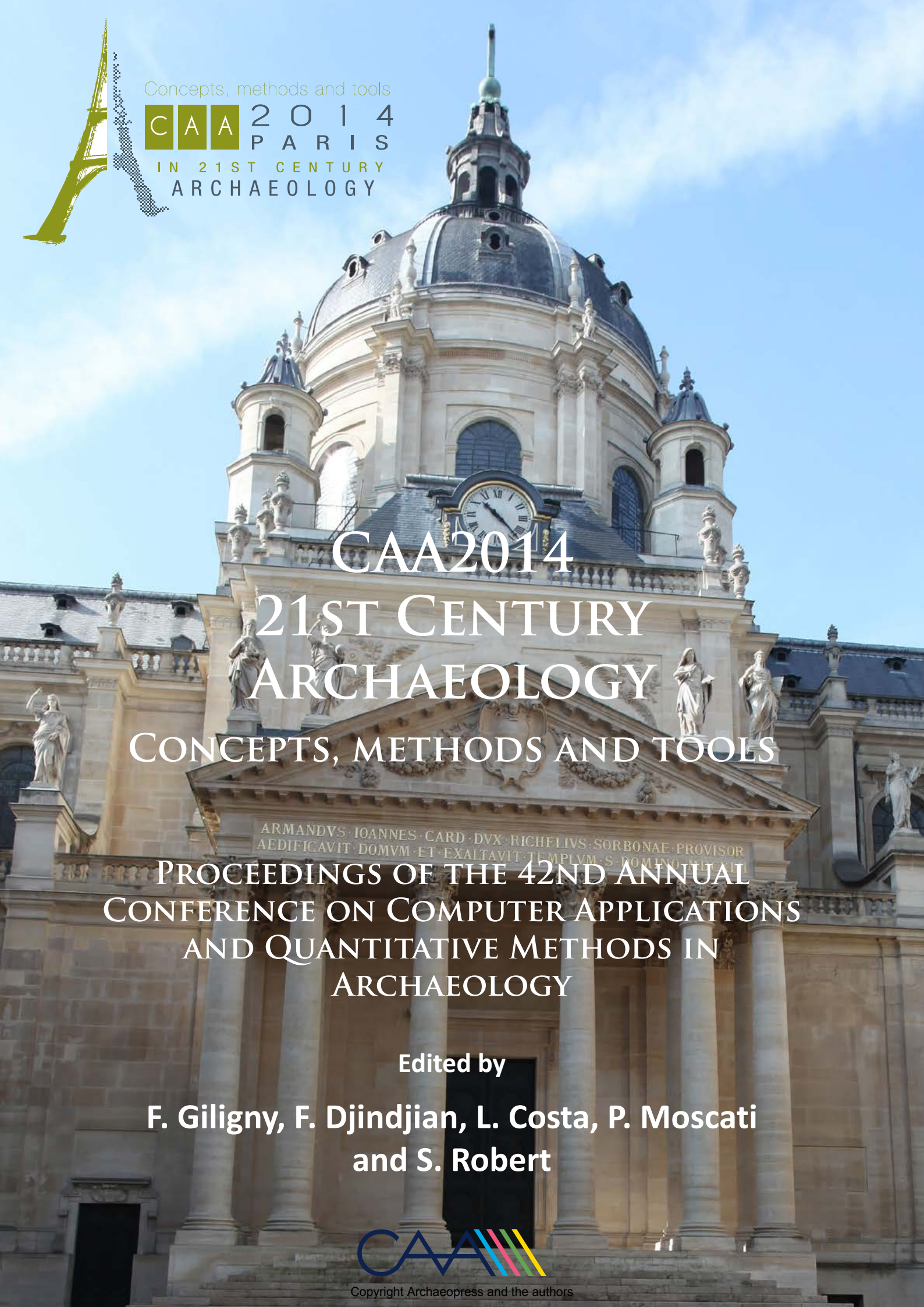

CAA2014 21st Century Archaeology

Concepts, methods and tools

Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology

Edited by

F. Giligny, F. Djindjian, L. Costa, P. Moscati and S. Robert

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Trajectoires
De la sédentarisation à l'État

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Foreword

This volume brings together a selection of papers proposed for the Proceedings of the 42th Computer Applications and Quantitative Methods in Archaeology conference (CAA), held in Paris (France) from 22nd to 25th April 2014.

