point clouds use is to import in Infraworks a topographic survey. In this case, the DEM represents a surface adherent to the archaeological pavement under study.

In this step were defined the processing rules, i.e., the level of detail of the terrain, the linear and the vertical features to be associated to the process, as well as some options related to the resulting model, i.e., the weight of the DEM, the overwriting of the DEM on the point cloud, the export of the file at the end of the process.

The next step was to extract linear features from the resulting DEM: from the Manage tab and Point Clouds menu, the option *"Linear Feature Extraction"* was used to manually draw characteristic lines directly on the DEM surface in correspondence of road axis, road margins, and sidewalk edges, in order to coordinate horizontal and vertical information.

Then, they were exported in a SHP file format, by means of the option "*Export Point Cloud*": this allows for the extraction of data related to lines drawn, in particular the X, Y and Z, coordinates of the lines' vertices, that correspond to Latitude, Longitude, Altitude.

In this way, 3D and geo-referenced feature lines were obtained, ready to be imported into a BIM modeling tool, such as Autodesk Civil 3D. These feature lines were the base to develop the H-BIM model itself.

3.4.2. Subassembly Composer custom subassembly modeling

Civil 3D has a well-stocked default library of structural and functional elements, but the assembly of the ancient Roman road does not correspond to any of those available, since these ones follow principles and materials of modern conception, so it was necessary to build it from scratch using Subassembly Composer that is automatically bundled with the Civil 3D license and is an extremely useful tool for customizing typological road sections.

The Subassembly Composer user interface (Figure 6) has five different areas:

1. Tool Box - to enter the basic elements of the new geometry, i.e., points, links, and shapes, and to define more advanced geometric elements such as curves and intersection points;
2. *Flowchart* - the visual programming workflow, where the various elements are logically connected to each other;
3. *Properties* - to view and edit the properties of the elements/nodes included in the flowchart;
4. *Preview* – to visualize the result of what has been produced through the flowchart;
5. An area to define: *Packet Settings*, i.e. the general settings, such as name, description and image to be used as preview of the subassembly once imported into Civil 3D; *Input/Output Parameters*, to define in detail the various parameters to be associated within the geometric elements constituting the new typological section, being able to choose between various types of input, such as double (double-digit precision numbers), string (text), grade (percentages), etc.; *Target Parameters*, i.e. target parameters for one or more points, such as planimetric and altimetric quotas or surfaces; *Superelevation*, to guarantee the possibility for the road surface to modify the transversal slope, i.e. the rotation of the edges in accordance with the curvature radii followed by the axis.

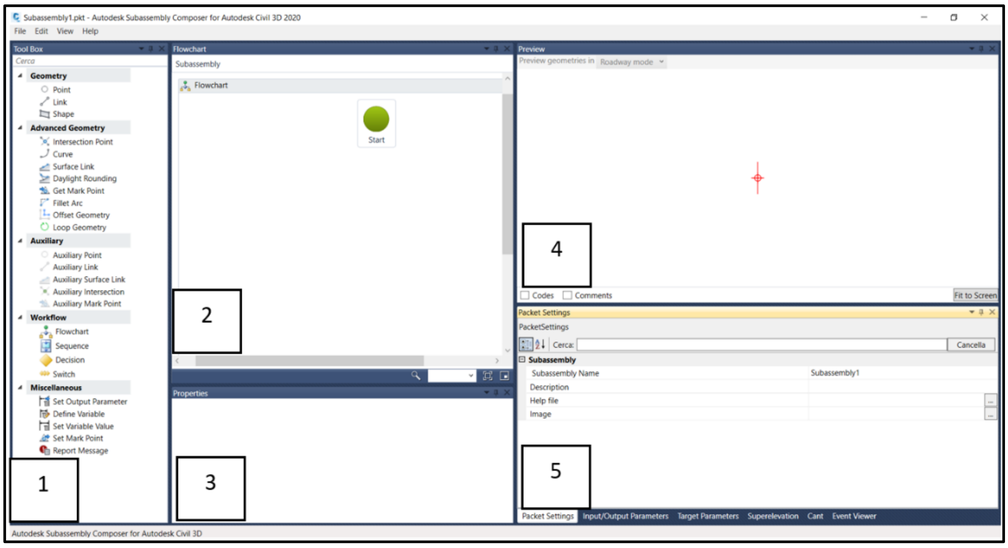


Figure 6. Subassembly Composer User Interface.

