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Mirko Novák und Deniz Yaşin (Hg.)

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Der hethitischen Kultkomplex und die Felsreliefs in Sirkeli Höyük

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Der hethitischen Kultkomplex und die Felsreliefs in Sirkeli Höyük

von
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Umschlagfoto: 3D-Modell von SİRKELİ 1 aus der orthofotografischen Aufnahme (© Massimiliano Marazzi)

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Inhaltsverzeichnis

Chapter 4

3D digitization of the Sirkeli rock reliefs

Leopoldo Repola

Introduction

With the advent of digital technology, aspects related to the study, understanding and enhancement of cultural heritage have undergone a radical change, shifting the limits of perception and critical schemes beyond the conventional evaluation procedures, imposing a joint knowledge of the humanities and technologies. Digital data generation processes require a clear strategy for their use, offering vast possibilities in terms of extending the quantity and quality of information. While the development of three-dimensional digitization systems, especially linked to the use of Structure from Motion technology and increasingly intuitive photogrammetry software and to the spread of high-performance and low-cost digital cameras and drones, has led to a strong increase in the applications of 3D surveying in numerous fields of the professions and research, there has not been an equal development of theories and methods of data management within their extended life cycle. More and more the post processing phases stop at the production of point clouds or mesh models as automatically generated by photogrammetric processing software, from which metric information, images or simple animations can be extracted. All this stems from the ordinary approach characterized by a total absence of a survey project and even more so of a strategy for using data, which, if well structured, allow complex processes of analyzing models, extracting information not visible in the real environment, managing and interrelating data in GIS or SIM platforms, and representing and communicating data through new languages that now extend the complex spaces of the virtual.[1]

Furthermore, the performance afforded by 3D scanners (quantity of points recorded per scan and speed of execution) allows even complex geometries to be studied and modelled far beyond the limits of conventional surveying techniques. The need to reconstruct surfaces with varying curvatures entails a continuous surveying of points in space that only a three-dimensional scan can offer through the so-called 'point cloud', which represents the real mathematical model of the object to be surveyed. This process therefore appears to be the opposite of the classic method, in which a number of fixed points are measured and then two-dimensional drawings are made and finally the volumes are reconstructed in 3D, whereas in the case of the 3D scanner survey, the starting data is a model in the form of points in its entirety, from which one starts to obtain the set of information sought, including, for example, orthogonal projections (the classic plans, elevations and sections). The three-dimensional survey can be performed with active or passive systems, to the former belong three-dimensional scanners in their different types, time-of-flight, phase-difference, optical triangulation, structured light; to the latter belong photogrammetric systems, based on the processing of images acquired according to specific procedures. The schedule for the three-dimensional digitization of the Sirkeli archaeological site involved the use of both systems, specifically ground and drone photogrammetric systems and Riegl's LMS-Z420i time-of-flight scanner and Artec Eva structured light scanner.

The 2017 three-dimensional survey campaign

In agreement with the Swiss Archaeological Mission of the University of Bern at Sirkeli Höyük, the research team of the University of Naples conducted a research campaign in the summer of 2017, the main objective of which was to survey, by means of innovative scanning procedures, the rocky outcrop located by and overlooking the Ceyhan River, on the surface of which the remains of two Hittite reliefs[2] and the adjacent architectural structures are locat-

1 Repola 2018: 781–788.

2 The activities of the Italian working group were supported by the Italian Ministero degli Affari Esteri e della Cooperazione Internazio (DG VI: Multilateral cultural cooperation, archaeological missions).

Fig. 1: Topographic survey phases (Photo: L. Repola, 2017).

Fig. 2: Location of topographic stations (Map: S. Tilia, 2017).

Name station	Local x, y, z coordinates	Area	Sirkeli stations
SOB 100 = REL001	3138.409, 6076.417, 19.032	Hittite building and adjacent rocky outcrop	REL001
SOB 200 = REL002	3138.071, 6081.526, 18.869		REL002
SOB 300 = REL003	3136.848, 6078.447, 19.179		REL003
SOB 400	3139.019, 6068.853, 19.221		
SOB 500	3111.202, 6044.465, 28.612		
SOB 600	3119.409, 6066.567, 30.471		

Fig. 3: Coordinates of new stations linked to existing topographic stations.

Target typology	Instruments used	Application area	
Black and white paper squares of 5cm sides	Panasonic DMC-TZ40 and Nikon D5300	Detailed survey of the decorated rock faces	
Cylindrical and flat markers of 5 and 10 cm of reflective material	TOF Laser Scanner Riegl LMS-Z420i	Survey of rocks and architectural structures	
Aluminum scale bars	GoPro Hero camera	Survey of rocks	
Aluminum scale bars	DJI Drone	Archaeological site	

Fig. 4: Type of targets used in reference to the instruments and the surveyed areas.

ed. The digitization activities followed an accurate planning phase of survey activities and data management, both focused on the objectives of the investigations: to obtain a general model of the area and the archaeological structures on the western side of the spur and an accurate survey of the rocky planes facing the river characterized by the presence of hieroglyphic reliefs. Therefore, a workflow of field survey activities and data processing was defined in order to obtain a series of models aligned in a single virtual space and scalable in relation to the needs of archaeologists and epigraphers, aimed at the recognition of artificial marks on the rock attributable to ancient reliefs now no longer recognizable.

