European Transport \ Trasporti Europei (2023) Issue 91, Paper n° 8, ISSN 1825-3997

https://doi.org/10.48295/ET.2023.91.8

Heritage BIM Approach for roman pavements

Salvatore Antonio Biancardo[1*], Mattia Intignano[1], Diego Menegusso Pires[1], Francesco Abbondati[2], Gianluca Dell'Acqua[1]

[1]Department of Civil, Construction and Environmental Engineering, University of Naples Federico II, Via Claudio 21, Naples 80125, Italy
[2]Department of Engineering, University of Naples Parthenope, Centro Direzionale Isola C4 Naples 80143, Italy

Abstract

The growing necessity to design and digitally representation of historical pavements has led the 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 disruption analysis of stone pavements. In detail, within Autodesk Infraworks the conceptual model of the road and the digital terrain model (DTM) was generated; then the road corridor design process was performed within Autodesk Civil 3D using a parametric road section which was created by means of Subassembly composer, a Civil 3D extension. Subsequently, a visual programming application, Dynamo, based on Python language, was adopted to extract and update corridor information. In detail, a workflow was developed to implement a disruption analysis of road stone pavements and the output of the calculation were inserted in the model. As preliminary results, a tool is proposed to support the authorities and experts during the managing processes.

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

1. Introduction

Ancient Romans built roads following the paths and the routes already present (Albenga, 1918; Forbes, 1964), trodden by the people in search of fertile lands, sources of drinkable water, and in general more favorable conditions for the development of their communities. Apparently, Rome itself was located at the cross-roads of two pre-Roman roads, the Via Salaria and the Via Latina (Sitwell, 1981). The development of trade, the enlargement of the Roman domain, troops movement and ensuring the delivery of information and messages were the main needs that the Roman road network met (Knapton, 1996). Roads made the Roman Empire: from UK to North Africa, from Portugal to Arabia, it has been estimated that Romans built more than 85.000 kilometers of main roads (O'Flaherty, 1974).

Regarding the construction technique, they had Etruscans, who ruled in central Italy during the period 800-350 BC as a model (Forbes, 1934). Roman roads can be distinguished in *via terrenae*, i.e., "dirt roads" or constituted by selected natural soils

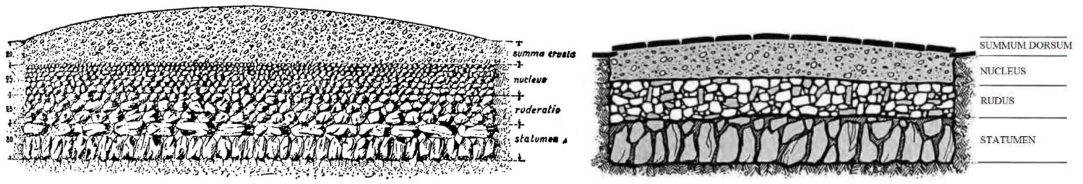
* Corresponding author: Salvatore Antonio Biancardo (salvatoreantonio.biancardo@unina.it)

which were placed within a dig, *viae glareae*, that were constituted by unbound aggregates, and eventually *viae silice stratae* which were coated with polygonal and unequal stone slabs having structural, functional, decorative, and hygienic roles, and gave monumental expression of power (Radke, 1981; Von Hagen, 1967; Forbes, 1934).

Therefore, in a first phase, roads were made up of well-traced paths in beaten earth, while only in a second phase the Romans provided for the construction of stone-paved roads (Garilli et al., 2017). Indeed, stone surfaced roads were mostly used in towns, while long distance roads were mainly surfaced with gravel. Paved roads sometimes used rectangular stones and sometimes used close fitting polygonal stones, often eight sided, and it is possible that Romans were already debating regarding relative structural advantage of different shapes in paves (Sitwell, 1981; Zoccali et al., 2018; Garilli & Giuliani, 2018; Soutsos et al., 2011; Moretti et al., 2021). Many Roman roads today have ruts that we can assume were dug during the construction of the roads to guide the chariot wheels, especially on steep roads, and then the repeated wheeling (vehicles could weigh up to 750 kg per axle) only increased their size.