To create the geometry, one must proceed by selecting from the Tool Box the necessary elements, i.e. nodes, connections and surfaces enclosed by them, and add them to the working scheme on the Flowchart screen through a drag&drop operation. The position of the points in the section plane can be set from an initial point, by default the origin, by means of Delta-X and Delta-Y, or by imposing a slope combined to a Delta-X or a Delta-Y. Links are defined by indicating the starting and ending nodes. Shapes are defined by indicating the links that constitute their edges. For each element, point, link or shape, it is possible to associate a code, which is of vital importance for subsequent operations in Civil 3D, that happens to be a strongly hard-coded software. As the geometry is formed, the preview of what has been coded is obtained. By defining parameters in the Input/Output Parameters section, it has been possible to use them to characterize the geometry and thus make the section parametric. For example, by defining the "width" parameter, encoded as “LaneWidth” since, as mentioned, Civil 3D is strongly hard-coded, this can be used to define the distance between two points within the geometry (the Delta-X or Delta-Y mentioned previously). In the same way it is possible to define parameters such as the material and its characteristics, through string type parameters, or the cross slope through the “CrossSlope” parameter of grade type, or percentage.

Due to the peculiar conformation of the infrastructure and the variable horizontal-vertical trend of the three-dimensional polygonal lines used as reference, it is essential to set targets among the other parameters of the typological section itself.

Once the subassembly is ready, it is saved in .ptk format, a kind of compressed file that contains all the information related to the Subassembly Composer process. Then, it can be imported in Civil 3D and used to complete the corridor modeling.

3.4.3. Civil 3D Corridor modeling

The 3D model of the road can be obtained using Civil 3D. Usually, the corridor is obtained by extruding an assembly along an alignment, drawn on a topographic surface and made three-dimensional by the coordination with a design profile. In this case, the three-dimensional axes were obtained by importing into Civil 3D the work done previously within Infraworks. At the end of import operations, 3D polylines with associate d spatial definition properties were generated as shown in Figure 7.

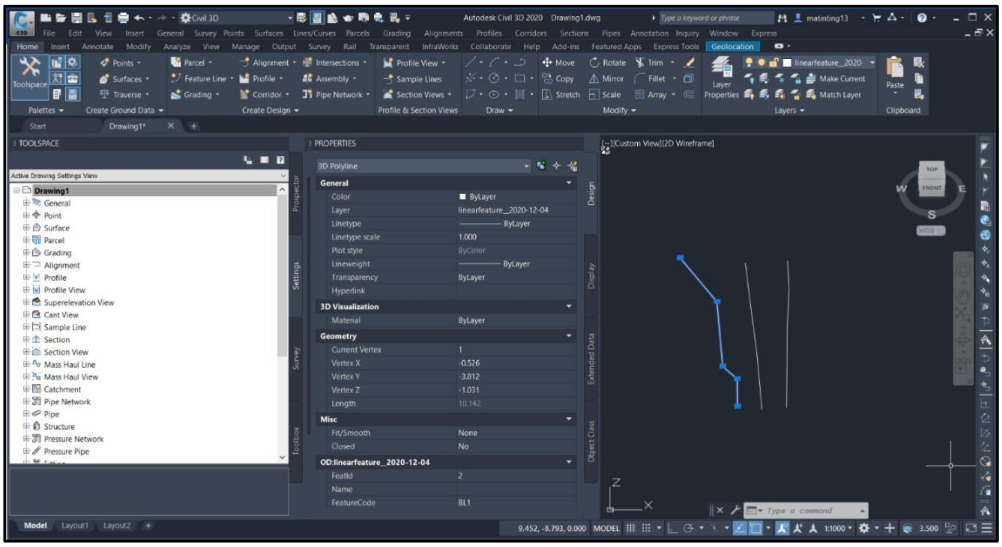


Figure 7. 3D Polylines Properties Visualization.

The next step was to create the corridor, converting 3D polylines into feature lines (“*Create Feature Lines from Objects*”) and then, associate a section type (“*Create Assembly*”) setting the target types as *"Width or Offset "* or "*Slope or Elevation* ".

Once the corridor has been created, it can be dispalyed on the drawing or within the *Object Viewer mode* as shown in Figure 8.