The conference venue was Paris 1 Panthéon-Sorbonne University, in the main building next to the Panthéon. Workshops were held at the Institute of Art and Archaeology and the EHESS School. This was the first time in 42 years that the CAA had come to France, and we are proud to have hosted this important scientific event in Paris.

CAA2014 welcomed 477 participants from 39 countries. Altogether 397 papers were presented in 26 different sessions. The 5 round tables and 12 workshops also contributed to the success of the conference.

The program was divided into different themes and this structure has been maintained in the arrangement of articles in the various chapters of this book.

We are grateful to the following institutions which made the conference possible and supported it financially. Paris 1 Panthéon-Sorbonne University, the *Mairie* of Paris, the CNRS, the EHESS – Ecole des Hautes Etudes en Sciences Sociales, the INRAP – Institut national de Recherches Archéologiques Préventives, the research laboratories from the Maison de l'archéologie et de l'ethnologie, Nanterre – UMR Trajectoires & UMR Arscan. We would also like to thank the staff of the university and the student volunteers.

We hope that the congress participants, the contributors and all people interested in computing in archaeology will enjoy these proceedings.

Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology
CAA 2014 - 21st Century Archaeology/F. Giligny, F. Djindjian, L. Costa, P. Moscati, S. Robert (eds.)

Laser scanning and Automated Photogrammetry for Knowledge and Representation of the Rupestrian Architecture in Cappadocia: Sahinefendi and the Open Air Museum of Goreme

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Abstract

The survey of the '40 Martyrs Church' in Sahinefendi and churches located within the Goreme Open Air Museum is part of a research project oriented to test systems for surveying and representation applied to the architecture excavated rock. The data acquisition using old and new technologies and processing in post- production involves a necessary critical action that affects not only each specific monument, but the same methodology of acquisition and processing. In particular, we tackled the problem of systematization of procedures for the architectural survey in the field of rock art according to the 'emerging' technologies like Laser scanning, automated photogrammetry and immersive photography. The rock architecture, unlike the one built, has the need to represent its particular, irregular, morphological feature, so it was necessary to conduct a trial of representation techniques unusual for architecture, most commonly used in cartographic representation, as contour lines and planar development of complex surfaces.

Keywords: Cappadocia, Rupestrian Architecture, Laser Scanning, Automated Photogrammetry

Premise

We know that these are concepts taken for granted; but we must continuously remind ourselves that architectural survey is a 'critical form' of knowledge, a way in which we organize and put together a set of sizes, of analysis and of observations that make up a 'discovery'. We know because we meet something again; discovery is a form of iterative deepening; we observe, we reveal, what we know becomes clear, we recognize, we re-reveal what we recognize, and we observe again. There are no alternatives to the operating practices that bind man to historical-architectonic goods, and from this 'union' knowledge is generated. The human factor, therefore, is not a 'frill' to be avoided but is instead the means. Certainly methods of measurement tend to extract more and more reliable objective data, but every technology brings with it diverse characteristics from the others and at the same time its own peculiarities to take advantage of and to interact with so as to obtain a 'homologation' of a final product. LASER and digital technologies have reached a global level and dimension just in this decade that has made them easily usable, with previously unthinkable precision.

Revolutionized Technologies

Think about digital photography, which until recently had to share its laborious evolution with chemical photography, well established and stable. Today cameras and software can provide instruments of precision and processing of data for any application, for any 'idea'. With chemical photography we had the constant problem of exposure range. Today the chromatic range of an image can be increased enormously with HDR (High Dynamic Range). Radial distortion of the optics was one problematic characteristic for architecture and accurate reproduction, and only the photogrammetric optics had the 'costly' advantage of high correction. Nowadays every perspective, even with varying focus, can be potentially associated with a specific transformation that tends to cancel out any deformation in any shooting condition. With a quantity of photodiodes near to 40 megapixels on full-frame, digital sensors have come to a definition, reaching and accommodating optical capabilities that until recently remained overabundant and therefore not taken advantage of (Carpiceci, 2012a).