Field survey activities

The digitization phases started with the planning of a topographic survey through a Leica TCR405 total station (**Fig. 1**), 3 new stations were materialized (their connection with the existing topographical stations and their positioning are shown in **Fig. 3** and **Fig. 2** respectively), aimed at surveying the targets to support the various instruments used, so as to guarantee the automatic referencing of the models. The following were placed in the area: 30 flat black and white square targets, 5 cm per side, to support the photogrammetric surveys; 12 cylindrical targets, 4 of 10 cm in diameter by 10 cm in height and 8 of 5 cm in diameter by 5 cm in height for the Riegl laser scanner surveys; 9 aluminum scale bars with pairs of markers at a distance of 50 cm for the referencing and scaling of the models produced by the Hero camera and the same 9 scale bars, placed in other positions, for the drone survey. Once the targets were located and surveyed, the digitization phases were started using the Riegl LMS-Z420i time-of-flight scanner (**Fig. 5**), and 18 scan positions were carried out, 12 of which were on the rocky outcrop and excavation area and 6 below the outcrop and along the decorated faces (**Fig. 6**).

The scans were produced with varying resolutions depending on the type of surfaces to be acquired: higher resolutions were used for the survey of

Fig. 5: Survey phases using the Riegl LMS-Z420i laser scanner (Photo: L. Repola, 2017).

Fig. 6: Scanpositions placing carried out with the Riegl LMS-Z420i laser scanner (© L. Repola, 2017).

wall septa and rock surfaces, with a resolution of 5 mm at a distance of 10 meters, and of decorated rock portions, with a resolution of 2 mm at a distance of 10 meters. The scans were aligned by 5 and 10 cm diameter cylindrical markers, automatically detected by the RiscanPro scanner and point cloud management software, therefore the final resolution of the model was higher thanks to the interpolation of the points of the different scanpositions. During the interpolation procedures, redundant points from the most distant scans were removed (due to the increased presence of noise) and the clouds were subsequently uniformed to a constant average resolution of 1.5 mm.

Digitization procedures using laser scanners were combined with acquisitions using a Hero camera, along the riverfront and summit surfaces of the rocky outcrop. 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 scale bars 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 the total station.

The surveys using photogrammetric systems were then integrated by detailed acquisitions of the rock surfaces characterized by the presence of hieroglyphic reliefs. Two different cameras equipped with zoom and macro lenses, a Panasonic DMC-TZ40 and a Nikon D5300, were used for these activities (**Fig. 7**).

A final photogrammetric acquisition procedure was carried out using DJI's Phantom 4 drone to sur-

Fig. 7: Phases of photogrammetric digitization (Photo: M. Marazzi, 2017).

Fig. 8 Drone surveying phases (Photo: L. Repola, 2017).

Fig. 9: Detailed surveys using structured light scanner Art Eva (Photo: M. Marazzi, 2017).

vey the broader context of the archaeological area and the rocky outcrop, in order to integrate the holes in the model produced by the scanner due to the presence of vegetation and deep cracks in the rock. Again, the scale bars for the previous Hero camera photogrammetric survey were used (**Fig. 8**).

Finally, the survey activities carried out using the Artec Eva scanner were of particular importance due to the versatility of use of this instrument and the high level of accuracy guaranteed by structured light stereophotogrammetry, which identifies homologous points of the surface to be acquired on the various images thanks to the different deformation of the light patterns detected by the cameras. In order to obtain a more accurate acquisition (up to 0.1 mm) of the articulated inscribed surfaces, a procedure was devised aimed at the attainment of a high level of continuity of points on the surveyed surfaces. The procedure concerning the use of the instrument was planned on the field, based on the dominating geometries of the symbols and shape of the area to be surveyed. Several reference points were defined by placing some markers on the rock, roughly in a square grid pattern, both to avoid more passages over the same areas and to use them to align the points clouds of the different scan positions. The acquisition procedures focused on all rock surfaces characterized by the presence of hieroglyphic reliefs and on neighboring areas that showed possible signs of workmanship that could be traced back to reliefs or rock preparation surfaces for future engravings (**Fig. 9**).

Data processing

The early stages of data management consisted in the alignment of point clouds produced by Riegl TOF scanner, by importing the topographic coordinates of the markers detected by the total station, within the local reference system. Then the data relative to the various scan positions were cleaned of vegetation and filtered to eliminate the effects of noise. Each point cloud of the different surveyed areas was managed separately, because they have different features. The basic procedures involve the segmentation of the clouds into points relative to the terrain, rocks and architectural elements. For each of them specific procedures for removing noise and discretizing the points are applied, greatly reducing the accuracy for the parts relating to the ground and maintaining maximum accuracy for rocks and walls.