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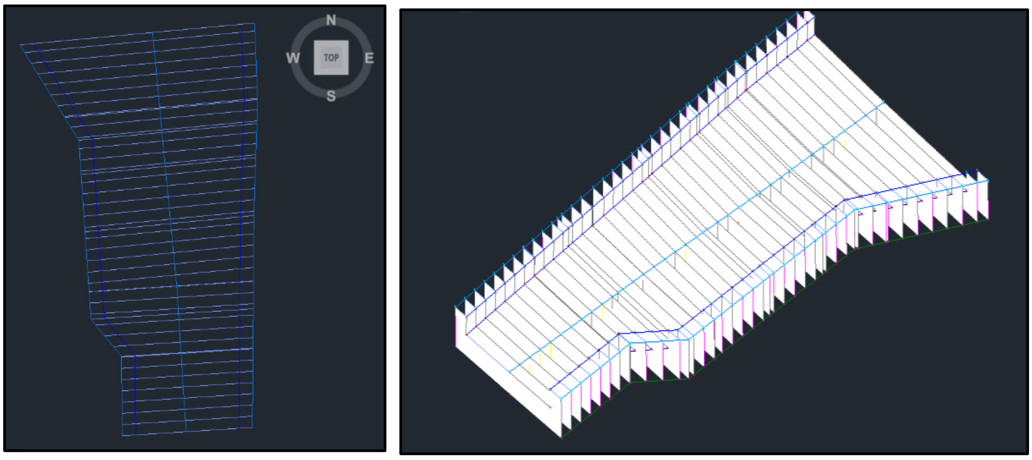

(a) (b)

Figure 8. Corridor visualization: (a) Drawing view; (b) Object Viewer mode.

To complete the corridor model, two more fundamental operations are needed, i.e. to build the extrusion surfaces and finally to assign materials for the render characterization.

The creation of surfaces is not free from common problems and errors. Often the triangulation does not perfectly follow the indicated links, because the sides of the triangles are produced with all possible combinations, giving a first problem of redundancy of the lines, and at the same time following the criterion of the minimum distance, going to cut the corners. This feature can lead to two types of errors:

1. the lines cut the curves of the axis, going to fill the concavities that should instead remain empty. The first error can be fixed by setting some *Boundaries* to the surface;
2. the lines do not slavishly follow the links, but cut the 3D space to make the minimum path. The second error is a so-called "Overhang error", i.e., the lines extend outside the appropriate planes of belonging; it is fixed by means of the "*Overhang Correction*".

The Corridor represents the geometric frame on which the structure of the BIM model is supported. In order to add informative content to the Corridor, it is possible to use the so-called "*property sets*", which are sets of various types of information that can be customized by the designer. The property set can be created from scratch, manually, in Civil 3D, or it can be imported from an external file, for example from an Excel csv. It is also possible to perform various operations on property sets through Dynamo, such as creation, import, update and export.

In this application, a property set was manually created manually in Civil 3D by the "*Define Propery Sets*" tab. Four different Property Set were created, each one matching a supposed layer of the roman road, namely: Nucleus, Rudus, Stratumen, Summa Crusta. For each Property Set the general properties are set , and it has to be defined to which kind of objects it will be attached, in this case *Solid (3D)*, and finally the characteristics are set one by one, being added by the items on the right vertical toolbar. The properties added were basically the material properties, such as shear modulus and density.

3.4.4. Infraworks rendering

The Civil 3D model was exported and reimported in Infraworks in order to visualize renders.

Before importing it, it is necessary to access to the "*coverage areas rule editing*" by entering the "*style rules*" menu that can be used to control the appearance of coverage areas; rather than using the defaults, a custom coverage area style rule was created and thus the default rules were deleted first.

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When importing a Civil 3D dwg, a dialogue window allows the data and objects selection to import; in this case, Top Surface and Materials were imported.

3.5. Algorithm scripting through Visual Programming Language environment within Dynamo.

Last, a Dynamo script was developed to update the Property Set attached to the Corridor Model. Dynamo is based on VPLE (Visual Programming Language Environment), that consist in a logic graph, which nodes represent *functions* that have inputs and outputs. Output of a node can be used as input for other nodes. Nodes are connected by means of links. Nodes can be selected among hundreds contained in the *Dynamo Nodes Library*. Since Dynamo is open to its community designers, there are several expansions to the default library, indeed everybody can create customized nodes for personal use or to publish them. In addition, functions can be developed by using Python language to customize nodes or merge more nodes in one.