Digital photography and computer science then provided the possibility of evolution of the old stereo-photogrammetry into photomodellation. The refinement of the software of digital processing has permitted more and more of an increase in the accuracy of the algorithms based on epipolar geometry. The latest evolution of the architectonic survey, however, is certainly due to the laser-scanner, which only recently has gained the possibility of 'transportability'. With an instrument of 5 kg carried in a briefcase, resting on a carbon fibre photographic tripod, it's finally possible to carry out scans in (almost) any place on earth.

And now drones are ever more insistently and forcefully at the door of architectonic survey.

We are therefore witnessing a phase of 'epochal' transition. The instrumentation at our disposal is evolving exponentially. And just as quickly it's changing the horizons of possibility that such technological growth gives us.

But it's just that precision and speed of data acquisition that can be helpful in those fields of research that were difficult to explore up until now. Rocky habitats are one of those fields where it has been difficult to obtain a precise architectonic survey that is correctly 'representative' of the subject.

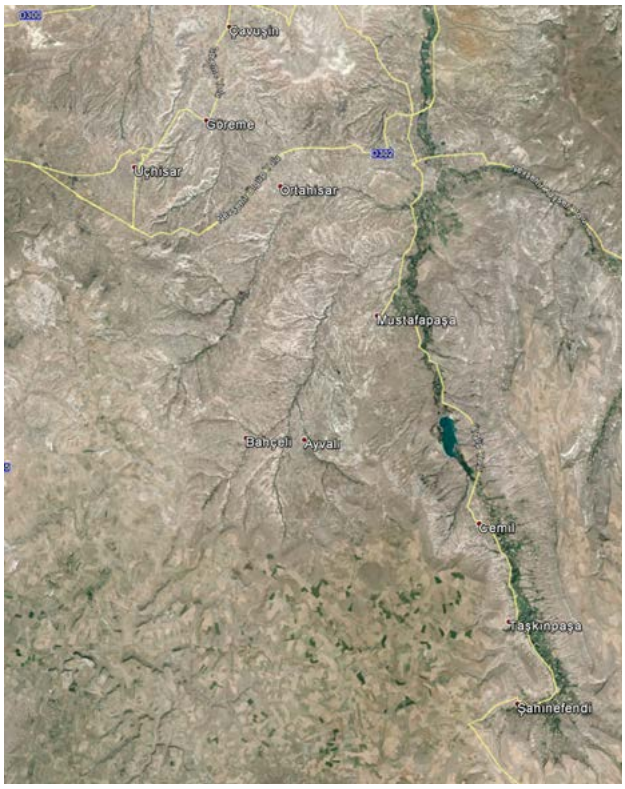

Figure 1: Turkey, Cappadocia, Goreme and the area between Sahinefendi.

Figure 2: Turkey, Cappadocia, Sahinefendi, the rock village on the slopes Orta Tepe.

You press the button, we do the rest

In 1889 Kodak used the motto 'You press the button, we do the rest' as an advertising phrase at the launch of automation in photography. Today the laser scanner is often considered in the same way as a Kodak camera, where it's enough to press the button 'scan' to obtain 'the rest'. And today it's often thought that panoramic photos are taken with a cellular telephone, assisted by software that recommends what movements we make. Today, it's often thought that the cloud of coloured points or the mapped mesh is architectonic survey but, unfortunately or fortunately, that's not the case.

The complexity of the technologies and their correct usage implicate a deep knowledge of their 'geometric' structure, in order to proceed with skill and a precise and correct realization of architectonic survey (Carpiceci 2012b, Carpiceci 2013a).

From the required concatenation of the scans in such a way to limit undetected zones as much as possible, to the realization of images for a correct 'chromatic mapping' of the mesh.

