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Extraction of constructive geometries from numerical models. The city walls in the Hattusa Gorge

The paper presents the results of research conducted in the gorge area of the archaeological site of Hattusa in Anatolia, Turkey (listed as a UNESCO World Heritage Site in 1986), aimed at developing a survey methodology and three-dimensional data management for the identification of traces of ancient walls on the rocks and their analysis within a digital simulation space. Within the area, digitization procedures were carried out by means of laser scanners, drone and ground photogrammetric systems, handy scanners, and total stations. All data produced were referenced and aligned by topographic points, in order to set up the models for the subsequent segmentation and spatial analysis phases. The traces, mapped and analyzed in relationship to the construction techniques of the Hittites, made it possible to redraw the possible trajectories and forms of the structures, addressing the complex issue of the gorge crossing of the city's fortification system. This approach emphasized the key role of three-dimensional surveying techniques and representation of numerical models in relation to data visualization procedures. The segmentation of the models and sequence of the signs allowed a new use of spatial data beyond the limits of a representation exclusively rendered by means of point clouds or continuous meshes, providing new solutions to the interpretation of an area of Hattusa that is still poorly studied due to the considerable complexity of the places.

Keywords:
3D survey, geospatial data analysis, archaeology

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1. INTRODUCTION

Within the cooperation project between the University of Naples Federico II - DiSTAR and the Archaeological Mission in Hattuša of the German Archaeological Institute of Istanbul, the workgroup of the University of Naples, since 2014, is conducting an extensive research, still ongoing, aimed at the digitalization and study of extensive archaeological contexts and architectural structures of the UNESCO site of Ḫattuša (Anatolia, Turkey), such as: the Nişantaş inscription, the Kammer 2 in the Südburg, the rocky site of Yazılıkaya, the gorge area , the Great Temple and the pyramid of Yerkapı.
The paper presents the results of research conducted in the gorge area aimed at developing a survey methodology and three-dimensional data management for the identification of traces of ancient walls on the rocks and their analysis within a digital simulation space. The signs mapped and analyzed in relation to Hittite construction techniques made it possible to redesign the possible trajectories and forms of the architectural structures, addressing the complex issue of the crossing of the gorge of the city's defensive system. This approach highlighted the fundamental role of numerical model representation techniques in relation to correlated data visualization procedures. The segmentation of the models and sequencing of the traces has allowed an unprecedented use of spatial data beyond the limits of a representation exclusively rendered by means of point clouds or continuous meshes (Croce 2023), providing new solutions to the interpretation of Ḫattuša site, still poorly studied due to the considerable complexity of the places.
This area has a complex orography due to the considerable unevenness of the rocky outcrops (Fig. 1). This is the rocky complex that, from the Ambarlıkaya massif, through a narrow gorge (characterized by the presence of a rock formation that is called 'Minaret') crossed by a stream, reaches the slopes of the southern ridge of Büyükkaya, the acropolis of the city. The traces of workmanship (and holes), at the top and on the intermediate levels of the various rock formations, as well as along the walls of the gorge itself, relating to the preparation of the surfaces for the housing of the elements that were to substantiate the elevation of this section of the fortification, have led in the past to various reconstructive hypotheses regarding the architectural and engineering characteristics, especially in relation to the "jump" over the gorge (Naumann 1971, Seeher 2007). At the base of the southern slope of Büyükkaya the presence of two sections of a tunnel, certainly excavated in ancient times and not completed, designed to cross the rocky spur in an east-west direction, poses significant problems of interpretation not only related to its functionality, but above all related to the construction techniques and the system of knowledge necessary to define the design "process" to support such a work.
The work carried out since the 2017 archaeological campaign has consisted of creating a georeferenced network of targets, using a Leica TCR405 total station, within which three-dimensional

Fig. 1 - General view of the gorge between the Ambarlıkaya and Büyükkaya massifs.

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surveys were carried out by a TOF laser scanners. These were supplemented by detailed aerial photogrammetric digitization procedures, using a DJI Phantom 4 drone, and from the ground, using Nikon D810 and GoPro Hero cameras, for a more effective capture of recognizable processing marks on the rocks.
In addition to these activities, detailed surveys were carried out by means of a Sense bodyscanner, in particular focusing on two holes in the rock detached from the Ambarlıkaya wall, of interest for the analysis phases of the uses and transformations of the places. These activities were all aimed at creating a basic topographic model, in which the specific models of the walls and surfaces of the gorge can be managed.

2. THE ḪATTUŠA ARCHAEOLOGICAL SITE

The archaeological site of Hattuša, added to the *UNESCO World Heritage* list in 1986, is the ancient capital of the Hittite Empire, one of the most important "territorial states" of the Near East in the II millennium B.C. Founded as moderate typical Central Anatolian town at the end of the 3rd Millennium BC the city was first extended by the establishment of a colony of Assyrian traders during the first centuries of the early 2nd Millennium BC. After the destruction by Anitta, the king of Neša, a rival Anatolian city, around 1720 BC the city became the capital of the Hittite state after c. 1650 BC. This development marks a clearly visible transformation of the town into a representative city. Not only the size was extremely enlarged but also new forms of official architecture, both religious and representative as well as military resemble the establishment of the new Hittite state and its imperial claims (Schachner 2015). Beside new architectural forms a bundle of social and technical innovations made this step possible leading to a degree of social complexity which is unique in the pre-classical history of Central Anatolia. This metropolis of the Hittite empire survived until c. 1180 BC. The incorporation of the complex topography is one of the many inimitable features of Ḫattuša. This allowed the Hittites to not only divide the city functionally along natural borders which were even amplified by man-made constraints, but even to incorporate the landscape into the urban setting thus becoming part of the function and meaning of individual buildings (Schachner 2017). This immediate relation between man-made buildings and the natural environment requires an integrated approach to fully understand the features. For this, a most accurate documentation is mandatory. The compilation of a new topographical map of the site which replaced the Kohl map of 1912 by a new plan, meeting modern standards, in 1998, revealed that several assumptions based on the early not that accurate map are no longer true and underlined the importance of most accurate measurements. In this respect the method of 3D scanning offer a complete new approach to analyze the relationship between the topography and the built environment.