The script developed for this case study is as essential as it is effective (Figure 9): the main operational process is led by the *Object.UpdateProperty* node that updates properties of the Property Set attached to an object. As inputs, the user must indicate the object, the Property Set name, the names of the properties to be updated and the values to update them with. The object was directly extracted by the current Civil file indicating name of the object ("Corridor") and name of the Property Set ("Summa Crusta"). Properties Names can be indicated with strings, manually introduced by means of the *string node*, and values can by indicated by means of the *block node*; in this case, names and values were imported from a .CSV formatted file, where first line provided the names and second one provided values.

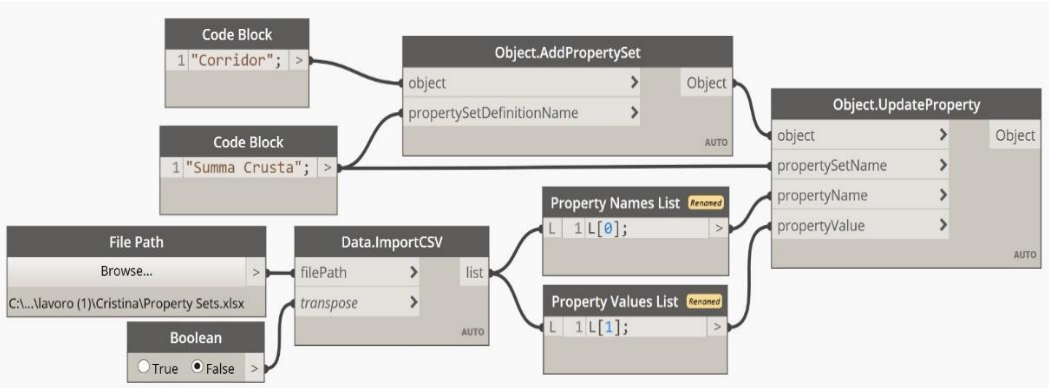


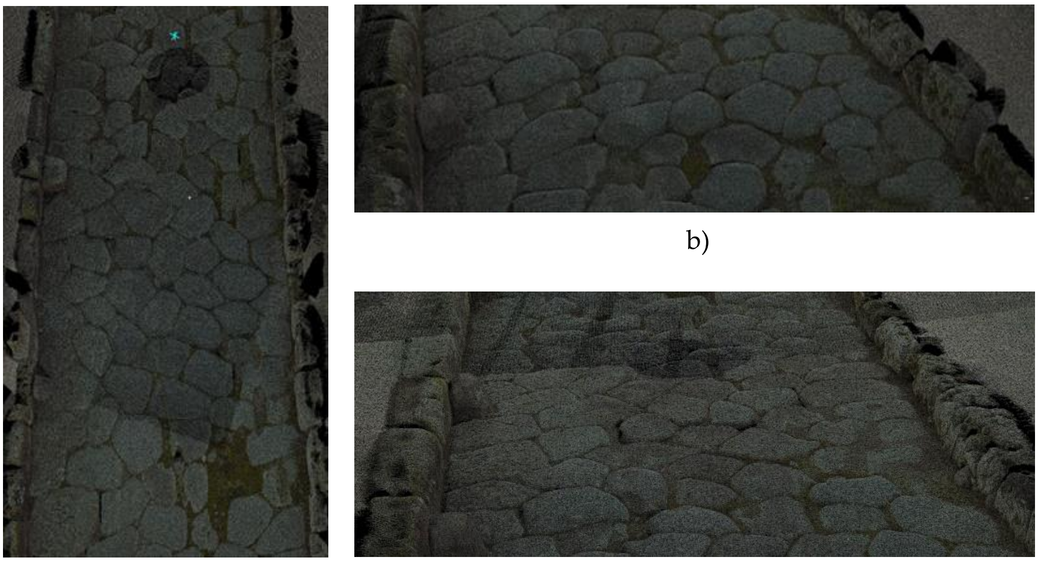
Figure 9. Dynamo Visual Script to update Corridor properties.