From the production of spherical photos through panoramic heads regulated on the front nodal point of the optic used, to the regulation of exposures as a function of the dynamic range of the subject (Carpiceci, 2011).

From the processing of metric data for the realization of a numerical uniform model, to the completion of elaborate graphics capable of describing the chosen architectural structures completely.

A careful analysis of the processes of survey and representation is essential, in light of modern technologies. This 'revision' allows us to consider the various potentials, in order to then take advantage of them with awareness in all the phases of analysis, processing and of communication.

From Sahinefendi to Goreme

The survey campaign in Turkey is concentrated on two significant places: the rupestrian village of Sahinefendi and the Open Air Museum of Goreme (Figure 1). These are two different and characteristic places (Carpiceci, 2013b).

In the valley of Sahinefendi, as in other valleys, erosion of crumbling land and rocks not worn down has generated peculiar forms of cones topped by blocks of hard, dark rock (Figure 2). These pinnacles present a coniform aspect, with walls sloping about 67 degrees, sometimes topped with a chapel of more resistant tuffaceous material.

The ease of working this material has facilitated its excavation by humans, who over time have created a series of areas with still-recognizable functions. Residential areas, places of production and of commerce such as the 'pseudo wineries' which have clearly recognizable tubs for the deposit and compression of the fruit, places for settling and maturation, and places of storage, conservation and marketing. The places of worship are also very important and characteristic. The most important and complex is the Monastery that is found in the high zone in the North beneath the plateau (the Orta Tepe), with a central body made by the excavation of a cliff front and some conical conformations, where we can find convent areas and a chapel (Figure 3).

The church of the Forty Martyrs, towards the valley, is certainly the best-preserved place in Sahinefendi, given that a painting cycle is still present in its cone, datable to the

Figure 3: Turkey, Cappadocia, Sahinefendi, the Monastery.

eleventh century (Thierry, 1963; Thierry, 1975, Figure 4). Its restoration was concluded in 2013 by a large group of Italian and Turkish restorers, led by Professor Maria Andaloro from the University of Tuscia. The church is set in a cone of about 20 by 10 meters. A series of rooms are divided over three main levels. The lower level is for the most part underground and is composed of two rooms of approximately circular shape and a flat roof and a third, slightly higher and a bit smaller, having a parallelepiped form. The middle level is the main level, where the church was developed, with two naves, ending in apses and with barrel vaults. The third level is made up of two small circular rooms that face towards the outside and into the naves of the church.

In 2008, restoration was begun on the paintings. These restorations were completed with the church's transformation into a museum in 2013. During this time, Sapienza University of Rome with its Department of History, Drawing and Restoration of Architecture, specifically Professor Marco Carpiceci, carried out some survey projects aimed at the measurement and knowledge of the monument through laser scanning and immersive photography. In the latest survey campaign (2013), Professor Carlo Inglese and Architect Giovanna Cresciani were added to the collaboration. With the coverage of the most significant places through laser scanning, we wanted to embrace the area no longer simply on the singular episode but instead on a co-contextual framework; a sort of relation of the single 'cone' with those around it.

The Open Air Museum of Goreme represents a complex of unique anthropological value on top of its art historical value, declared a UNESCO World Heritage Site in 1985, for which there is not currently a workforce for architectural survey (Figure 5).

The area of Goreme is extensive and includes rocky conformations of various types. It's the biggest spread of cave habitats with a monastic function (Rodley, 1985).

The heart of the area is made up of a large natural rock hemicycle, with a radius of about 40 meters and a height of 15-20. The large exedra overlooks a series of conical shapes of various sizes (Figure 6).

Figure 4: , Cappadocia, Sahinefendi, Church of the Forty Martyrs, left aisle.

Figure 5: Turkey, Cappadocia, Goreme, the area of the Open Air Museum.

From an anthropological and functional point of view, the Museum makes up a complex aggregation of small groups of 20-40 people. Every group was independent from the others, was distinguishable by an autonomous series of rooms: a place of worship (church or chapel); a refectory; a kitchen; areas used for everyday activities and for rest.