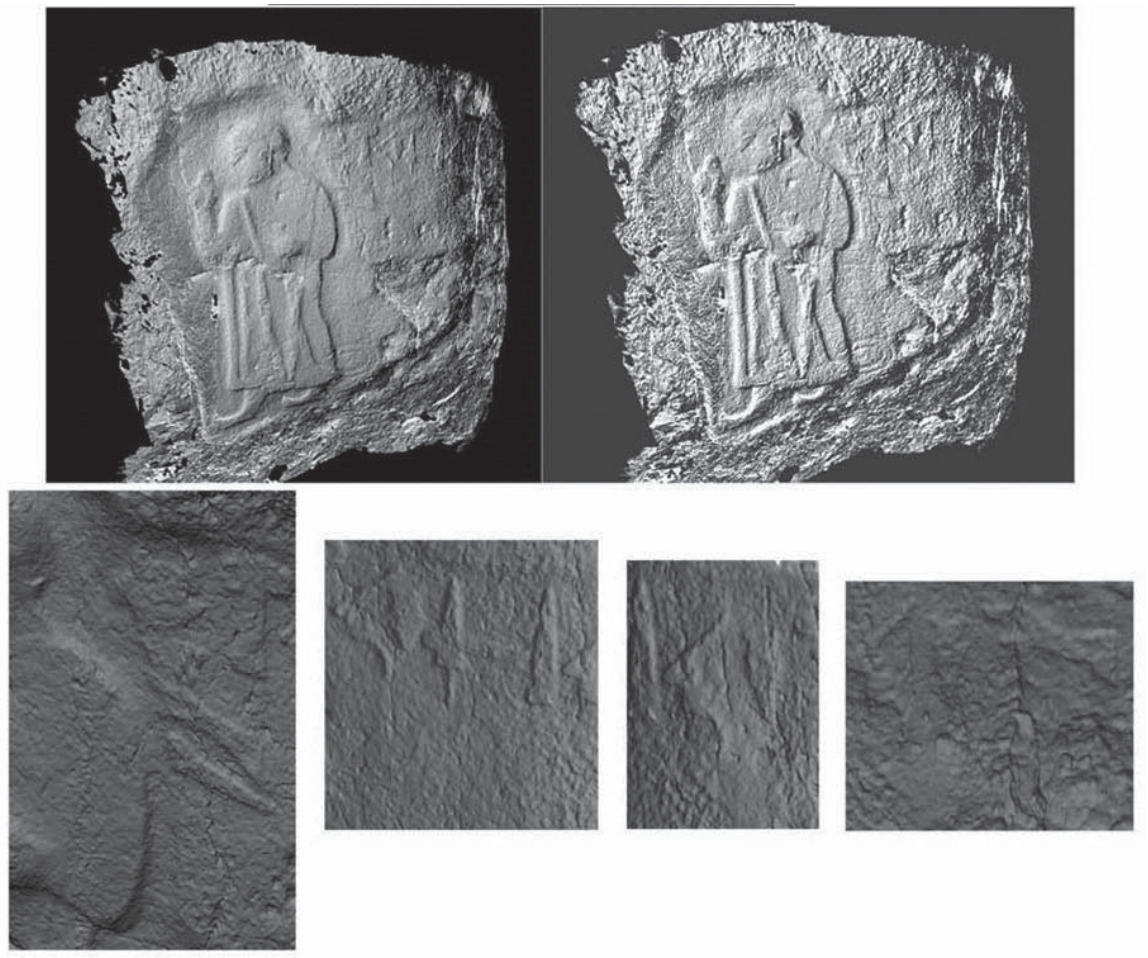

Fig. 10: Different views (with different light and rotation settings) of the Muwatalli model (generated by structured light scanner) and its hieroglyphic inscription (© L. Repola, 2017).

The detail models produced by the different surveying systems were aligned on the point clouds generated by the TOF scanner and subsequently textured mesh models were generated. Once the alignment and subdivision phases of the different clouds were completed, the polygonal models were generated, the analysis procedures were then carried out on the detailed geometries of the hieroglyphics, but also on the architectural structures and the geometric features of the rocks.

With reference to the study of the reliefs and hieroglyphics, very high-definition models of the surfaces were produced, with and without textures, in order to guarantee differentiated procedures for the visualization of the signs. The files were then prepared to be managed within software for virtual animations in which to verify interactive procedures of modeling and the control of the points of view and lights, as well as of characterization of parts and possible geometric lines referable to the signs, to better read forms not otherwise recognizable with traditional systems of investigation.

In particular, the relief of Muwattalli (II), which has long been known, has already been graphically and photographically documented several times. The hieroglyphic inscription is the *Classicum* of that phase of Anatolian hieroglyphic writing characterized by the monumental use of glyphs which serve simultaneously as characters and iconographic elements of the relief compositions.[3] However, models without high-resolution textures offer interesting insights into the volumetric and paleographic properties of hieroglyphic reliefs and forms (cf. **Fig. 10**). In addition, the high resolution of the models made it possible to highlight the surface characteristics of the rock preparation areas in relation to the unpolished natural areas, allowing morphological comparisons to be made with the surfaces of the other two reliefs studied. These investigations were carried out by superimposing 10 × 10 cm and 5 × 5 cm model portions of possible homologous areas, depending on the curvature of the extracted surfaces, within the Cloud Compare software (**Fig. 11**).