4 Results

4.1. Database managing and Point Cloud editing.

4.1.1. Cyclone database managing.

In this research work, Leica Cyclone was used to manage a geographic database, i.e., a large amount of data collected in the field using a Terrestrial Laser Scanner. In Cyclone, the point cloud is shown at a very high level of definition; color gradients, the slightest depressions and differences in level can be easily appreciated and one can get an idea of the degree of macro roughness of the paved surface (Figure 10). These features make it a fantastic tool for visualization and project orientational exploration.



a) b) c)

Figure 10. Cyclone Point Cloud visualization: (a) Top view. (b) Front view. (c) Back view.

4.1.2. Recap Pro point cloud editing

Recap Pro was subsequently used to modify the original point cloud, in order to make it lighter and more manageable (Figure 11), and for reasons of interoperability with other software used in the following phases of the workflow. It is a software that has a steep learning curve associated with it, providing effective editing and visualization tools.

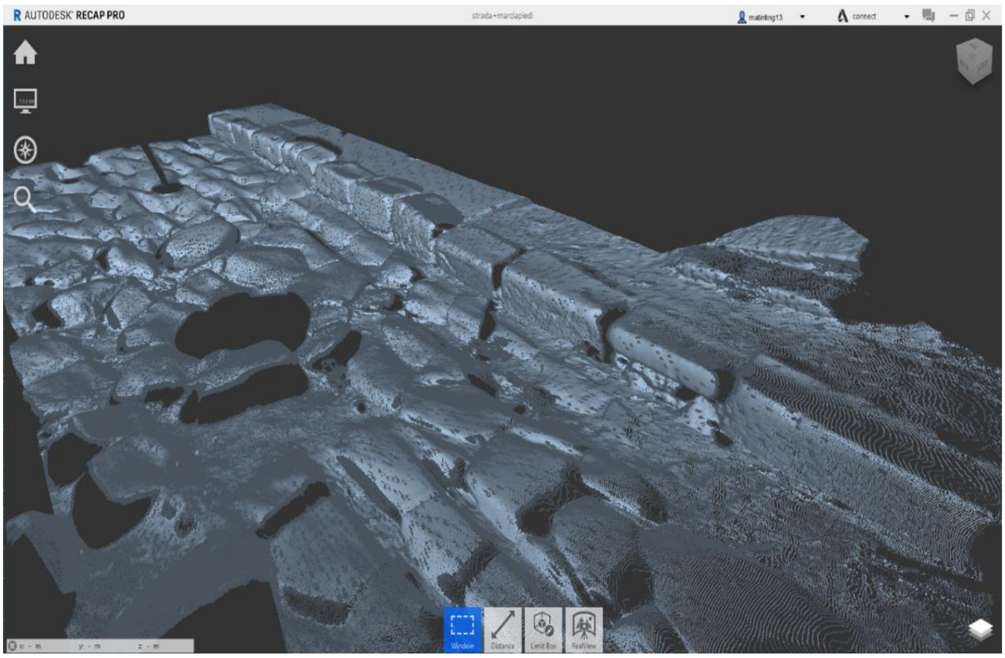


Figure 11. Point Cloud edited in Recap Pro.

4.2. H-BIM modeling

After the collection and processing phases of the survey data, the workflow was developed on a group of software used synergistically to obtain a model in a BIM environment.

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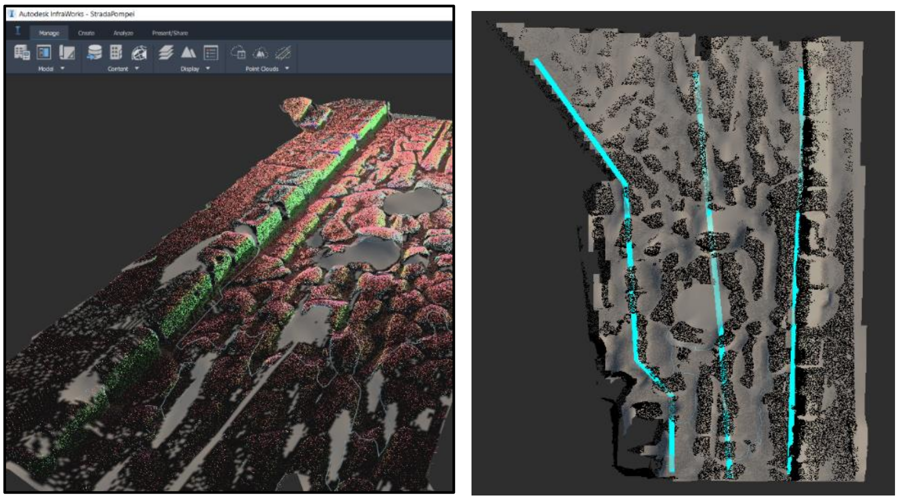
4.2.1. Infraworks DEM modeling and feature lines extraction

