Stone Paved Road Digital Reproduction: A Workflow

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Abstract. The growing necessity to design and digitally represent historical pavements has led specialists to use different Building Information Modelling (BIM) tools to control the road design and construction phases. In this research paper, a Heritage BIM (H-BIM) approach was developed to recreate an archaeological road to accomplish the structural analysis of stone pavements. In detail, starting from the Digital Elevation Model (DEM) generated with Autodesk Infraworks, the road design process was performed. The corridor was modelled with Autodesk Civil 3D using a parametric road section created with the Subassembly composer tool. Subsequently, a visual programming application (Dynamo) based on Python language was adopted to extract corridor information (such as areas, volumes, subassembly parameters) and apply changes based on conditions established through code scripts. In detail, a workflow was developed to implements a disruption analysis of road stone pavements. As preliminary results, a tool is proposed to support the authorities and experts during the managing process.

Keywords: Heritage-BIM · Stone paved road · Procedural Modelling · Point Cloud

1 Introduction

The continuous search for new methods and approaches for increasing process efficiency in the AEC industry (Architecture, Engineering and Construction) has found in digitisation and computerisation an effective answer for the reduction of costs and production times issues.

BIM is defined as a process involving the generation and management of digital representation of a facility's physical and functional characteristics [1]. It is now recognised as the most appropriate methodology to undertake building and infrastructure projects [2, 3], having revolutionised the field of architecture and construction

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for some years now [4], being both a technology and a methodology [5]. Although 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 states of the EU [6].

The immense road heritage of European stone road pavements, starting from the Italian capital city, has never been the subject of wide-ranging policies aimed at enhancing recent times. The reconstruction of models managed in BIM tools can help the conservation of cultural heritage. Therefore, BIM has been declined in the so-called Heritage-BIM (H-BIM). It is defined as "a new way of modelling 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].

Therefore, along with the consolidated experience in the architectural field [8–10], it has been proven that H-BIM is suitable also for infrastructures. Most of the historical urban areas in western countries are paved with stone elements [11], and Italy has one of the highest numbers of UNESCO Heritage sites, as the case of the Via Duomo in Naples [12].

H-BIM approach needs cutting-edge technologies, such as VR (Virtual Reality) [13] and UAV (Unmanned Aerial Vehicle) photogrammetry. The latter is an intelligent survey technology that can be used to automatically detect stone pavement's patterns [14, 15]. It was used effectively to the production of the 3D H-BIM for archaeological excavations in Hierapolis in Phrygia, Turkey [16], and Via del Vesuvio in Pompeii, Italy [17].

This research study aims to define a new approach to use the H-BIM methodology for the analysis and the management processes of archaeological sites focusing on the study of a stone pavement road located in Pompeii. The case study involves the terminal part of Via Stabiana on Porta di Stabia in the Archaeological Site of Pompeii. The paved area is 12 m long with a 5.20% average slope, that guarantees the outflow of the rainwater into an underground canal on the right side (North-South direction) and then outside the walls thanks to a change in the road's cross inclination.

The main idea of this work is to integrate archaeology and BIM, offering archaeological heritage protection agencies an innovative management and archiving tool. The proposed methodology, which will be discussed below, represents an element of novelty in the current panorama. It is the integration of engineering, digitisation and archaeology and poses a starting point for important questions about the possibility of studying the deep layers of the archaeological road infrastructure. This would help the investigation of the past construction techniques allowing for analysing their differences and similarities with present ones.

Since any H-BIM application should include an informed preliminary analysis of construction criteria, previous research works have been investigated to obtain an in-depth picture of knowledge on the case study, such as for Roman road building technologies and practices [18] and their design criteria [19]. Particularly significant is the study conducted in the archaeological site of Pompeii by Poehler and Crowther [20] on the paving techniques hypothesised from the surveys carried out.

2 Methodology

The pivotal methodology shown in Fig. 1 is the so-called Scan-to-BIM, which allows for the generation of a 3D BIM model from a point cloud [21, 22], involving two main work phases: 3D surveying through Laser Scanner processing the information surveyed with several BIM authoring software.