3 See Marazzi in **chapter 3**.

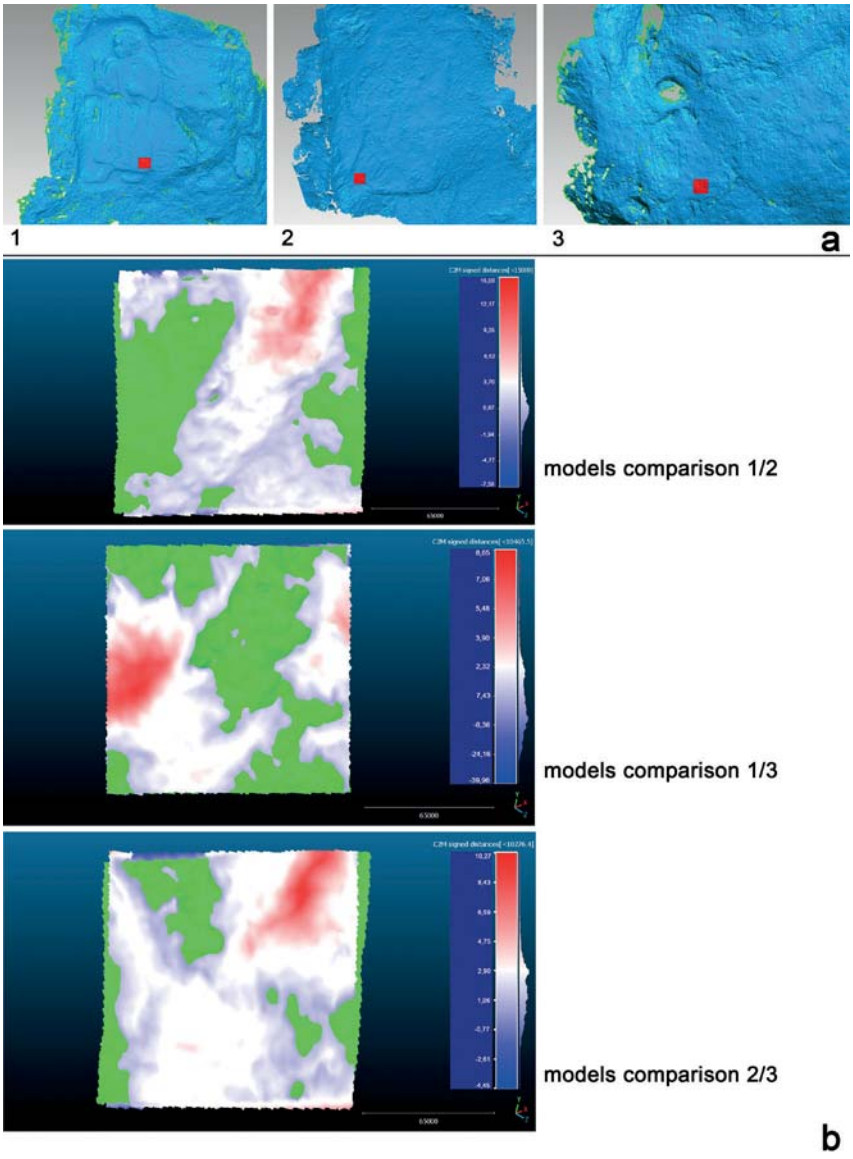

Fig. 11: **a.** Location of the areas analyzed on the three surveys. **b.** Comparison procedures for pairs of models with indication of deviations in millimeters (© L. Repola, 2023).

The second, unidentifiable hieroglyph, discovered only in 1994, is located on the right side of the rock face.[4] Its surface is considerably damaged, but it is possible to identify some worked areas on it, that suggest prior surface preparation activity, as can be seen on the model, which shows a clear regularity compared to the rough inner parts. The local analysis of the surface also shows that the rock face forms a slight curve, requiring a more complex work of cutting and smoothing the rock to obtain a sufficiently flat area necessary for the relief figure, as evidenced by the presence of a frame, 'threshold', still partially present on the lower edge of the relief. The model of this second relief, subjected to a stretching procedure along the axis perpendicular to the plane of the rock face, made it possible to highlight many details of the figure (**Fig. 12**) while the area of the figure may appear to have been eroded by the action of atmospheric agents, the interpretation of the marks in correspondence with the face is more controversial. The geometry of the face appears to be more rugged and to follow inclinations that are not entirely consistent with the flow of water, the effects of which are evident at the edges of the figure on both sides (**Fig. 13**).

On the other hand, the similarity of the surface at the face with a small gap in the lower right-hand part of the relief, the latter probably not due to human activity, does not completely exclude the hypothesis of a natural disruption (**Fig. 14**).

In addition, a third surface located in a natural depression between the two previously described