After being processed within Recap, the Point Cloud file was exported in RCP formatted file thus to be imported into Infraworks (Figure 12.a) and an DEM was developed. Feature lines were drawn on the DEM (Figure 12.b) and data related to the coordinates of their vertices were extracted. The use of Infraworks in this phase was essential to maintain the geo-referencing of the project and to not increase the computational weight of the file used.



a) b)

Figure 12. Infraworks: (a) DEM tracing the Point Cloud imported; (b) Feature Lines drawn over the DEM.

4.2.2. Subassembly Composer custom subassembly modeling

Subassembly Composer, on the other hand, was fundamental for the next phase, in which the BIM model was created using Civil 3D in accordance with the coordinates previously obtained through the work done in Infraworks.

In fact, Subassembly Composer is an extension of Civil 3D for the customization of typological sections, and Civil 3D was used to create the 3D model of the infrastructure, operation that is based on the extrusion of a typological section along a 3D axis.

The tools made available by Subassembly Composer were exploited to create a typological section shown in Figure 13 that was as consistent as possible with the studies carried out on the typological section of urban Roman roads. Moreover, the use of this tool has been fundamental for the definition of parameters characterizing the section itself. Among these, a logical-geometric parameter is that of the "targets" which has allowed to adapt the section to the horizontal-vertical alignment of the three-dimensional axes imported in Civil 3D and previously produced in Infraworks which precisely follow the trend of the DEM and therefore the data obtained from the Laser Scanner survey.

This is an element of unquestionable innovative value that demonstrates how the reverse engineering technique can be applied to infrastructural elements of complex and non-standardized geometry.

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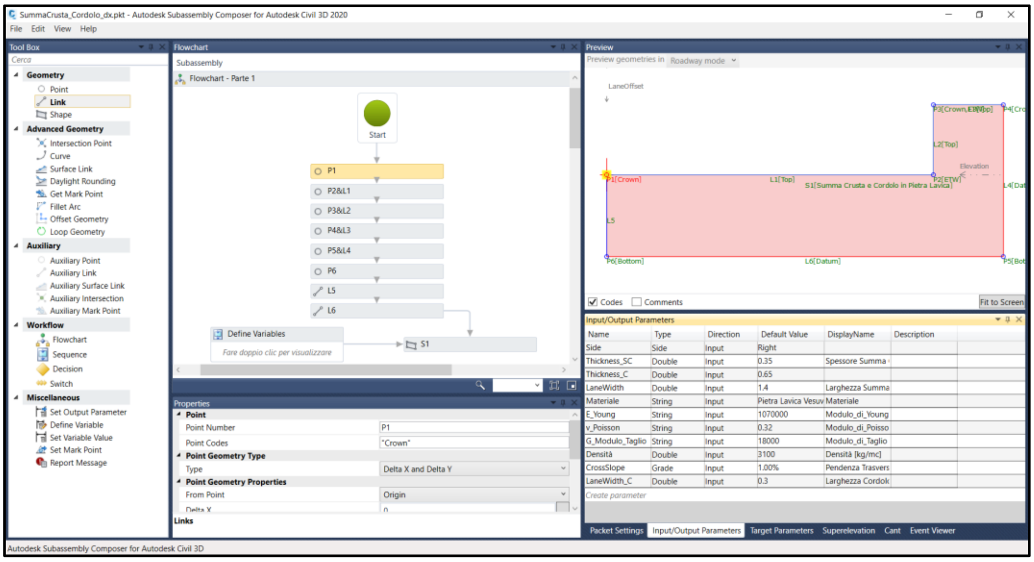
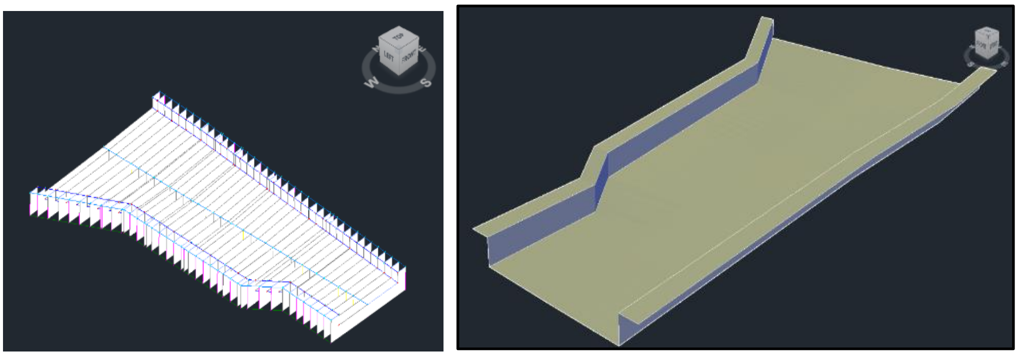