Fig. 2 - Riegl VZ400 laser scanner survey phases.

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Fig. 3 - Scale bars to support photogrammetric surveys.

Fig. 4 - Scanning activities of the southern portion of the tunnel.

3. 3D SURVEY PROCEDURES

Research activities carried out in the field have defined a survey and study methodology of some areas and monuments of the Ḫattuša archaeological site strongly connected to the integrated use of different technologies for three-dimensional digitization and innovative data management procedures, both optimized to the characteristics of the analyzed places. The adopted methodology has allowed the management of all the models in a single digital space, aligned to the general topography of the entire site, guaranteeing a dynamic analysis of the models at the different scales of representation. The survey took into account the long duration of the project, given the complexity and the extension of the site, modulating the actions in the field in relation to the characteristics of the places and the phases of management of the models.

In particular, the digitization activities of the gorge area, subject of this paper, involved the integrated use of different technologies and procedures in order to manage the different levels of model resolution in relation to the different scales of analysis of the contexts, integrating together the study of geological aspects with archaeological and architectural details.
The first level of acquisition of the entire valley and the rocky walls of the gorge was carried out by time-of-flight laser scanners, in 2017 a Riegl LMS-Z420i was used for the topographic survey, in 2020 a Riegl VZ400 for detailed acquisition of the rocks north and south of the stream on which there are more traces of wall building, in this case the surveys were also extended to the eastern slope near the bedrock. Numerous scans were produced with varying resolutions depending on the type of surfaces to be acquired: higher resolutions were used for distant objects and for rocks that showed evidence of building structures; lower resolutions were used for closer surfaces (i.e., with distances less than about 10 meters) and for rock cliff faces. The scans were aligned by 5 and 10 cm diameter cylindrical markers, automatically detected by the RiscaPro scanner management software, then surveyed by Leica TCR405 total station for their referencing within the single local reference system.
In order to better detect all artificial marks on the rocky walls along the narrow gorge below the rock called Minar, to support studies for the understanding of the architectural solutions adopted by the Hittites to close the perimeter of the defensive walls at the stream, two integrated 3D survey procedures were carried out, the first by means of a time-of-flight laser scanner, the second of the photogrammetric type by means of a Hero camera. The laser scans were carried out along the stream bed

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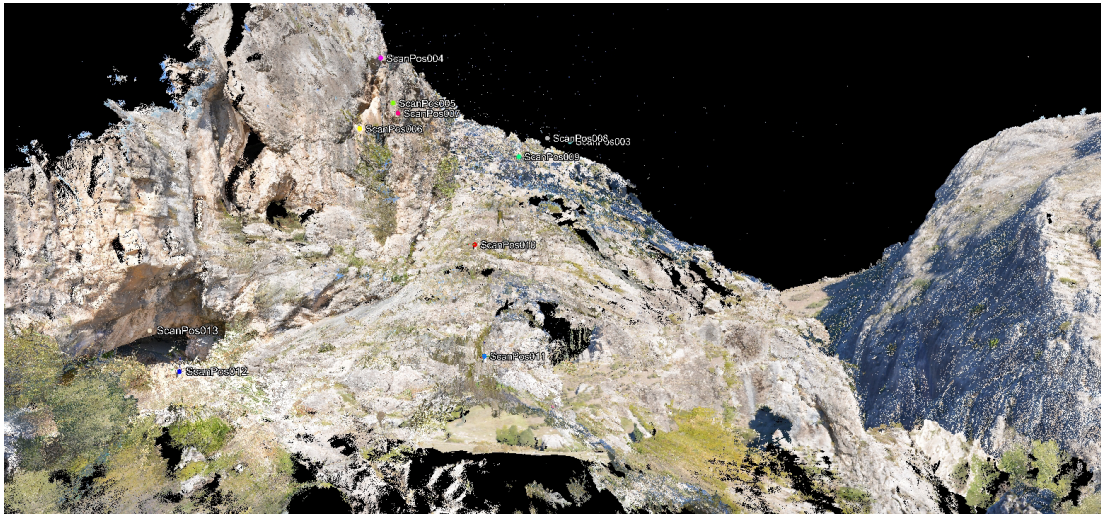
and inside the gorge from ground level. The acquisitions of the images concerned the highest parts at the top surfaces of the gorge cliff faces.
Concerning the study of the high rocky outcrop called the Minar, given the logistical difficulties of the area, which is bounded on all sides by steeply sloping walls that prevented the transport of the TOF scanner to the points envisaged by the survey path, two acquisition sequences were carried out using a HERO, Black Edition digital video camera. This digital video camera, in fact, being equipped with a very wide-angle lens, made it possible to effectively acquire the entire area through a reduced number of photos and with a percentage of overlapping of far more than 60%. Special aluminum sights of 50 and 100 cm were previously set up inside the scene, whose references, automatically recognized as markers by the Agisoft Metashape software, were measured by means of a total station, for the subsequent alignment of the point clouds to the models produced by the scanner and the other acquisition systems.
To complement digitization activities from the ground, drone photogrammetric surveying procedures of the entire gorge area were carried out in 2019 focusing on the survey of the summit parts of the higher rocky outcrops and the signs for the connection of blocks found on the southeastern slope of Ambarlıkaya, there where the wall had to abruptly change the slope to make it possible to connect the horizontal planes of rocks near the river with the steep side of the mountain in the southwestern direction.
In continuity with this area of the gorge, the two sections of the tunnel through Büyükkaya were also digitized using time-of-flight laser scanners. The surveys were carried out first on the northern arm and then on the opposite side. The clouds were acquired in high resolution and at angles suitable for recording the greatest number of geometries of the surfaces excavated in the rock. The alignment of the two groups of points, referring to the two portions of the tunnel, was carried out by cylindrical markers placed in the space in order to verify the closure of the survey polygon that has structured the entire data acquisition path.
Different problems presented the survey of the high massif of Ambarlıkaya where acquisition activities were carried out by the laser scanner Riegl LMS-Z420i and covered both the orographic context and all the architectural structures present along the ridges and on the top of the mountain. Particular attention was also paid to the two areas in front of the access gates to the two tunnels on the opposite side of the valley, for a future study of the trigonometric processes implemented by the Hittites at the basis of the tunnel construction.