4 Ehringhaus 1995a: 66.

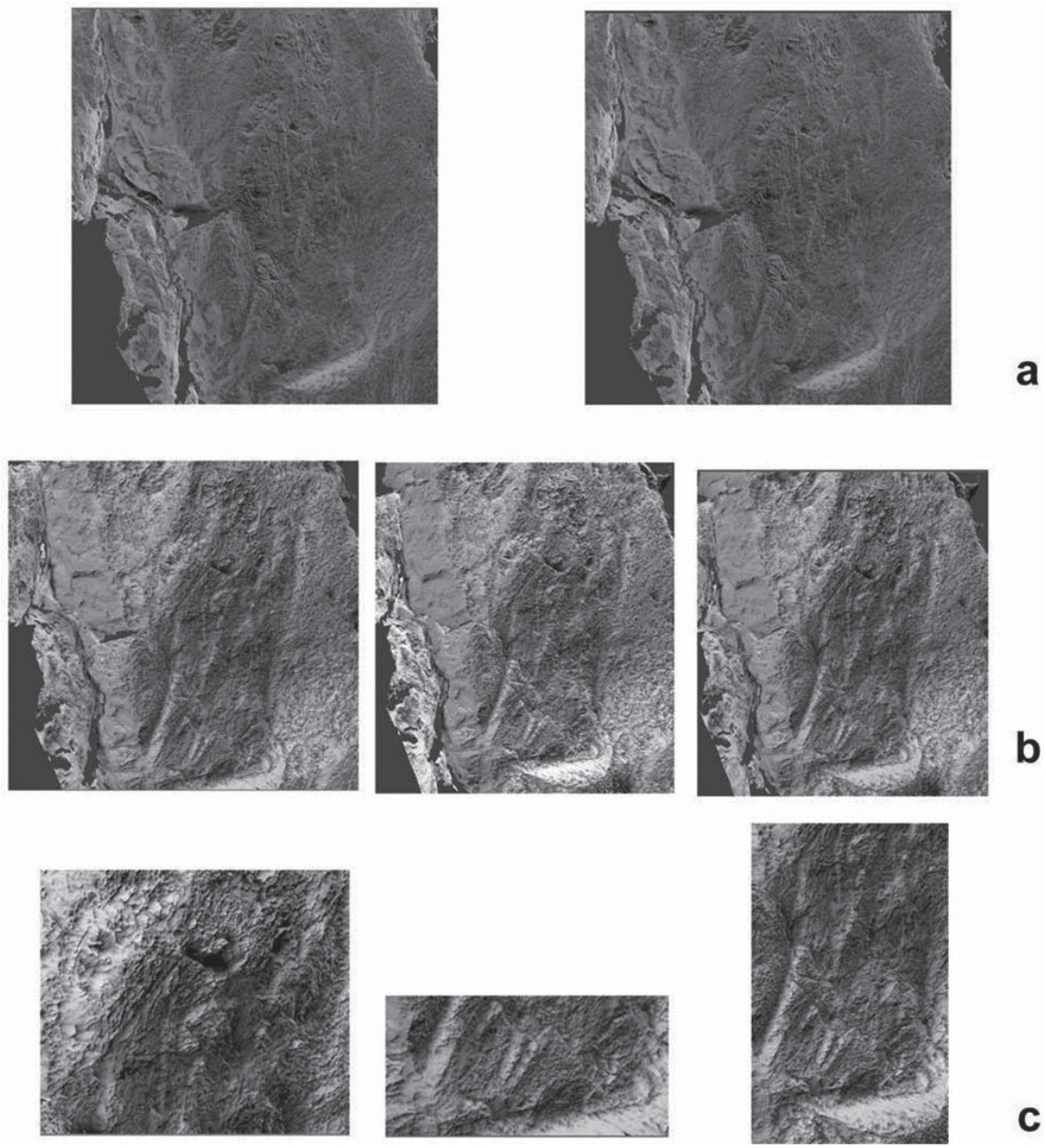

Fig. 12: Model of the 2nd relief generated by the structured light scanner. **a.** The overall relief at different light settings; **b.** The overall relief (200 % stretching setting) at different light settings; **c.** The details (200 % stretching setting) of the hand, the lower part with the right shoe, the entire lower part (© L. Repola, 2023).

reliefs was examined. Traces of workmanship on the rock surface suggested either the possible presence of a third relief (now completely disappeared), which, based on new data processing procedures focused on a segmentation of the mesh by areas according to roughness and curvature indices extracted by means of a rasterization process of the model in Cloud Compare (**Fig. 15**) and the selective use of noise reduction filters by curvature priority for each area. Such processing allowed for a higher density of the point cloud that revealed traces of an original relief that point towards the hypothesis of surface erosion related to the complex cracking state present on the summit surfaces of the spur, as evidenced by the model produced by a time-of-flight laser scanner and by drone (**Fig. 16–17**).[5]

Furthermore, the more extensive models generated by drone photogrammetry, which were also filtered to remove noise and optimized for the subsequent phases of alignment with the models produced by laser scanning, highlighted the close relationship between the path marked out by the reliefs,

5 See Schneider in **chapter 5**.

Fig. 13: Checking rainwater downflow areas, comparing the numerical model with the real image (© L. Repola, 2023).

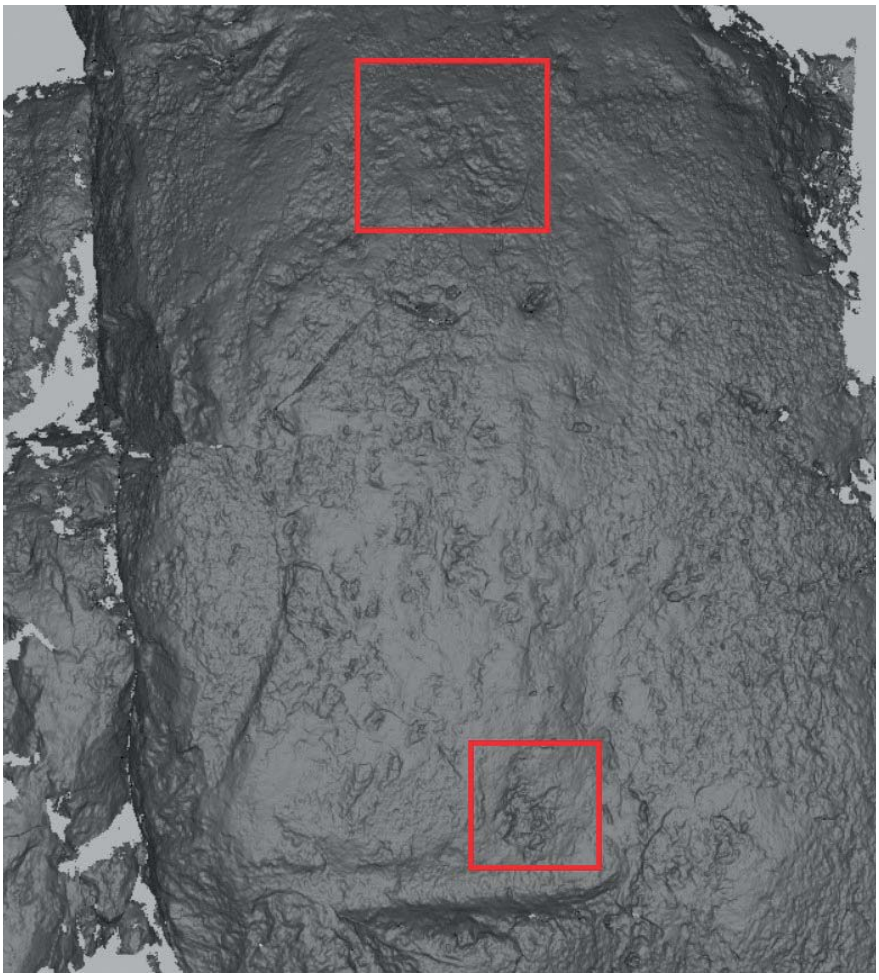

Fig. 14: Location of the face area and the gap near the base of the relief (© L. Repola, 2023).