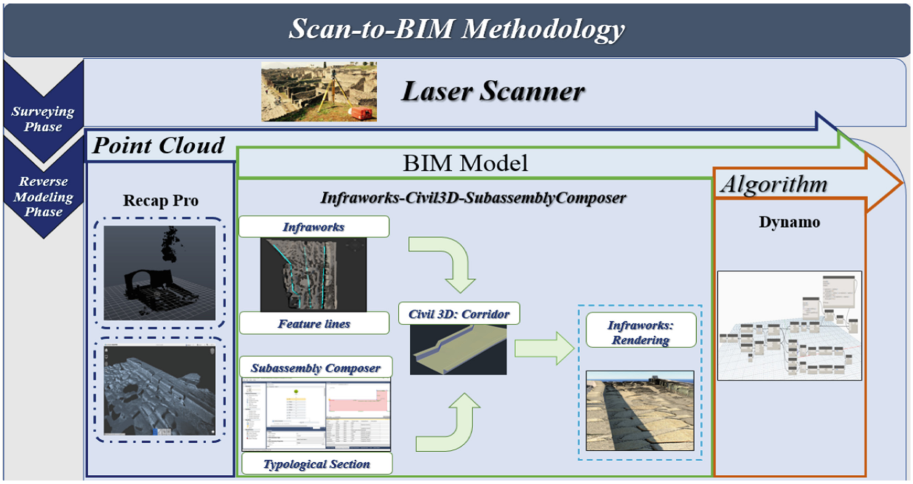

Fig. 1. Methodology workflow.

2.1 Scan-To-BIM Surveying Phase

The surveying phase of the Scan-to-BIM process relies on Laser Scanners technology. Electro-optical instruments are capable of surveying the surface of any object by mapping points in 3D. A Leica RTC360 model Laser Scanner has been used for the present work: it 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 was performed in one minute and 50 s, obtaining a point cloud composed of 2 million 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 concerning 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. These coordinates were georeferenced through the parallel use of a GPS detection system to record the scanner's position at the time of scanning in a Gauss-Boaga system.

2.2 Scan-To-BIM Reverse Modelling Phase

The information thus obtained represents raw data, requiring a subsequent "reverse engineering" process that consisted of creating a 3D model shaping its surfaces on the points of the point cloud. 3D surfaces are generally divided into two main categories: (i) NURBS (Non-Uniform Rational Basis-Splines); (ii) Polygonal Meshes. In the first case, surfaces are defined by mathematical equations, very precise and stable. The latter are easier to model but they are highly dependent on the degree of simplification of the mesh itself usually providing rougher images compared to Nurbs ones. The final step of 3D modelling was the assignment of textures to Mesh surfaces using as a source of customised texture photographic images taken during the survey to obtain 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 also using tools able to develop semi-automatic algorithms.

2.3 Tools for the Modelling Phase

Autodesk BIM-based tools were used as tools to ensure 100% interoperability and the perfect success of the Scan-to-BIM methodology just described: (i) Recap Pro, for surveying 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 customised typological road section with its add-on Subassembly Composer and develop algorithms by mean of its add-on Dynamo.

After the laser scanner-based survey, the starting point of the subsequent modelling phase was a point cloud in PTX format. This is an ASCII based format for saving point cloud data, that associates each point with 4 (X, Y, Z, intensity) to 7 values depending on whether there is colour information (RGB - Red Green Blue). Colourization and illumination tools were used to identify the parts of the cloud considered of interest, i.e., the road pavement. Normal and Elevation colourations were used to identify all those undesirable vertical elements, and Selection Tools were used to delete them, resulting in a lighter point cloud.

Recap Pro was also fundamental to ensure interoperability with other software used. Indeed, it was used to convert the original file format from PTX to RCP in order to import it in Autodesk Infraworks. Infraworks is a civil infrastructure design software that enables AEC professionals to model, analyse and visualise their projects in a real-world context, improving decision-making and project outcomes. In the first phase of the work, Infraworks was used for the DEM creation, that is, the model of the Elevation of a surface compared to a plan of referment. In this case, DEM represents a surface adherent to the archaeological pavement under study. Characteristic lines have been drawn on this surface at the road axis, road margins, and sidewalk edges to coordinate horizontal and vertical information. Then, they were exported in an SHP file format, extracting the spatial coordinates of the vertexes by which they are defined. In this way, 3D and georeferenced feature lines were obtained, ready to be imported into a BIM modelling tool, such as Autodesk Civil 3D. These feature lines are the base to develop the BIM model itself.

The 3D model of the road was obtained using Civil 3D. Usually, the corridor representing the infrastructure is obtained by extruding an assembly along an alignment, drawn on a topographic surface, made three-dimensional by the coordination with a design profile. In this application, the three-dimensional axis was obtained simply by importing into Civil 3D what has been produced with the work done previously with Recap Pro and Infraworks, that is, the characteristic lines consistent with the information reported by the point cloud.

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 customising typological road sections. To create the geometry, one must proceed by selecting from the Toolbox 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, one can then use them to characterise the geometry and thus make the section parametric. Due to the 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.