4. DATA PROCESSING

All the point clouds were filtered and aligned, in order to integrate the parts into the general topographic model already set up in the previous digitization and study campaigns. Concerning the area of the gorge, different procedures were carried out for the management of point clouds, both for the large size of the area, and for the presence of different types of artifacts. In particular for the surfaces corresponding to the ground and for the areas covered by thick vegetation, strong point cloud reduction was performed using the reflectance levels acquired by the instrument, which can be associated with the different types of materials detected, and applying robust noise reduction algorithms; for the parts of the mountains where there is no vegetation, a medium resolution of the point clouds was maintained; for the rocky elements connected to the ancient city walls in the vicinity of the narrow gorge, manual procedures were carried out to eliminate the vegetation in order to preserve the maximum resolution of the models; finally, the point clouds relative to the two parts of the tunnel were processed in very high resolution, characterizing in particular the relationship between these and the surrounding orographic context. The clouds were also processed in order to obtain textured polygonal models at different levels of resolution and the technical drawings for the verification of the heights and topographical relationships between the various elements analyzed.

Fig. 5 - Textured point cloud of the gorge area.



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5. EXTRACTION OF GEOMETRIC FEATURES AND ANALYSIS OF GEOSPATIAL DATA

The starting point of the methodology applied in this research was the study of Hittite construction technologies and the field verification of the devices adopted to solve the problems of anchoring of the large blocks to the ground planes. Combined with the study of construction techniques, the typological-formal analysis of the large gates of the city of Ḫattuša was tackled, as well as the structures with corbeled masonry vaults (Naumann 1971, Schachner 2017, Seeher 2007). Very high resolution surveys were carried out of the three monumental city gates called the Lions, the Sphinxes, the Kings and two of the west gates near the reconstructed portion of the mud brick city wall, in order to extract the dimensions and geometric pattern of the different types of gateways on the one hand, and to better study the techniques of connecting the blocks on the other. In addition, the digitization of the Lion's Gate and King's Gate also allowed us to obtain exact surveys of the curvatures of the jambs of the pseudo arches of the gateways in relation to the blocks layout beside them.
The research, making use of digital technologies and therefore of more complex types of data, included the overall orography of the sites in the analysis. The architectural structures, which here had to connect the city walls that descended from the Ambarlıkaya and Büyükkaya massifs into the valley and that has left numerous traces for the adaptation of the natural surfaces to the construction requirements. Starting from the identification on the numerical models obtained from 3D scanning of the signs referable to possible masonry structures and the series of holes, still readable on the rocks, an interpretative model of the spatial data was produced, largely managed within Rhinoceros 7 software. This file has imported: all the topographic CAD data produced by DAI over the years, to which our topographic surveys have been correlated to support the referencing of the three-dimensional data (Bollati Guzzo 2017). All the models produced by the various acquisition systems described above have been organized in specific layers.

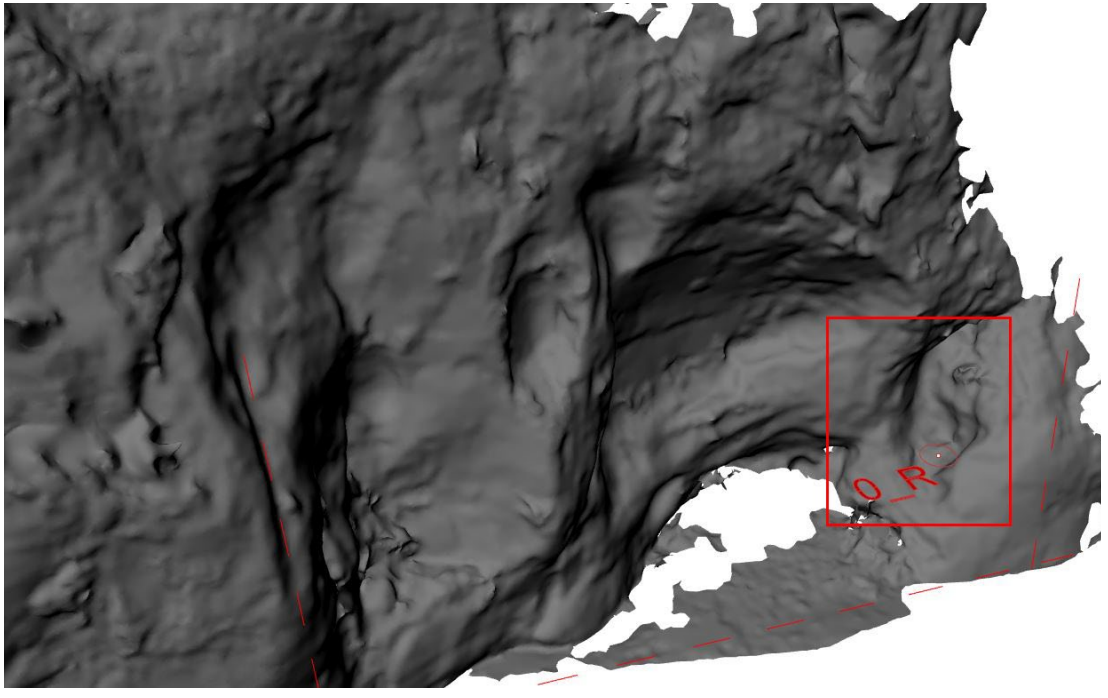

Fig. 6 - Detail of the niche with location of point 0_R.