One of the best documented accounts of the way in which Romans built their roads is Statius poem Silva (De Cristofaro, 2014) that describes what the poet observed during the construction of the Via Domitiana, built in 95 a.d. by Emperor Domitian. In particular, first, builders would mark the roadsides and then dig to the necessary depth. Next, the laying surface was prepared, so as to have a compacted base. Next, one or more layers of pebbles of various sizes and composition were laid. In the meanwhile, other builders would clear the way on the path for the road to be laid. Finally, a layer of bound material consisting of sand and tuffaceous material was laid on top of this unbound material, over which the stone slabs were then placed.

Figure 1.a shows a paradigmatic representation of section of viae stratae, commonly reproduced in several texts, inferred from the description of Vitruvius (Vitruvius, tr. Galiani, 1758). Figure 1.b shows the scheme published by Bergier in 1622 (Bergier, 1622), that have been so successful to be reproposed till today. Actually, it is safe to assume that both of these models are an exception rather than a rule, since the way roads were built varied according to the level of anticipated traffic, the nature of locally available materials, climate, topography and disposition of local people towards the Romans. Indeed, some roads in UK were constructed on an embankment, to give the roman users greater visibility and advantage of height in the case of attack, and also, for the same reasons, a significant clearing was formed each side of the road (Knapton, 1996).



(a) (b)

Figure 1: Viae Stratae structure from literature: (a) Vetruvius; (b) Bergier.

Romans' roads were used over the centuries and only surpassed in technology around the 18th century (Thompson, 1997). This system can be said to have been a first draft on which the modern western road system was built (Witcher, 1998).

Technique and technology have advanced by leaps and bounds, yet some schemes have remarkable analogies. Up to today, digitization is a pivotal element in the advancement of state-of-the-art engineering techniques, sustained by the innovative drive that forms its backbone. In this context, BIM is a technological methodology that is revolutionizing the AECO (Architecture, Engineering and Construction and Operation) world (Charef et al., 2019), involving a wide range of areas, from new design to maintenance planning of infrastructure works (Russo et al., 2021; Oreto et al., 2021; Biancardo et al., 2020). BIM mainly consists in the use of advanced software for the realization of digital models of the works, composed from the geometry of solid instances, and the information related to it (Eastman et al., 2011). These models, so called digital-twins, reproduce both all phases of design of new works and as-built models of newly constructed structures or already existing buildings (Borrmann et al., 2018; Guerra de Oliveira et al. 2022; Oreto et al., 2021, 2022, 2022). In the latter case, if buildings have historical character, BIM becomes H-BIM (Murphy et al., 2013) or Archaeo-BIM (Archaeological BIM) if the buildings have archaeological value (Banfi et al., 2022; Intignano et al., 2021).

From this, spontaneously arises the question about the relationship between technological advancement and heritage, both in terms of techniques and assets. Our research teams wondered how the latest innovations in the digitization of engineering works can intervene, not only on modern infrastructures, but also on immortal works such as Roman roads

2. Research Motivation and Objectives

The possibility offered by BIM as a tool for digitizing buildings and the information related to their functionality is widely established (Liu et al., 2019). Indeed, there are several case studies related to the realization of as-built models of historical buildings (Lopez et al., 2018) that have confirmed the validity of this methodology for the realization of back-analysis and reverse-engineering workflows (Adekunle et al., 2022; Abbondati et al., 2020). Yet, few studies focus on roads of historical and/or archaeological character, and they are often limited to particular works of art (bridges, aqueducts, etc.) (Conti et al., 2020; Biancardo et al., 2020).

The aim of this work is to broaden the research perspective and include archaeological roads that are still open to vehicular traffic today. It is not only extremely remarkable that some Roman roads have formed the route for modern infrastructures that play a key role in the global road system, but some of them still materially constitute key roads for preferential access to residential areas of not minor importance. It is the case of the case study that will be addressed in this research.

3. Methodology

The methodology workflow used for this research work is shown in Figure 2.