Two other steps are needed to complete the corridor: build the extrusion surfaces and finally assign materials to characterise the render. It is possible to create the corridor surfaces through the Corridor Properties panel, click on Surfaces, and then specify the referment code; in this case, links defined in the assembly were used. Surfaces are created by triangulation – Mesh – using the vertexes of the links used as referment codes. Some errors and inaccuracies occurred but then these were fixed manually. Regarding the texture, it must reflect the component material of the 3D object to which it refers. Meta-data about materials are already contained in the parameters assigned to the section during the creation process with Subassembly Composer, but to give a visually appreciable result, it was chosen to customise a material-texture in Infraworks through photographic evidence taken during the survey.

Once the H-BIM model was obtained, Dynamo, an add-on of Civil 3D useful for creating an algorithm to automatise and speed up any process, was used to query the BIM model itself and develop side operations. The programming environment is a VPL - Visual Programming Language - that is based on the construction of a graph, in which the nodes are the elements of the logical content of the algorithm and the arrows connect them in input-output relationships. Moreover, the Dynamo feature for the creation of custom nodes by writing scripts in Python language was exploited to write an algorithm able to read the elevations of the profile of the characteristic baselines of the corridor. Further operations were developed in the script for the calculation of the local and total deviations between the linear interpolation of the elevations and the elevations themselves, in order to obtain an index designed to highlight the state of instability and irregularity of the pavement, useful information in order to plan the accessibility of weak users, with walking difficulties or other special needs, to the archaeological site.

3 Results and Discussion

Starting from the georeferenced point cloud obtained by Laser Scanner, the use of Autodesk Recap Pro allowed resizing the cloud itself by selecting the specific area of interest (Fig. 2a), resulting in an effective procedure for data manipulation (Fig. 2b). Brought from PTX format to RCP format, the point cloud file has been imported into Autodesk Infraworks, where DEM was obtained, i.e., a mesh surface consisting of the sum of the many triangles' surfaces vertices correspond to the points on the cloud.

Usually, the concept of DEM can be overlapped to DTM, especially when using Infraworks which helps the engineer to contextualise the work by dropping it in its territorial context. This time, the DEM faithfully depicted an already built surface, but a very irregular one, given the archaeological nature of the stone road under study.

Based on the paved road DEM, three feature lines (Fig. 2c, cyan colour) have been drawn. Afterwards, the spatial information has been extracted from the feature lines and imported in Civil 3D. Here the actual 3D model has been created: first the typological road section was created using Subassembly Composer Civil 3D add-on and then it was extruded along the feature lines previously imported from Infraworks (Fig. 2d). In this step, there is another element of innovation: where usually for the creation of the three-dimensional model of the road infrastructure Civil 3D requires a topographical surface on which to draw the alignment, having made the operations previously described on Infraworks, it was possible to realise the corridor using the spatial information obtained directly from the point cloud, i.e., from the survey of the existing artefact. The final render of the 3D model was then created by means of Infraworks using a customised texture (Fig. 2e). The H-BIM model obtained was then used to operate side automatised operations through Civil 3D add-on Dynamo, which allows for coding in VPL based on Python Language (Fig. 2f). The algorithm reads the elevation information of the H-BIM model, and after calculating a coefficient of disruption and irregularity of the pavement, it associates different levels of risk and practicability of the road stretch itself.

The uniqueness of the archaeological context is a major issue of the whole procedure since the software used have been conceived for the realisation of new structures whose typical feature is seriality and repetition. Therefore, it was necessary to adapt the available tools to the need to create unique three-dimensional elements to be inserted into a complex BIM paradigm composed of a multiplicity of these elements. This case study was an attempt to take another step forward in this direction, integrating established approaches with innovative modelling and scripting methods.

To conclude, the integration of advanced technological instrumentation, BIM software and innovative digitisation methodologies constitue a technical tool to produce the H-BIM of an archaeological reality. The model's core is the fidelity to the reality detected in the field and its purpose is flexible at user needs.