Figure 6: Turkey, Cappadocia, Goreme Open Air Museum, the hemicycle natural rocky.

The historical hypotheses tend to date most of the wall paintings to between the tenth and eleventh centuries (Thierry, 1963; Thierry, 1975). This, therefore, must have been the moment of maximum splendor of this great monastic city. An orderly community of autonomous nuclei of various sizes, but all belonging, evidently, to one general organization.

In the exedra, the most numerous community was the Karanlik Kilise (dark church) that would go on to represent one of the principal objectives of the survey campaign of 2014. Slightly less extensive, but still important from an iconographical and architectural point of view, is the Carikli Kilise (church of the sandal) that was surveyed in 2013 together with the chapel of St. Catherine. In the cones in front of the hemicycle, there are a number of churches detected between 2011 and 2013: St. Barbara; Elmali Kilise (church of the apple) and St. Basilio. A bigger cone, finally, is thought to possibly have been used as a female community. Inside it, there is a church detected in 2013 called just that, Kizlar Kilisesi (church of the girls).

Outside the Open Air Museum there is Cappadocia's most significant church: Tokali Kilise (church of the buckle), in which there is a mosaic cycle on a lapis lazuli background from the eleventh century. Tokali underwent survey in 2013.

Acquisition Techniques

The morphological prerogative of excavated architecture is that this, apparently attributable to forms similar to 'built' forms, in reality is nearer to a sculpture, where we can make out features and similarities with another reality, but that instead is the result of the aggregation of complex shapes.

And so in the traditional measurement practices (for constructed architecture) we proceed to the scanning chain, numerical model, geometric model, and representation for orthogonal projections. In rocky habitats we face an almost total impossibility of determining the geometric model, and the only intervention on the numerical model consistent with a decimation of the point cloud where the formal variation allows for a descriptive simplification.

A determining factor for the execution of this type of survey is given by the transportability of the instrumentation, which in our case is 'unique' and depends on the size and the weight of 5 kg of the scanner FARO Focus3D. With this type of scanner we were able to easily 'climb' down the cliffs without needing to transport bulky crates of several tens of kilograms.

Another decision, in order to take advantage of the portability of the instruments, consisted in giving up the Total Station. We tried, as much as possible, to use targets or spheres scattered around the subject to make the stations interrelated without the necessity of closed (almost impossible) or open polygons for their topographical 'structuring'. The recognition of homologous points, sometimes unspecific but seen in multiple scans, was useful in the 'registration' of the clouds. Basically the laser scanner measures points according to a polar geometric concept (distance, horizontal angle, vertical angle), like the Total Station, and therefore by excluding the topographical instrument we just recognized the functions already included in scanning. It should be added that the easily possible 'compensations' only in closed polygons, in the registration of the clouds are carried out on a great number of recognized points, automatically by the software (Carpiceci, 2012b).

A fundamental and peculiar aspect that we had to confront was the survey of painted surfaces. The paintings should have their chromatic aspect registered as well, but this is wishful thinking. We already know that dimensional measurement registers one unique figure, more or less precise but constant in time with possible dimensional variations normally infinitesimal and mostly due to the metric tolerance of the scanner. For colour, we enter in a world made of variations, starting from the fact that we record reflected light and therefore the chromatic aspect of the subject is influenced by the lighting conditions. But the thing we'd like to record is not a particular lighting condition but exclusively the colour of the subject.

These considerations make us realize how complex a registration that 'excludes' or minimizes the factor determined by lighting could be. Try to think of an external corner of a cubical plastered building. The two contiguous facades will always appear to be of different colours at every moment of the day, even if we 'know' they are the same colour. And so even the internal painted surfaces will undergo different local alterations based on their inclination in relation to lighting sources. It is therefore necessary to separate the part of chromatic registration from the part of scanning, in such a way to carry out specific photographs for similar parts of surfaces and with the same specific lighting. These then are 'mapped' on the cloud (or on mesh) in such a way to obtain a chromatically correct model (Carpiceci, 2011).