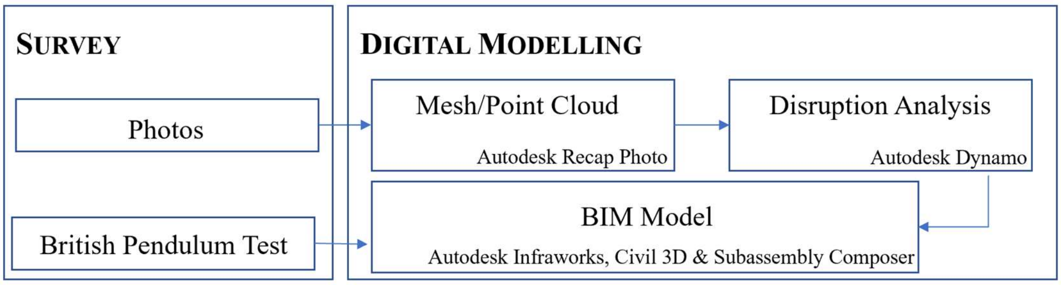


Figure 2: Methodology workflow.

There have been two operational phases: the first involved field survey operations and the second involved the processing of data in a digital information model.

As for the survey, the research team went to the site in broad daylight to take several photographs and measurements. It has been observed that part of the original paved road had been covered by a layer of asphalt wearing course. The initial dismay was overshadowed when it was realised that there was the opportunity to compare the functional performance of a road that is characteristically heterogeneous but affected by the exact same volume of traffic. Given the impossibility of performing invasive or destructive tests, it was decided to perform a British Pendulum Test (BPT), according to the EN 13036-4:2011 standards, exploited to assess the road surface friction, in terms of British Pendulum Number (BPN).

In addition, it was decided to carry out more detailed modelling of the road section corresponding to the transition between the asphalt pavement and the paving stones. It has been used the photogrammetry technique in order to analyse the road macro-texture. Photogrammetry is a technique for metrically determining the shape and position of objects from at least two separate frames of the same object (Stereoscopic Pair). The software used to carry out the photogrammetry was Autodesk Recap Photo. This allows the 3D mesh and Point Cloud of an object to be obtained from at least 20 photos that must be taken going around the object, at different heights and angles, making sure that the successive frames overlap by at least 50%. For more clarity, in computer graphic, a polygonal mesh is a collection of vertices, edges and faces that defines the shape of a polyhedral object; a point cloud is a set of data points in space that may represent a 3D shape or object. Around 700 photographs had to be taken to obtain a suitable database for the subsequent modelling operations. Of this high number of photos taken, only a small part was suitable for the work, due to the lighting conditions, that must be as homogeneous as possible, and to the vehicular traffic, which forced the interruption of operations several times.

The point cloud obtained in Autodesk Recap Photo was exported as a .pts file format extension. A pts file is a simple text file used to store point data. The first line gives the number of points to follow. Each subsequent line has 7 values, the first three are the (x,y,z) coordinates of the point, the fourth is an "intensity" value, and the last three are the (r,g,b) colour estimates. The (r,g,b) values range from 0 to 255 (as number of information a byte can represent). The intensity value is an estimate of the fraction of incident radiation reflected by the surface at that point, 0 indicates is a very poor return while 255 is a very strong return.

Therefore, it was imported within Excel, and from Excel in Dynamo, an extension of Autodesk Civil 3D, i.e., a VPLE-based tool (Visual Programming Language Environment) in order to analyse the macro-texture of the road pavement through an algorithm. The results of this analyses were then imported in the BIM model of the road, realised by means of Autodesk software Infraworks and Civil 3D.

4. Case Study

The case study focuses on the road paving of the ancient Roman road Via Domitiana, at Arco Felice, a hamlet of Pozzuoli, in the province of Naples, Campania, Italy. The road originated from the ancient Via Appia at Sinuessa (today's Mondragone) and then was running along the coast north of Naples. The complete route from Sinuessa to Puteoli (today’s Pozzuoli) was 33 roman miles long, i.e., 49 kilometres (Figure 3.a) (Marino, 2014).