The analysis of the relative heights of the various marks surveyed on the rocks made it possible to relate the different areas investigated to the technical-constructive requirements and possible functions, referring to: the variability of the river level, the defense capability of the walls in an orographically complex and strategic point for water supply, the management of access from the southern areas along the gorge. From these analyses, the relative heights between the different marks referable to human activities and their absolute heights with respect to a 0 point, located on the rock on the north side of the gorge near the present creek level, were highlighted.
Following the model management procedures, the traces found on the rocks were segmented and moved to different layers: 1. marks identified by Naumann and Neve (Naumann 1963, Neve 1980); 2. marks referable to the Hittite civilization due to the type of stone working compared to the tools in use at the time; 3. signs of working that cannot be attributed to the Hittites; 4. geometries that can be attributed to man or of natural origin suitable for building. A different color has been assigned to each layer for an easy reading of the data within the drawings.
On the north side of the gorge, based on the study of the untextured model, points B, D and F identified by Naumann appear to be edges and surfaces prepared for the housing of large boulders to form a rectified wall structure (Fig. 7), the dimensions and shape of which may be assumed from a probably artificial niche of approximately 55 cm, and from the cut coinciding with Naumann's point B.

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The 0_R point was virtually placed inside this niche, directly on the rock and therefore not susceptible to changes in the stream banks, because it can be associated with the lowest sustaining ledge level of possible wall structures on this side of the gorge. The same niche was taken as a reference for the redesign of the walls in the northern direction, interpolating the data with the few geometries readable on the western side, due to the presence of thick vegetation covering the rock. To remedy these gaps within the models, additional surveys were carried out in 2019 using the Riegl VZ400 laser scanner of the eastern area of the gorge, the data of which were interpolated with the polygonal model obtained from the contour lines of the DTM of the area, thus managing to represent part of the rock surfaces covered by vegetation and other marks on the eastern rock faces.
The analysis of the structures continued towards the north, where the vegetation becomes sparser and it was therefore possible to read more clearly the planes of the rocks, which on the north-eastern side show regular cuts at the junction of the walls descending from Büyükkaya. More archaeological information about this point of the site would help to better understand the connection between the architectural structures of the gorge and the continuation of the walls towards the north-east, especially in their relationship with a possible gate. In any case, the setbacks of the rock in regular shapes suggests a clamping point of the walls by means of large blocks, both for static and design reasons, suggesting a lateral bastion at the entrance, as is typical of the city gates of Ḫattuša (Seeher 2010). Moreover, this graft is aligned with the tall Minaret, which was also probably remodeled on the south-east and north-east sides, which would have contributed both to the statics of the walls, which were, here, probably very high for the considerations that we will make below, and to absorbing the horizontal thrusts of the wall structures that descend from Büyükkaya by means of a sharp drop in height. In addition, this area is of considerable interest when analyzed as a whole, considering the slight marks of workmanship on the rocks towards the north and the regular slope of the rock immediately north of the Minaret, one could assume a further quadrangular building within the perimeter of the walls and a large flight of steps towards the stream level.
Although this hypothesis required further investigation on the area following the necessary cleaning of the rocks from vegetation and soil accumulations, it was verified by producing numerous sections from the model and developing a simulation of a staircase on them, which provided a constant ratio of step to riser of 20x20 cm. The course of the inner wall that runs southwards from the base of the Minar is clearer, the location of which was verified by an archaeological dig essay conducted in 2021, which uncovered rows of stone as the base of a wider wall exactly in correspondence with the geometries extracted from the models along the marks. This septum can be assumed to connect the structures encompassing the spur with those descending the north wall of the gorge.
On the south side, even more clearly, the analysis of the gorge wall models has revealed a large area of artificially smoothed rock, highlighted by the red area in the third orthophoto of Fig. 11, roughly between Naumann's points A and E but limited at the top by a slightly sloping frame and at the bottom by possible signs of housing large boulders.

Fig. 7 - Orthophotogrammetry of the gorge north face - analysis and location of marks.

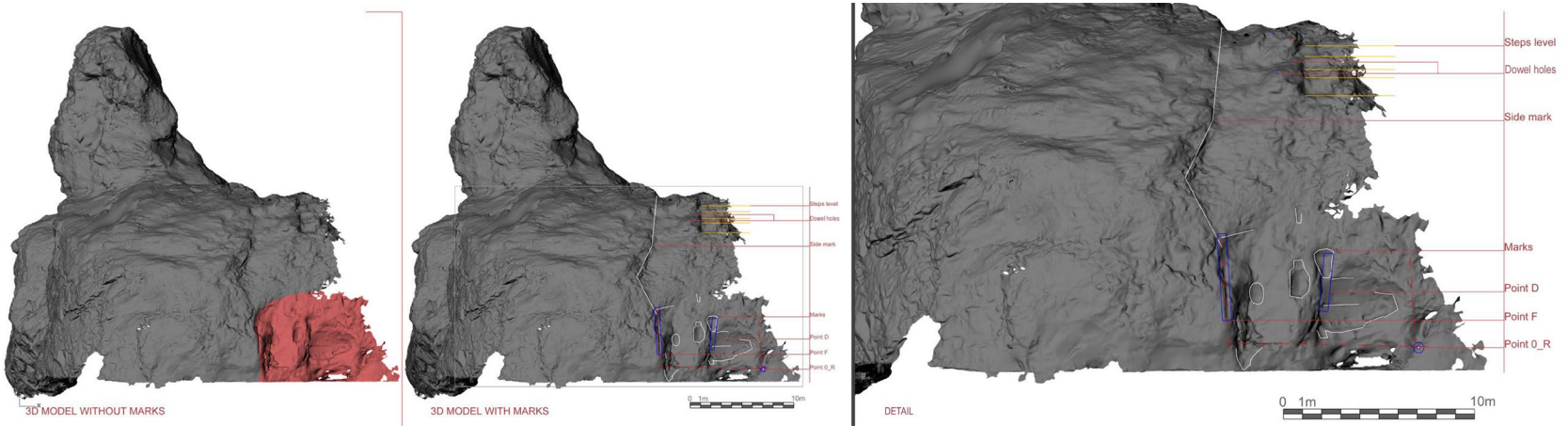

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Fig. 8 - Riegl VZ400 laser scanner survey of the east side of the gorge