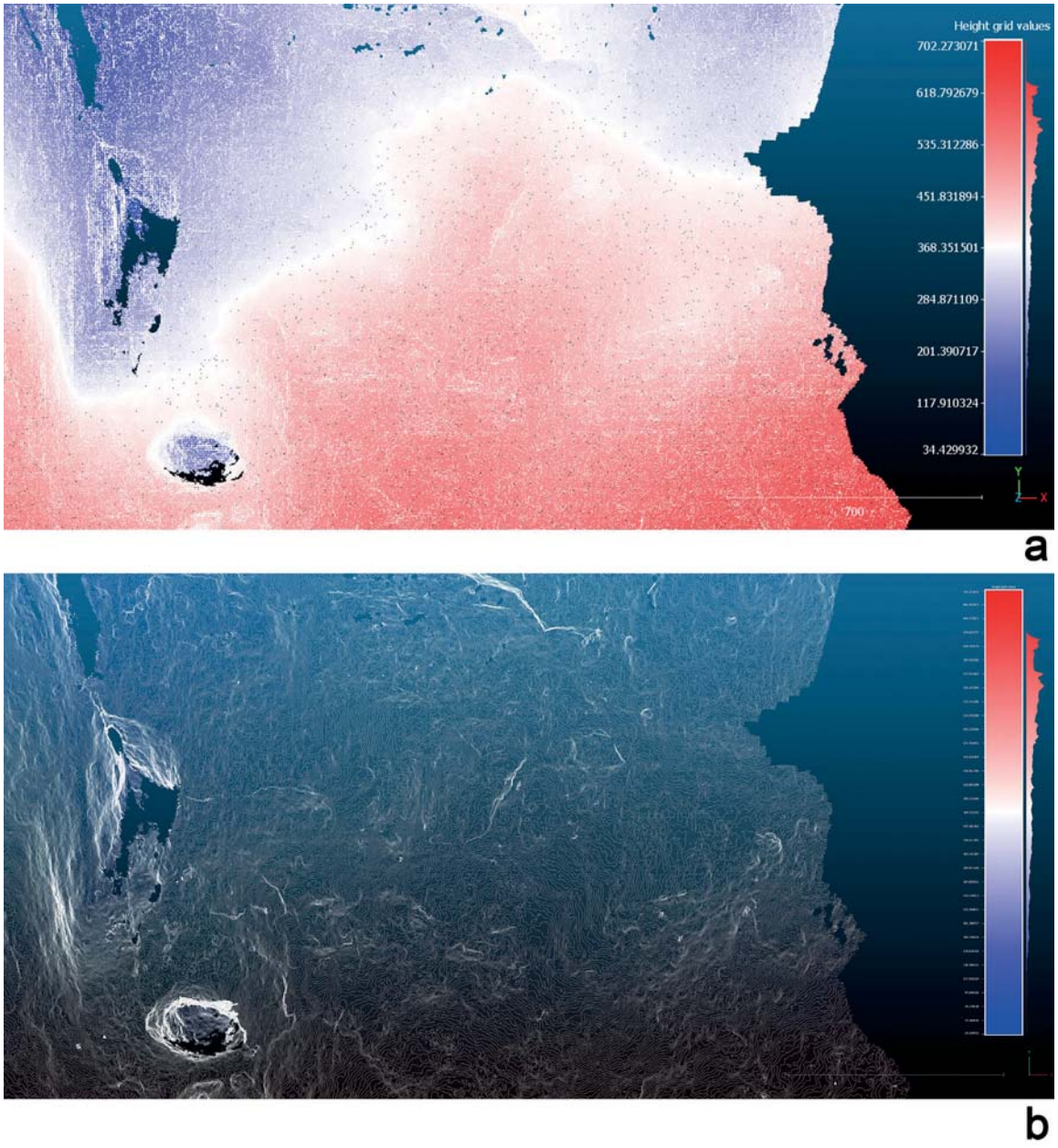

Fig. 15: Chromatic scale (**a**) and roughness map (**b**) obtained in cloud environment appears, through the "convert cloud to 2D raster" command. Grid: step 1.5; Projection direction: z; Cell height: average; Interpolate (SF): average value; Empty cells Fill with leave empty; Contour plot: start contour lines 0, pitch 1.5 (© L. Repola, 2023).

the rocky planes and the river, as well as between the west side of the rocks and the neighboring architectural structures. The combined analysis of the drone and laser scanner models have in fact highlighted areas of the rock probably worked by man to adapt them to new uses, particularly towards the septa, in order to better collaborate with the bottom structures, and on the top, also in relation to the presence of deep cracks that lent themselves well to the regular cutting of blocks and the preparation of support surfaces for any structures. Further on-site investigations aimed at the high-resolution survey of such areas, aligned with the general models, could contribute to a more extensive re-reading of the architectural space in relation to the monument's functions and compositional layout. From the ongoing research on the site of Hattuša,[6] it is becoming increasingly clear, in fact, the strong symbolic value that Hittite architects gave to certain architectural solutions in relation to the use of rocks as the base of their buildings and as parts of a broader 'image' representation of their civilization. Moreover, by ex-