Figure 13. Subassembly Composer geometric typological section design.

4.2.3. Civil 3D Corridor modeling

Once the process was completed in Subassembly Composer, it was possible to complete the construction of the 3D model in Civil 3D, extruding the customized typological section along the three-dimensional line corresponding to the central axis of the road and adapting the horizontal-vertical alignment to that of all three 3D lines imported from the previous work carried out in Infraworks for the geographical orientation of the surveyed data (Figure 14.a.). A top surface was then modeled on the corridor thus formed, to which a custom material corresponding to Vesuvian lava stone was associated (Figure 14.b).



a) b)

Figure 14. Civil 3D Object viewer mode: (a) Corridor. (b)Surface.

A BIM project is characterized by the association of technical information with a three-dimensional geometric model.

For this reason, the BIM model has been completed with the creation of a Property Set that reports the information related to the mechanical behavior of Vesuvius Lava Stone [28] and that can be viewed in the corridor properties in the section *extended data* (Figure 15).

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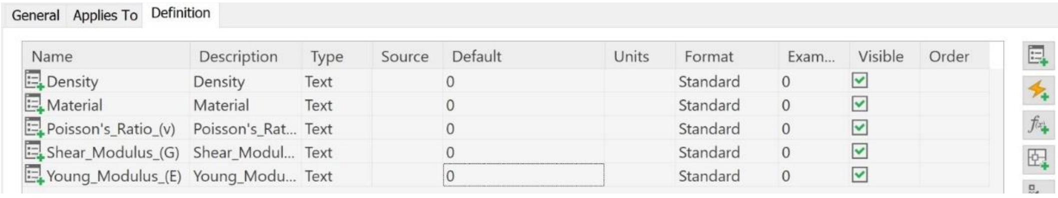
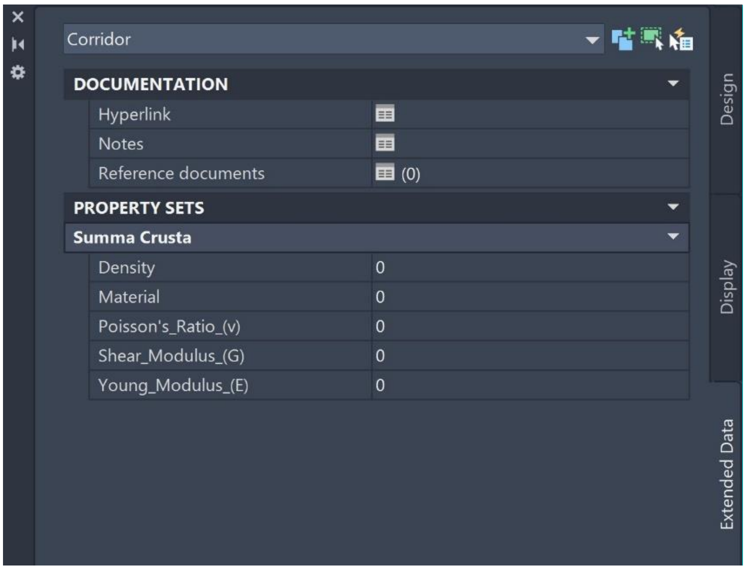


a)



b)

Figure 15. Property Set: (a) Parameters Definition. (b) Property Set visualization in Corridor's Properties Extended Data.

4.2.4. Infraworks rendering.

The model was then imported in Infraworks, used again for a second phase purpose, i.e., the final graphical rendering. The characteristics of the Vesuvius Lava Stone were imported in Infraworks' Project and a new material was customized and then associated to the BIM model (Figure 16).

Figure 16. Infraworks rendering.