Between Cumane and Puteoli, the road crossed Monte Grillo, tracing an old passageway probably built in Greek times. This passage was widened, and an arch, called Arco Felice, was built (Figure 3.b), serving as a monumental gateway to the city of Cumae, and as support to the slopes of Mount Grillo. The Arco Felice was built in brick and covered in marble, 20 metres high, 6 metres wide and 17 metres long, surmounted by two orders of lighter concrete and brick arches. Supposedly there were niches with statues on the piers (Catuogno, 2013).

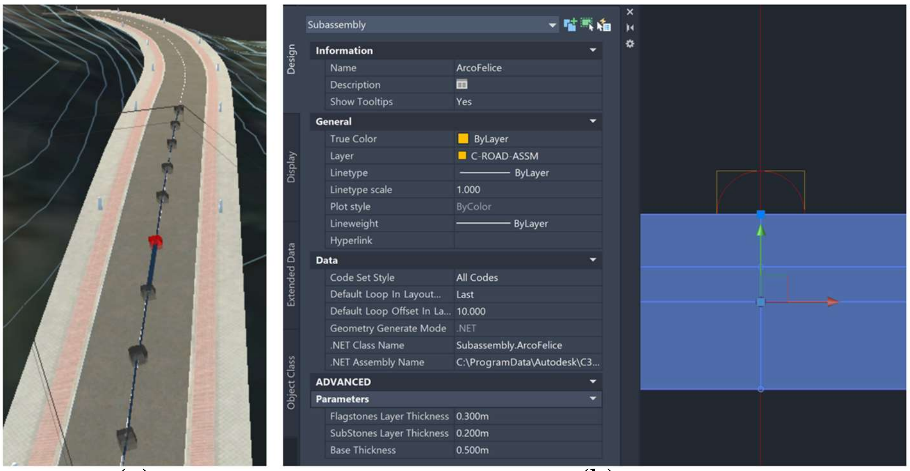
The road passing under the arch is still open to vehicular traffic and is one of the main access roads between the towns of Bacoli and Pozzuoli. The pavement consists of flagstones that probably date back to a Roman reconstruction. As anticipated, during the in-situ survey operations, it was noticed that the Roman paving ends abruptly, actually covered by a thin layer of asphalt wear (Figure 3.c).

(a) (b) (c)

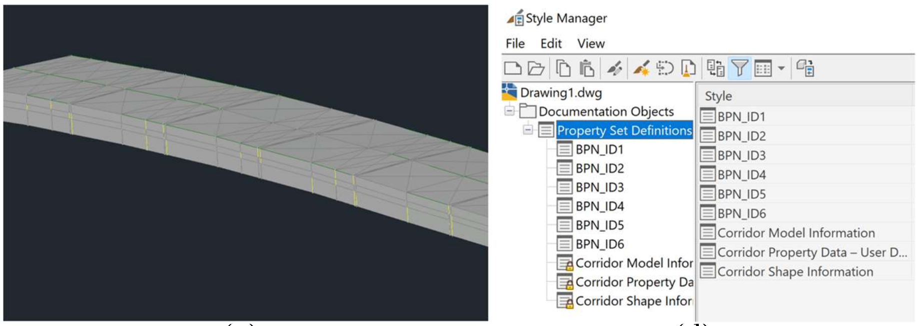
Figure 3: Location overview: (a) Ancient Via Domitiana layout; (b) Arco Felice; (c) Pavement transition section.

5. Case Study

Regarding the modelling in the BIM environment, the conceptual model of the road, realised by means of Infraworks, placed in the appropriate geographical context, is shown in Figure 4.a. The latter was used to extract geographical localization and horizontal-vertical coordination of the central road-axis and edges. The feature lines thus obtained were subsequently imported into Civil 3D as 3D polylines. Here, the assembly was created by importing a subassembly customized by means of Subassembly composer, according to the knowledge of literature about typological cross-sections of roman roads (see Figure 1 and Figure 4.b). By extruding the assembly through the central axis, the software can build the road corridor. This was adjusted by targeting the edges axis, adding external surfaces, and building the corridor solid. Therefore, the 3D solid obtained is a proper corridor that follow the real orientation of the road, also in its offset and elevation irregularity (Figure 4.c). After the construction of the 3D model, additional information was added to it, specifically the results of the BPT, in the form of attributes, thanks to the property set tool. Property sets are archives of various types of properties that can be organised into lists (Figure 4.d). In this work, the possibility of modifying the property sets through Dynamo was also exploited, as it will be shown later.