6 Repola 2019–2020: 181–200.

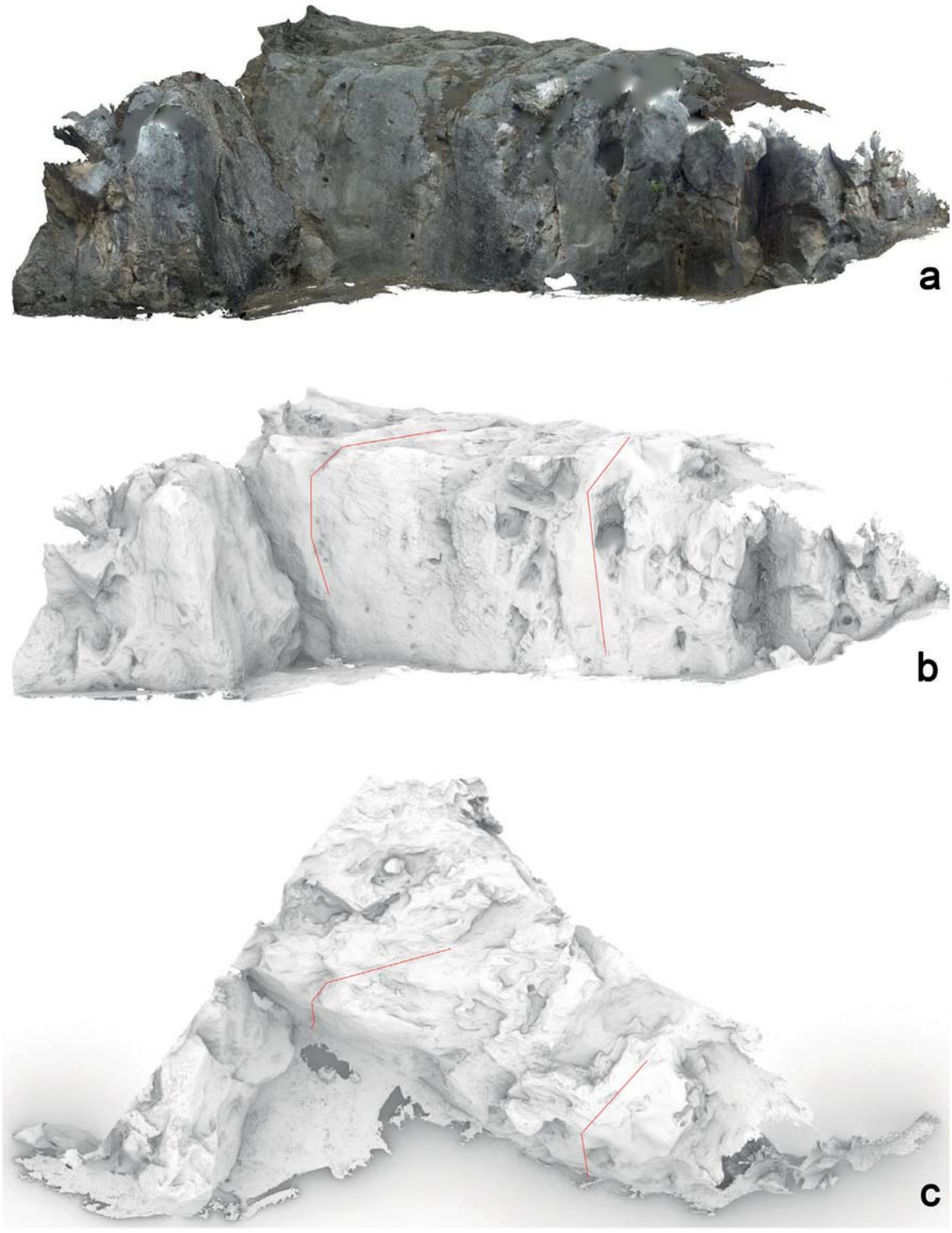

Fig. 16: Location of rainwater downflow areas from the top of the spur towards the reliefs. **a.** Orthophoto of the decorated slope of the spur; **b.** Black and white orthophoto of the decorated slope of the spur; **c.** Black and white orthophoto of the top of the spur (© L. Repola, 2023).

Fig. 17: Orthophoto by drone of the top of the spur (© L. Repola, 2023).

tending the surveys using drone Lidar beyond the excavation area, the ancient orography of the places could be redefined, digitally recomposing the features of the ancient landscape within which to relocate the signs of an architecture that had a strong dialogue with the territory, placing itself as a scenario for the representation of the cultural identity of a people.

New developments in geospatial data management and communication

It is from the *genius loci* of archaeological landscapes that it is necessary to start for a profound understanding of the meaning of ancient places, of the value of cultural identities that are recomposed among the signs of archeology, among the languages of the arts that restore the sense of the vision of reality, among the forms of architecture that contained functions and even more the symbols of a coexistence between nature and the supernatural. Ancient cities, monumental architectures and more, give us back the traces of the being of peoples in a place, with all the folds of proximity and distance, of belonging to a landscape as to the subtle links of routes that cut through heights, go along valleys bordering watercourses or rocky plains. All this must compose the data analysis of an archaeological context, using the digital far beyond the reduced schemes of reproposing, re-presentation, of reality. While the numerical models produced by three-dimensional acquisitions provide spatial representation systems in which to move in order to recognize and survey signs, they can also implement, if appropriately processed and segmentized, topological platforms for the interrelation of geospatial data, through which more complex analysis processes can be developed. Indeed, the role of digital technologies in developing