4.3. Algorithm scripting through Visual Programming Language environment within Dynamo.

Dynamo is another Civil 3D extension that implements the computational design technique, which relies on the use of scripts to automate operations to support the design. Dynamo provides the ability to generate parametric geometry and edit its characteristics

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and properties. It is also a useful tool for database management and collaboration between multiple Autodesk applications.

In this case study, Dynamo was used to fill in the empty Property Set created in Civil 3D with data imported from a .CSV file as shown in Figure 17.

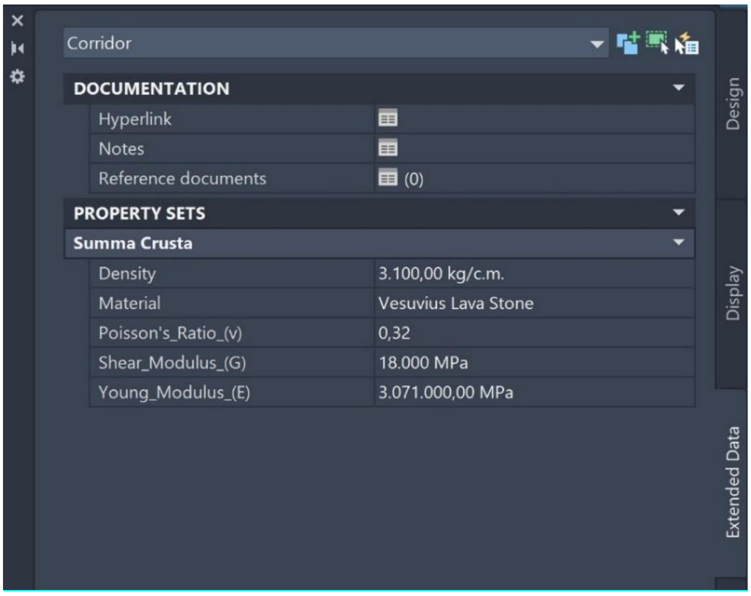

Figure 17. Property Set visualization in Corridor's Properties Extended Data Civil 3D section updated by means of Dynamo script.

5. Discussion

The results obtained showed the goodness and effectiveness of the workflow set up. The implemented methodology allows to manage and process the data collected during the survey phase in a smart and effective way. The use of the latest technologies of topographic survey, has allowed for the accumulation of a huge database consisting of point clouds defined by millions of points.

Leica Cyclone software has been critical to the management of this database and its geo-referencing. The subsequent use of Autodesk applications for the creation and management of projects in BIM environment has allowed the processing of data and the obtaining of a BIM model representative of what was surveyed in the field.

Recap Pro proved to be the perfect bridge between the Cyclone's improved visualization and exploration performance of captured data, and the start of geometric modeling operations to support the BIM modeling.

Civil 3D and Infraworks are industry-leading tools for delivering infrastructure projects; it is much rarer to find applications in H-BIM and even less so in archaeology. In this, the work described in this research is completely innovative, and the features of these software, conceived to optimize the infrastructural design from scratch, have been exploited for the reproduction of unique artifacts with an immense historical and cultural value, being part of an important UNESCO archaeological site such as Pompeii.

The possibilities offered by the integration between the tools for writing calculation codes have been exploited using Dynamo - which leverages the visual programming environment to open the doors of the programming world to the widest possible user base - to manage the semantic heritage of the created BIM model, ensuring the possibility of updating its content from external databases and surveys of architectural, structural, geotechnical type.

6. Conclusions

In this research work, software tools were leveraged to apply techniques and methodologies that have previously been successful for infrastructure projects. The desire to find workflows that are functional to the process of reverse engineering of existing artifacts is not new, but being able to coordinate technologies and software designed for the BIM approach for linear infrastructures, where the BIM methodology is widely used in architecture and new projects, and less so in maintenance operations and even less so in infrastructure, is an ambitious goal, and this research was able to take another small step in the right direction to achieve it, including the results obtained in the broader context of historical and cultural heritage conservation, creating a precedent for the application of Heritage-BIM to archaeological heritage, declining BIM to what could be called Archaeological-BIM.

The research should go further in the direction of digitalization of Europe's immense cultural heritage, strengthening the knowledge of processes and methodologies that make the analysis for the conservation of the architectural-infrastructural heritage more effective and simpler, with a focus on stone paved roads – which constitute the most of historical roads in urban centers.

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