(a) (b)



(c) (d)

Figure 4: BIM environment modelling: (a) Conceptual model in Infraworks; (b) Detail of Assembly and its Properties in Civil 3D; (c) 3D Geometric Model in Civil 3D; (d) Property Set Definitions.

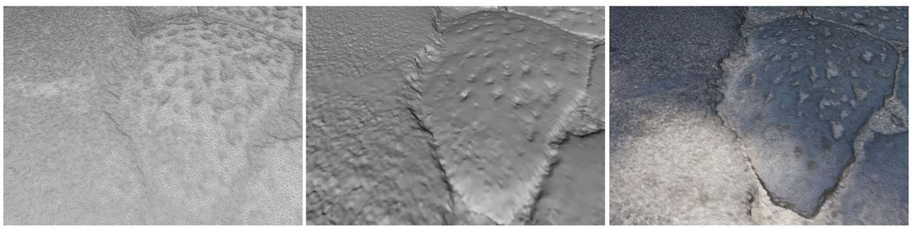
As mentioned, our research team was prompted to carry out the same friction test for both types of pavements found in site, since they are subjected to the exact same vehicular traffic (Autelitano et al., 2022). The test adopted was the British Pendulum Test. The results of the BPT are reported in Table 1.

Table 1: British Pendulum Test results.

Test location ID			*BPN*			*Mean*
1	49	48	49	47	49	48
2	45	43	43	44	43	44
3	66	68	69	67	70	68
4	70	68	69	67	70	69
5	61	64	61	63	62	62
6	63	64	63	64	65	64

Test ID 1 and 2 are located on the asphalt; ID tests 3 and 4 are located on side paving stones, which are hardly affected by the passage of car tyres; ID tests 5 and 6 are located on two more central paving stones, exactly where cars normally pass. The results reflect this: lower BPN values mean lower frictional resistance offered by the pavement.

After the survey operations, the photographs taken were used to create a mesh surface and a point cloud of a specific transition point between the asphalt pavement and a flagstone (Figure 5). To do so, Recap Photo was used.



(a) (b) (c)

Figure 5: Pavement graphical models: (a) Wireframe; (b) Solid; (c) Textured with wireframe.

The analyses of the paved surface micro-variations in terms of height and regularity using an algorithm developed in Dynamo was performed. To do this, the point cloud was exported in .pts format, imported in Excel, and finally imported in Dynamo.

The algorithm graph in VPLE is shown in Figure 6.