dynamic data-relationship structures within which to interpolate quantitative and qualitative data into the geometric consistency of real space, simulated by means of three-dimensional acquisition technologies, is becoming increasingly clear. Such information relationship structures require multi-disciplinary approaches in the recognition, registration and data management phases, and similarly require a dynamic approach to the development of the logical modeling process, which underlies patterns of relationships between fields of research and qualitative relationships between information. In such a research framework, numerical models are defined as a digital artefact for the cataloguing, analyzing and representing archaeological data, in which the complexities of spatial relationships synchronously compile information from the different research fields. While the development of logical data interrelation models is therefore open to the use of tools such as ArcGIS PRO's ModelBuilder, it can also support simulation processes of research hypotheses at different scales of information representation. These visual programming tools for the construction of geoprocessing workflows will allow to automate and document the spatial analysis and data management processes, whereby data interrelation sequences will verify the coincidence of contextual, historical-cultural conditions and technologies, which have influenced over time the shapes, dimensions and location along the Sirkeli rocks of the iconographic layout and wall structures. The potential offered by digital technologies intervenes from the earliest stages of data structuring, extending their effects on archiving methodologies and the development of relations that link them to events, thus opening the historical narration to new forms of representation and learning through languages that go beyond the outcomes of scientific research alone. The digital, whether it relates to texts, objects or architectural space, places the data in a metamorphic nature that is strongly related to its contexts and events, which can be associated according to complex connection schemes (in some cases non-consequential) and which refer to meta-structured relationships. These relations open the use of information to sharing models proper to the development mechanisms of collective intelligence, which, in turn, require management models belonging to the logics structuring topological spaces. In fact, digitization processes produce not only geometric and quantitative information about objects and architecture, but also make it possible to relate them within virtual space to support unprecedented representation and analysis procedures. These systems include virtual objects in sharing mechanisms, which go beyond the boundaries of the disciplines of study that first determine them, so the use of technologies is connected to the issues of information exchange and management within their life cycle, which in the digital age coincides with the need to transform the interdisciplinary approach into a rigorous scientific method.

Hence the new research perspective at Sirkeli, shared with Prof. Mirko Novák and colleagues at the University of Bern, to develop model processing procedures to support forms of data visualization in augmented environments. The idea is to standardize the different types of data into a single multidimensional system of representation and defined by means of common information layers, aimed at the graphic development of the complex patterns of relationships between finds, contexts of provenance and the extended set of information that make up the Hittite cultural environment in the Cilician plain. What is proposed is a modular exhibit design, reconfigurable in different exhibition spaces, in which to represent the characteristics of the archaeological landscape that determined the flourishing of the city along the banks of the river Ceyhan, from which to resurface the archaeological areas through semantic maps to which to connect information levels related to the study and interpretation of the excavation data. This first block of information would be followed by a second area of narration of the figurative languages traceable from the material heritage, of the possible symbolic or functional role of the objects from which the interpretative schemes of the built space are derived. In this way, the numerical data from three-dimensional scanning would collaborate in the entirety of their documentary potential in the construction of the analytical datum, on the one hand in its representation within a logical process that defines its presumed qualities, and on the other hand in its representation in a narrative framework that defines it within the space of use and the matrices of actions that are linked to it as a result of the semantic interpretation of the archaeological context. Representation systems will have to remodel themselves according to generative diagrams capable of providing perceptive-cognitive maps oriented towards a deep knowledge of the data and its environment. Digital and representation as its generating tool, define a connection between the real and its own forms of abstraction, which take place in thought and imagination. The image of the space in which possible correlations between information take place has been greatly enhanced, including the dimensions of the possible alongside the categories of the real, of the actual alongside the extended contexts of the virtual.[7] What the use of the virtual must investigate and map into dynamic structures of list is the possibility of including different perceptual states in the synchronic instant of representation and generation of 'variable contexts', rendered through multi-dimensional images. A spatially based hybrid scalar system is thus outlined,

7 Deleuze 1997: 107–115.

recalling the concept of the *Spatial Turn*[8] and mapping the geography of places according to indices of relationships, which, in the case of Sirkeli's exhibit project, would provide a visual relationship scheme between the various excavated areas and zones of the city with the articulated plan of events that composed the histories of the settlement. And it is here, at the point where architecture becomes material and the site of events, that the twist takes place from a history composed according to the index of time to a narrative that traverses the folds of space along the infinite dimensions of possible, supposed, imagined times. "Spatial imagination redeems geography from the subordinate role to which it had been confined in the 19th century by a 'decapitalized' view of the historical process hinged on the image of successive 'stages' of development and marked by an 'orientalistic' non-observance for the multiplicity and contingency of the dynamics of change." [9] Time and space accord themselves in sequences of actualities that contain, without concluding them, all possible lines of events. The latter, as nodes of actuality, persist due to the extension of the virtual that encompasses them and the signs that reveal them in images in the flow of narratives, of stories.

"Actualization is creation, the invention of a form from a dynamic configuration of forces and purposes. There is more going on here than the conferring of reality on a possible or choice within a predetermined whole: a production of new qualities, a transformation of ideas, a real becoming that in return feeds the virtual itself."[10]

In turn, the virtual by means of the digital, which is one of its possible means of actualization, alters the relationships of proximity and scale of the contexts and signs found in them. The virtual opens matter to its complex phenomena, while digital languages allow for complex forms of recording and procedures of data representation. Similarly, the virtual connects matter to the extensive phenomena of the spaces in which it takes shape, while time traces the signs of the events that occurred on it. In this multidimensional and variable place, perceptual experiences, registration schemes and representation maps of the mind contribute to the formation of critical processes and the production of solutions of thought beyond the limits of established logical-deductive mechanisms. Hence the idea of our project to redefine and integrate the data construction procedures, to then include it using parametric modelling software in consistency verification schemes into which historical, aesthetic-formal and technological-constructive information can be merged, to then feed data visualization systems of a poetic narrative type by means of immersive spaces, rendered only through mapped projections and soundscapes.

8 Warf/Arias 2009: 1–10.

9 Marramao 2013: 31–37.

10 Lévy 1997: 7.

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