The surfaces within this area show, in several places, portions of smoothed surfaces, probably prepared, once again, for the laying of stone blocks. Such worked surfaces can also be found in the westernmost portion of the rock near Naumann's point E, where a niche for a boulder can be found at the point where the natural rock curves southwards. On this gorge's side, the study of the course of the walls is more complex due to the strong irregularity of the stone, the presence of dense vegetation and deposit soils. As for the north side, all the marks were detected and related according to compositional schemes compatible with the places, the defensive functions and the possible course of the walls beyond the gorge. Starting from the most evident traces near the stream, the geometry of the rock was followed on the eastern side, which here is very overhanging (as detected by the model obtained from the DEM) but rises with high steps towards the second spur, near the slopes of Ambarlıkaya. On the south-eastern side no obvious signs of stone processing were found, probably the walls rested directly on the top of the rock (to the east), according to the geometries assumed by Naumann. The dowel holes could give information about the foundation plans on this side of the walls, probably made directly with stone blocks fixed to the rock by wooden or bronze pins, as documented by Seeher in reference to the Kings' Gate (Seeher 2009). In any case, the role of the holes on both sides would require a more accurate investigation of the rocky surfaces to check for the presence of pitting marks, made with typical stone hammers, or polishing, if stones and abrasive materials were used. This analysis and careful study of the holes would also better clarify the role of the steps that on both sides seem to be connected at the same height, for the impost of an older stone structure, if built by the Hittites, or in wood if built in more recent times, when the defensive function of the walls in this area had ceased. On the southern side, as on the northern side, the spur plays a fundamental role in understanding the course of the walls, much lower than the Minaret, but probably predisposed to fulfil the same static role, stiffening the walls and supporting the transversal thrusts of the walls that descend steeply from the Ambarlıkaya slopes. Other marks have been found below the spur and to the north, but they have not yet revealed a clear compositional sequence.

To complete this first series of hypotheses regarding the walls crossing the gorge it is necessary to analyze the sequence of holes on the north-eastern wall of Ambarlıkaya at an altitude of about 13 metres from the present riverbed and the two sections of the tunnel crossing Büyükkaya are missing.

As far as the holes are concerned, the survey data are reported in order to better contextualize the considerations gathered from the two articles by Naumann and Neve: they are aligned following a slope towards the valley of about 4° and that, interpolating the DTM model of the valley with a plane

Fig. 9 - Geometric-spatial simulation of the architectural structures on the north side of the gorge

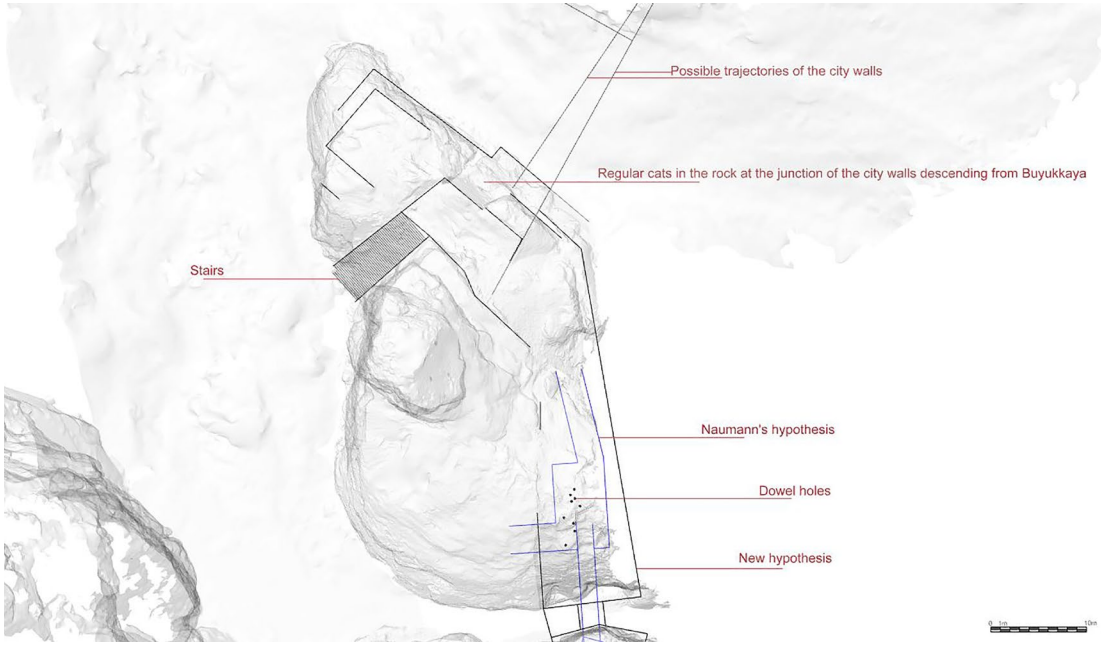

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Fig. 10 - Excavation area with evidence of the ancient wall structure.