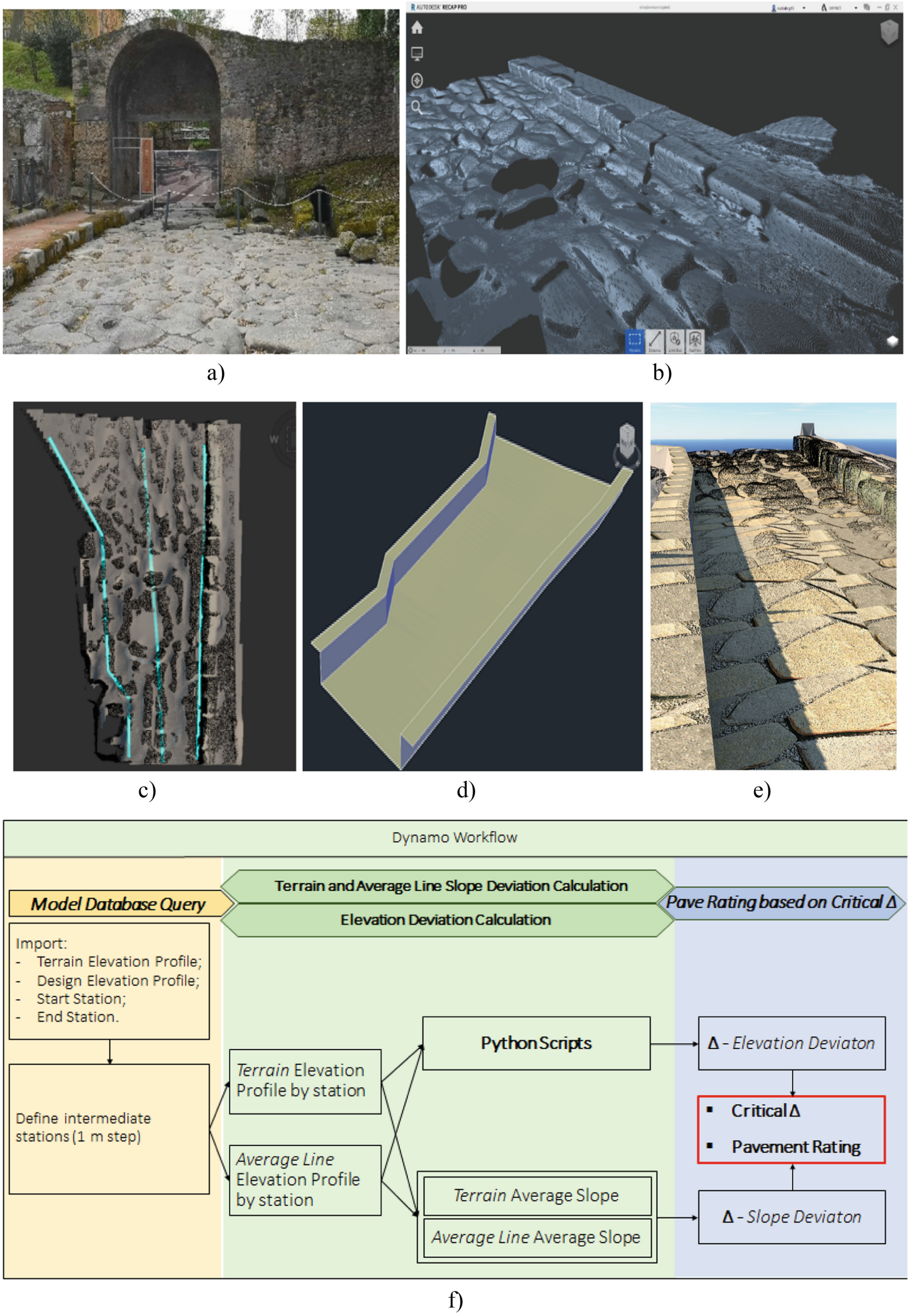

Fig. 2. Results: a) case study location; b) RCP output c) Infraworks EDM output; d) Civil 3D corridor output; e) Infraworks render; e) Dynamo algorithm in VPL.

4 Conclusion

The research paper has shown how the use of specific methodologies allows accurate detection of the geometric elements and their state of preservation for further evaluations for planning and managing maintenance treatments in the field of archaeological sites.

To date, the Scan-to-BIM methodology can be recommended for H-BIM digital reproduction, proving important advantages.

In fact, the use of laser scanner allows for (i) more precise surveys of the artefact than traditional techniques ones; (ii) collection of data in the form of a point cloud in a single file or in multiple files that can be merged in one, easing data managing; (iii) integration with GPS systems that ease georeferencing data collected; (iv) fastening the survey itself and therefore it can be repeated more times in the same day if needed.

Also, digital data of point cloud allows for BIM approach implementation to design and managing processes, lowering the overall costs.

Finally, it allows the integration between the use of industry-leading software and coding skills to automate queries and computational operations.

Some critical issues also emerged during this research work, represented by the difficulty of perfectly matching the 3D H-BIM model and the surveyed archaeological artefact. Therefore, it is desirable to further develop research in this direction, trying to use a more versatile and perhaps open-source 3D modelling BIM-based tool.

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