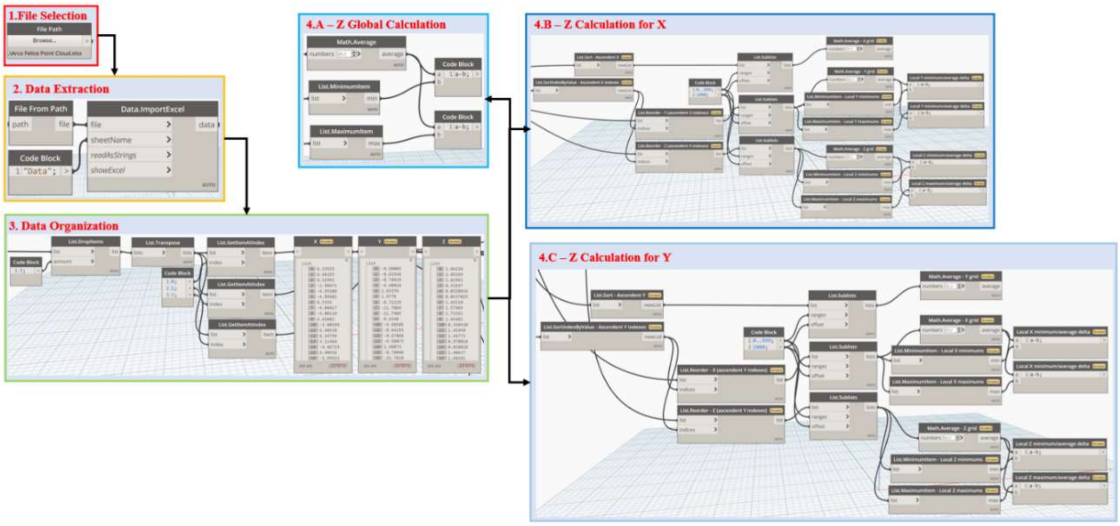


Figure 6: Dynamo VPL graph.

Part 1 selects the Excel file; part 2 extracts data from a precise sheet of the selected Excel file; part 3 was used to organize data, that is the x, y, z, points coordinates were separated; part 4.A identifies the minimum, maximum, mean, the difference between mean and minimum and the difference between maximum and mean of the Zs; part 4.B operates a discretization of the points, ordered according to increasing X, in subgroups of 1000, and identifies of each group the minimum, the maximum, the mean, the difference between mean and minimum and the difference between maximum and mean of the Zs; part 4.C performs the same operations as in part 4.B but ordering the points according to increasing Ys. In this way it is possible to appreciate the variation of Z in the global domain (part 4.A) and in the local domains according to X and Y directions. The maximum local variation of Z is 2.7 cm. This is an indication of a fairly regular pavement, considering its nature and origin.

A further script updates the information in the property sets of the Civil 3D model.

6. Discussion and Conclusions

The results obtained in this work mainly concern the realisation of a digital model of a road infrastructure that is more unique than rare. Indeed, the Via Domitiana, the subject of this research, is an ancient Roman road of archaeological character but still open to vehicular traffic. The digital information model realized is rich in information obtained from the Skid Test performed on the road surface, information inferred from the analysis of the detailed model of the road surface obtained through the technique of the photogrammetry, and information retrieved from the study of the existing literature regarding the Roman roads and the methods for their construction.

The resulting model is a useful tool for preserving currently available information on the engineering/archaeological asset. In fact, it represents a digital archive, also containing the geometric and spatial information of the asset, which is intelligent, i.e., it can be updated interactively by the different actors whose interest is the study, protection and conservation of the asset itself.

The limitations of the current research can currently be identified as follows:

- the lack of possibility to carry out an excavation to analyse in detail the structural composition of the pavement in order to gain further information on the construction techniques used by Roman engineers;
- the limited opportunities granted by the software currently on the market for modelling horizontal structures of an archaeological nature in a BIM

environment (there is no dedicated software, one can only decide to adapt to the characteristics of existing software).

Possible future developments could concern:

- 1. the use of non-invasive and non-destructive methods for the analysis of the road structure underneath the pavement, in order to get an idea of the stratigraphy and the materials used;
- 2. the use of BIM to carry out structural simulations and make a comparison with modern structures.

In conclusion, BIM for infrastructure and archaeological/historical assets has enormous potential, the implications of which, whether quantifiable or not, need to be further explored by international research.

References

Albenga, G. (1918). *La evoluzione della strada – I. La strada antica. Estratto dagli annali delle università toscane*. In: Tipografia editrice Cav. F. Mariotti, Pisa.

Abbondati, F., Oreto, C., Viscione, N., Biancardo, S.A. (2020) "Rural Road Reverse Engineering Using BIM: an Italian Case Study", Proceedings from the International Conference on Environmental Engineering, Vilnius, Lithuania.

Adekunle, S.A., Aigbavboa, C., Ejohwomu, O.A. (2022) "SCAN TO BIM: a systematic literature review network analysis", *IOP Conference Series: Materials Science and Engineering* 1218, 012057.

Autelitano, F., Bruno, N., Martinelli, R., Calvanese, V., Garilli, E., Biancardo, S.A., Dell'Acqua, G., Veropalumbo, R., Zerbi, A., Roncella, R., Giuliani, F. (2022) "The construction of a street never opened to traffic. The extraordinary discovery of pavement engineering in vicolo dei Balconi of Pompeii", *Journal of Cultural Heritage* 54, pp. 108-117.