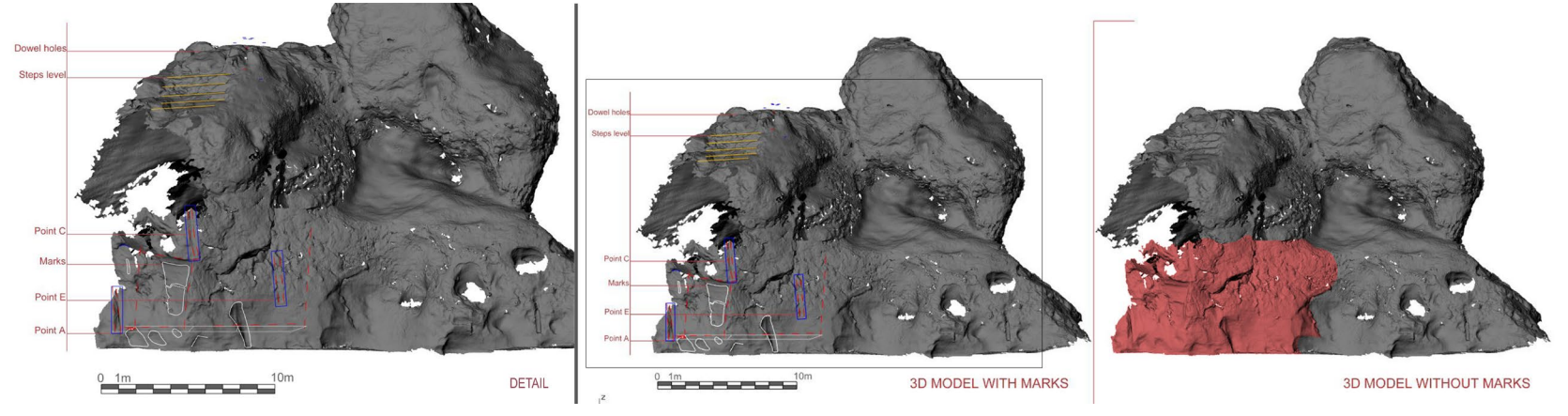
with the same inclination and passing through the holes, the stream intercepts the same height as the first hole at a distance of over 500 metres to the south. Downstream, the same plane, in the area of the excavations of the lower town, is 12.80 metres above the current stream bed. These slope ratios, which would suggest important canalization works upstream, would require precise investigations along the Ambarlıkaya slopes to identify any traces of connection between the hypothesized canal and the architectural structures, the dating of which could shed light on the periods of use of these waterworks. In any case, based on Seeher's studies on the techniques for making dowel holes (Seeher 2005) and taking into account the geometries of the holes on the Ambarlıkaya rocky wall, which are not perfectly circular, sloping downwards (to allow the hooking of cantilever beams) and with undercut areas that suggest the use of chisels or metal tools, it is possible to assume that the work was made later than the Hittite period.

Finally, special attention was given to the survey of the two sections of the tunnel, which had to cross the Büyükkaya massif in an east-west direction, just above the gorge. The processing of the numerical models, the study of the water basin immediately upstream of the gorge and the analysis of the relationships between the height of the stream bed, the entrance to the east tunnel, the entrance to the west tunnel and the traces of the fortification support structures clearly present on the walls of the gorge, have allowed the following considerations to be made:

- The tunnel was most likely designed for water control purposes, with a 9° gradient to the north, i.e. towards the valley in the direction of the so-called 'Unterstadt' area;
- On the basis of the orientation of the two sections, as shown in the plan (Fig. 13), two corrections in the orientation were made during the execution of the work on the south side, the first after about 5 meters, the second about 11 meters from the first;
- These elements lead us to believe that the tunnel designers used trigonometric calculations, which will certainly have to be deepened in further research, perhaps starting by removing the thick layer of soil and guano that covers the entire floor of the southern part of the tunnel, that make the real geometries and height of the cavity difficult to read.

In particular, the height of the southern entrance to the tunnel, if the hypothesis of a use related to the management of the stream's waters is confirmed, could contribute to the reinterpretation of the plane-volumetric development of the walls in correspondence with the gorge, whose reduced width could, in fact, have represented a point of accumulation of debris or vegetation transported by

Fig. 11 - Orthophotogrammetry of the gorge's south face - analysis and location of marks



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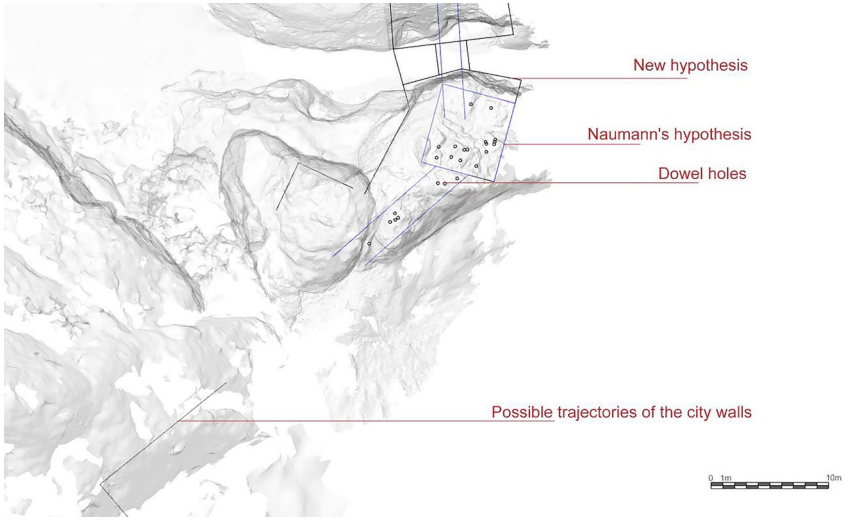

Fig. 12 - Geometric-spatial simulation of the architectural structures on the south side of the gorge.

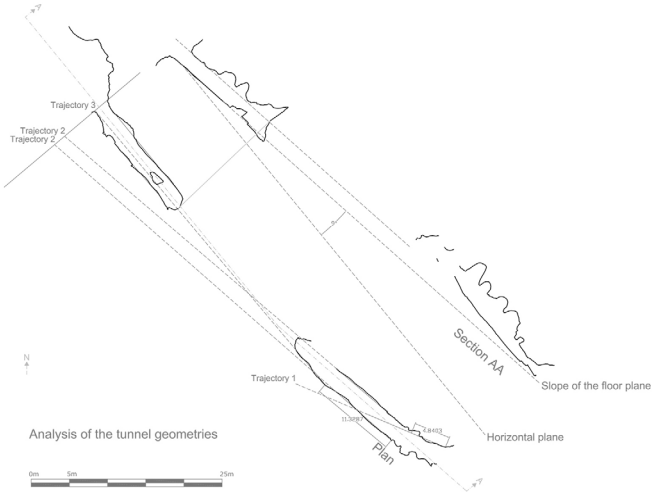

Fig. 13 - Analysis of the tunnel geometries.

the current, either as a result of natural floods or the actions of possible assailants. Such a blockade would in any case have caused the accumulation of a considerable mass of water, which could have damaged the walls on the one hand due to its weight and the thrust of the current, and on the other hand would have allowed the attackers to reach the top of the walls by floating on it. Therefore, the tunnel would have allowed the water to drain away before reaching a critical level, probably lower than the walls at the gorge, thus providing an indication of the possible height of the defensive walls. By simulating with a virtual plane the maximum level of the river in relation to the height of the entrance to the south tunnel, it was found that it exactly intercepts the top level of the south spur and the Minaret in correspondence with an area probably prepared for the laying of stone blocks. This hypothesis, if integrated with the previous considerations regarding the possible stiffening function of the spurs within the masonry, would seem to reinforce the hypothesis that the defensive walls at this point must have been very high and thick.

By interpolating the planimetric and spatial data, structural and technological-constructive considerations, it was possible to hypothesize that the walls were strongly connected to the rock, in some cases encompassing it or continuing its overhanging profiles (mostly on the south, east and north sides), and in others resting on top of it after having smoothed its surfaces (west side). Such a compositional layout and the traces of grafting of large blocks near the gorge would suggest the presence at this point of an arch similar in shape to the other gates of Ḫattuša, stronger than possible wooden structures, which would have guaranteed a greater opening than solutions with stone lintels, indispensable for controlling the flow of water.

6. SIMULATION MODELS AND PARAMETRIC MODELLING

Following the segmentation and analysis of the models, a new parametric modelling activity was undertaken to verify the coherence of the wall development hypotheses at the gorge. In particular, within the virtual space, in which all the models and traces of the marks on the rocks are aligned, volumetric models were generated through the interpolation of analytical and geometric data. The volumes took into account the role of the spurs to the north and south of the gorge, in part by incorporating and relating them to the elevations of the profiles descending from Büyükkaya and Ambarlıkaya, taking into account the more or less evident traces of the blocks' notching along the slopes. The internal geometries of the walls followed the carving marks on the horizontal planes of the rocks, while the external ones were located along the limits of the escarpments, connecting them to the marks on the vertical surfaces of the gorge
The parametric modelling activities, in the development phase, started from the definition of: 1. the input, consisting of the numerical-real data converted into geometric entities; 2. the processing, represented by the geometric modelling of the volumes; 3. the output, the set of logical

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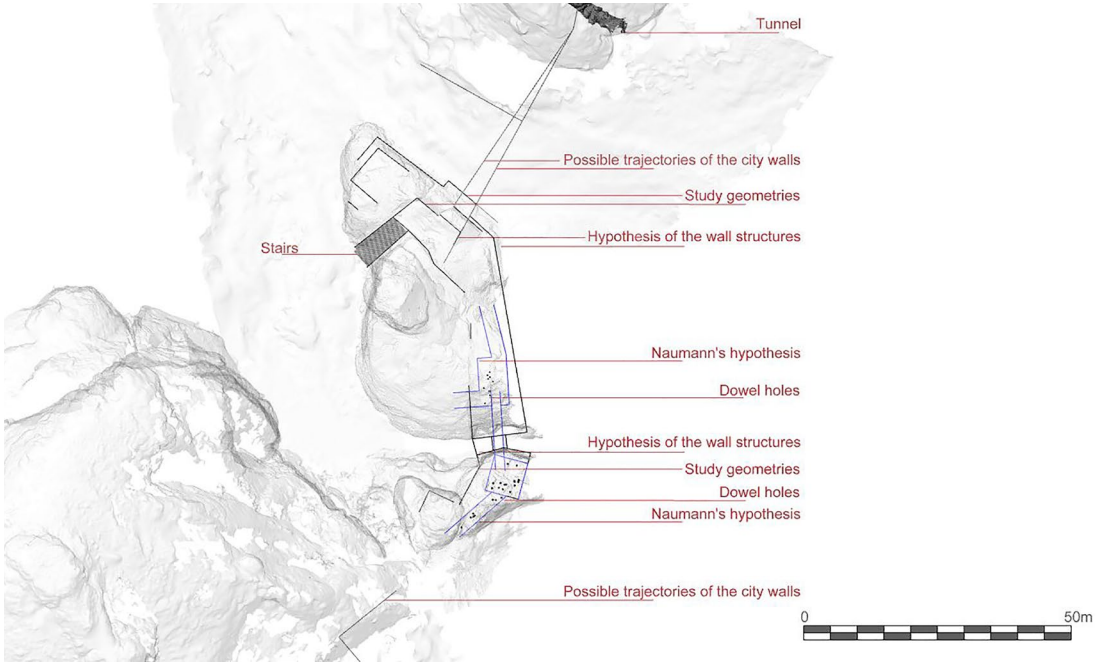

Fig. 14 - Planimetry of the marks drawn by means of model analysis.

schemes that define the modulation processes of the structures on the basis of fixed (the marks drawn on the rocks) and variables parameters (construction hypotheses formulated from functional and technical- construction considerations). The current work steps involved the processing of real data into digital information to be sequenced through the algorithm developed in the Grasshopper software.
Operationally, the different geometric entities were categorized:

- localized real points and numerical surfaces acquired by means of 3D scanners
- interpolated real points to create objects: polyline or spline
- NURBS modelled from the previously generated polyline or spline.