Banfi, F., Brumana, R., Landi, A.G., Previtali, M., Roncoroni, F., Stanga, C. (2022) "Building archaeology informative modelling turned into 3D volume stratigraphy and extended reality time-lapse communication", *Virtual Archaeology Review* 13 (26), pp. 1-21.

Bergier, N. (1622) *Histoire des grandes chemins de l'Empire Romain*. In: Hachette/BnF (Ed.). France, pp. 955.

Biancardo, S.A., Russo, F., Veropalumbo, R., Vorobjovas, V., Dell'Acqua, G. (2020) "Modeling Roman Pavements using Heritage-BIM: a case study in Pompeii", *The Baltic Journal of Road and Bridge Engineering* 15 (3), pp. 34–46.

Biancardo, S.A., Abbondati, F., Russo, F., Veropalumbo, R., Dell'Acqua, G. (2020) "A Broad-Based Decision-Making Procedure for Runway Friction Decay Analysis in Maintenance Operations", *Sustainability* 12 (9), 3516.

Borrmann, A., Konig, M., Kock, C., Beetz, J. (2018) *Building Information Modeling, Technology Foundations and Industry Practice*. In: Springer (Ed.), Germany.

Catuogno, R. (2013) "Paesaggio e architettura: il rilievo dell'Arco Felice Vecchio a Cuma. Patrimoni e Siti UNESCO: Memoria, Misura e Armonia", Proceeding from the 35° Convegno internazionale dei docenti della rappresentazione, Matera, Italy.

Charef, R., Emmitt, S., Alaka, H., Fouchal, F. (2019) "Building Information Modelling adoption in the European Union: an overview", *Journal of Building Engineering* 25, 100777.

Conti, A., Fiorini, L., Massaro, R., Santoni, C., Tucci, G. (2020) "HBIM for the preservation of a historic infrastructure: the Carlo III bridge of the Carolino Aqueduct", *Applied Geomatics* 14, pp. 41-51.

De Cristofaro, A. (2014) “Termini tecnici nel poema sulla Via Domitiana di Papinio Stazio (Silv. 4, 3, 40-66)”, *Giornale Italiano di Filologia* 66, pp. 215-223.

Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. In: John Wiley & Sons (Ed.), Hoboken, New Jersey.

Forbes, R.J. (1934) *Notes on the history of ancient roads and their construction.* In: Noord-Hollandsche Uitgevers Mij (Ed.), Amsterdam.

Garilli, E., Autelitano, F., Giuliani, F. (2017) “A study for the understanding of the Roman pavement design criteria”, *Journal of Cultural Heritage* 25, pp. 87-93.

Garilli, E., Giuliani, F. (2018) “Stone pavement materials and construction methods in Europe and North America between the 19th and 20th century”, *International Journal of Architectural Heritage* 13 (5), pp. 742-768.

Guerra de Oliveira, S., Biancardo, S.A., Tibaut, A. (2022) “Optimizing H-BIM Workflow for Interventions on Historical Building Elements”, *Sustainability*, 14, 9703.

Intignano, M., Biancardo, S.A., Oreto, C., Viscione, N., Veropalumbo, R., Russo, F., Ausiello, G., Dell’Acqua, G. (2021) “A Scan-to-BIM Methodology Applied to Stone Pavements in Archaeological Sites”, *Heritage* 4 (4), pp. 3032-3049.

Knapton, J. (1996) *The Romans and their roads - the original small element pavement technologists*. Pave Israel 96.

Liu, Z., Lu, Y., Peh, L.C. (2019) “A Review and Scientometric Analysis of Global Building Information Modeling (BIM) Research in the Architecture, Engineering and Construction (AEC) Industry”, *Buildings* 9 (10), 210.

López, F.J., Lerones, P.M., Llamas, J., Gómez-García-Bermejo, J., Zalama, E. (2018) “A Review of Heritage Building Information Modeling (H-BIM)”, *Multimodal Technologies and Interaction* 2 (2), 21.

Marino, A. (2014) Gli antichi insediamenti nella plaga aversana. Aversa Turismo. Available at: https://www.aversaturismo.it/gli-antichi-insediamenti-nella-plaga-aversana/

Moretti, L., Cantisani, G., Carpiceci, M., D’Andrea, A., Del Serrone, G., Di Mascio, P., Loprencipe, G. (2021) “Effect of Sampietrini Pavers on Urban Heat Islands”, *International Journal of Environmental Research and Public Health*,18, 13108.

Moyano, J., Odriozola, C.P., Nieto-Julián, J.E., Vargas, J. M., Barrera, J.A., León, J. (2020) “Bringing BIM to archaeological heritage: Interdisciplinary method/strategy and accuracy applied to a megalithic monument of the Copper Age”, *Journal of Cultural Heritage* 45, pp. 303-314.

Murphy, M., McGovern, E., Pavia, S. (2013) “Historic Building Information Modelling - Adding intelligence to laser and image based surveys of European classical architecture”, *ISPRS J. Photogram. Remote Sensing* 76, pp. 89-102.

O’Flaherty, C.A. (1974) *Highways Vol. 1 Highways and Traffic. 2nd Edition* In: Edward Arnold Publishers Ltd. (Ed.), London.

Oreto, C., Biancardo, S.A., Veropalumbo, R., Viscione, N., Russo, F., Abbondati, F., Dell’Acqua G. (2022) “BIM-LCCA integration for road pavement maintenance”, *Transportation Research Record: Journal of the Transportation Research Board*, 2676 (6), pp. 259-273.

Oreto, C., Biancardo, S.A., Veropalumbo, R., Viscione, N., Russo, F., Abbondati, F., Dell’Acqua, G. (2022) “BIM-LCA Integration Framework for Sustainable Road Pavement Maintenance Practices”, *International Journal of Transport Development and Integration* 6 (1), pp. 1-11.

Oreto, C., Biancardo, S.A., Viscione, N., Veropalumbo, R., Russo, F. (2021) “Roads Pavements Information Modeling through Maintenance Scenarios Evaluation”, *Journal of Advanced Transportation*, 8823117.

Oreto, C., Massotti, L., Biancardo, S.A., Veropalumbo, R., Viscione, N., Russo, F. (2021) “BIM-Based Pavement Management Tool for Scheduling Urban Road Maintenance”, *Infrastructures* 6 (11), 148.

Radke, G. (1981). *Viae Publicae Romanae - Traduzione di Gino Sigismondi*, In: Nuova casa editrice Cappeli (Ed), Bologna.

Russo, F., Veropalumbo, R., Biancardo, S.A., Oreto, C., Scherillo, F., Viscione, N. (2021) “Reusing jet grouting waste as filler for road asphalt mixtures of base layers”, *Materials* 14 (1), 3200.

Sitwell, N.H.D. (1981) *Roman Roads of Europe*. In: Cassell Ltd. (Ed.), London.

Soutsos, M.N., Tang, K., Khalid, H.A., Millard, S.G. (2011) “The effect of construction pattern and unit interlock on the structural behaviour of block pavements”, *Construction and Building Materials* 25, pp. 3832-3840.

Von Hagen, V.W. (1967) *The roads that led to Rome*. In: World Publishing Company (Ed.), Cleveland.

Vitruvius, P. (1758) *L’architettura di Marco Vitruvio Pollione tradotta e comentata dal marchese Berardo Galiani.* In: Stamperia Simoniana (Ed.), Napoli.

Zoccali, P., Moretti, L., Di Mascio, P., Loprencipe, G., D'Andrea, A., Bonin, G., Teltayev, B., Caro, S. (2018). “Analysis of natural stone block pavements in urban shared areas”, *Case Studies in Construction Materials* 8, pp. 498-506.

Acknowledgements

This research was developed within the PRIN 2017 “Stone pavements. History, conservation, valorisation and design” (20174JW7ZL) financed by the Ministry of Education, University and Research (MIUR) of the Italian Government.