These three categories define the levels of interoperability of the referenced data: the first defines the spatial matrix of the algorithm; the second defines the influence that the geometric matrix has on the reconstruction process, emphasizing or reducing the features of the simulated architecture; the third, hooking up to the second point, develops the architectural/design aspects, i.e. the identification of a formal recurrence or a building typology. The activities carried out have verified the consistency of the automatic generation of a polyline from the surveyed points, from which to extract the geometric model that follows precise rules dictated by the algorithm's core; in addition, the digital translation of the construction types of the walls of Ḫattuša is being carried out, starting from the portion reconstructed by Seeher and surveyed by means of the Riegl laser scanner, so as to provide the algorithm with proportional averages of the volumes and geometric recurrences in the relationships between towers, walls and openings.

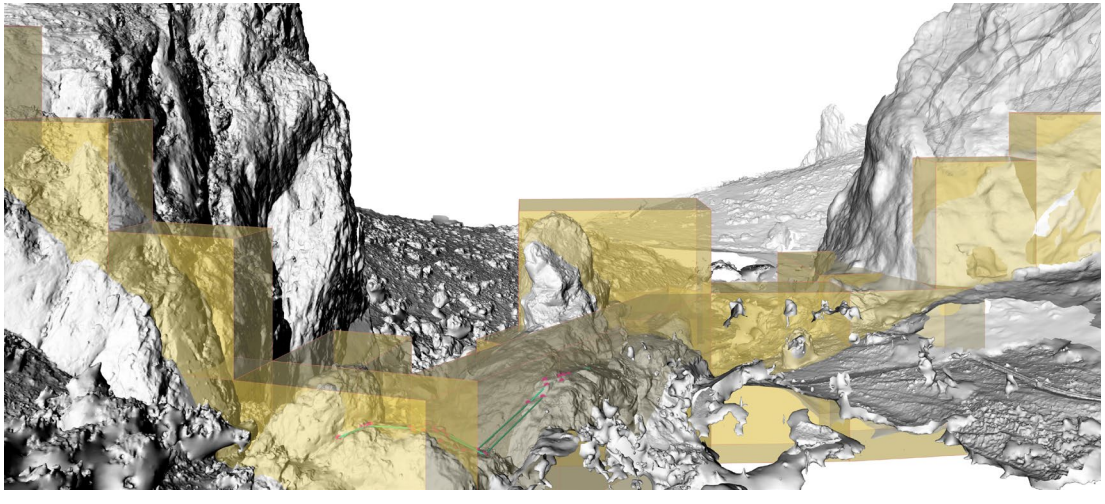

Fig. 15 - Volumetric study of the walls.

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7. FINAL REMARKS

The paper presents the first outcomes of a methodology for the study of a complex archaeological landscape, such as the Ḫattuša Gorge, based on the extraction, cataloguing and topological analysis of the marks surveyed by three-dimensional digitization instruments and systems. These marks, starting from experimental procedures of management and segmentation of point clouds and numerical models, have been sequenced in logical relationship patterns within information matrices referring to archaeological, technological and functional studies related to Hittite architecture. The extracted features were managed within the parametric software Grasshopper, which allowed a progressive verification of the reconstructive hypotheses of the architectural structures consistent with the marks detected on the rocks and with typological models obtained from the walls reconstructed in the north-west sector of the site. Future developments of the algorithm will aim at a greater automation of modelling procedures and in particular of the interpolation of data related to ancient building techniques, the latter still verified non-automatically.

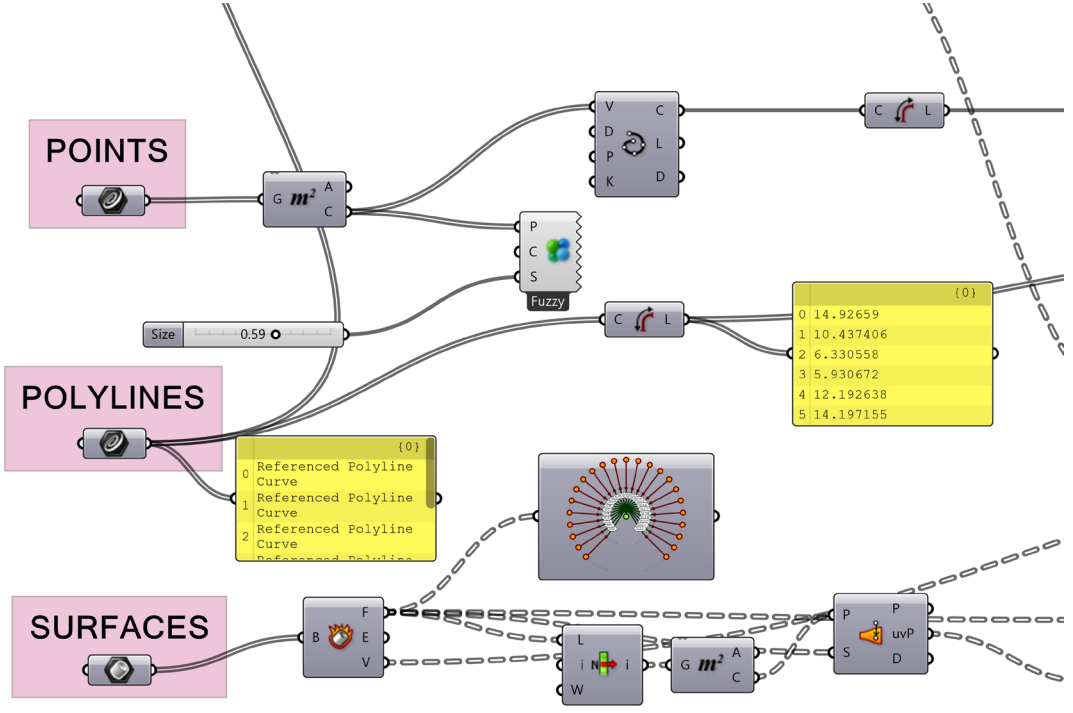

Fig. 16 - Logical diagram of data interpolation within the Grasshopper software.

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