The phase of scanning was therefore carried out with the exclusion of the chromatic recovery from the scanner, which also has a very limited photographic section, certainly not comparable to a high level external camera.

Figure 7: Turkey, Cappadocia, Goreme Open Air Museum, Church of the Tokali, photo lighting set up (left) and scan the dark with the reflectance (right).

Despite the exclusion of RGB (Red, Green, Blue), the laser scanner registers the light intensity (reflectance) of the surfaces (Figure 7). This intensity is influenced both by the objective light of the surface where the measured point is found, and by the light from the reflection of the laser ray from the scanner itself. For the interior, therefore, this problem of variability was solved simply by carrying out the scans in the dark. In this way the registration was done with the actual reflectance of surfaces lighted exclusively by the laser of the instrument.

Some differences can be found in the cases in which parts of the surface had been registered with a grazing laser and others with a frontal laser, but these are particular cases that have not affected the validity of the solution found.

Representation

Classic architectonic representation is characterized by lines that describe essentially apparent outlines, corners and surface discontinuity (difference of elements, colours, etc.). The latter can be successfully substituted by photoplans, which nowadays are finally possible even for subjects, or parts of subjects, not plans.

Excavated architecture, however, with its more 'sculpted' than architectonic aspect, presents notable difficulties. In summary, not being able to retrace real edges, if not random and certainly not descriptive of the geometry of the volumes, using a form of 'diverse' representation is necessary (Carpiceci, 2013b).

For this reason we decided to borrow the 'diverse' technique from another applied field of 'two-dimensional' representation: territorial. Cartography bases its capability of representing the morphology of the land thanks to the use of isoipse (contour lines). Contour lines have two fundamental characteristics that make them significant to 'form', the first (etymological) is that lines composed of coplanar points, at the same height. The second characteristic is equidistance, or the constant difference between the planes: this constant determines the only variability that is represented by the interval, or the different dimension of every line of maximum slope traceable between a contour line and the limit. In cartography, equidistance is canonically 1/1000 of the scale of representation expressed in meters, for example: for the scale 1:25,000 the equidistance is 25 meters with lines marked every 100 meters.

In 'rocky' architectonic representation it's been noted that this relationship would involve an excessive concentration of lines. A good compromise was found by bringing the relationship to 1/500 and therefore for a classic representation 1:50 we have contour lines every 10 centimetres of difference and lines marked every 50 centimetres (figure 8).

The vertical sections have the 'flat' lines with the same spacing.

A great work of post-processing is also represented by the cleaning of the undercuts. In fact, the operator must keep track of the visible and hidden zones and therefore must

Figure 8: Turkey, Cappadocia, Sahinefendi, Church of the Forty Martyrs, plant of the entrance level and the church, contour lines at 10cm equidistant.

emphasize the apparent outlines of the forms and delete what is found behind them.

This 'manual' job could be avoided if a function were implemented that was capable of deleting these zones. Basically the sections are usually carried out by the mesh. Therefore the reconstruction of the surface of the numerical model establishes a separation between the interior and exterior of the material. This allows a common visualization with exclusion of the 'back faces'. It would suffice to make it so the invisible parts were cancelled out and then the determination of the sections were applied, to get the automatic elimination of the undercuts.

Next phase: inaccessible places

Rocky habitats certainly represent a subject very far from the concept of traditional architectonic survey. Such diversity is emphasized by the imitative aspect of traditional (constructed) architecture. An aspect that to a careful analysis demonstrates itself far from easily geometricised forms. Excavated architecture assumes sculptural characteristics that make it a unique typological and formal example. Another characteristic generalized in Cappadocia is inaccessibility. Beyond the 'museum' areas, which are fitted with stairs and walkways that allow easy access and pathways, the rest has spaces only reachable with specific equipment, such as that of spelunkers and climbers. And above all of it, there are then the peaks of the cones and rocky formations that would require a flying device such as a helicopter.

Recently we have seen the use of UAV (Unmanned Aerial Vehicles), commonly called drones, more and more. The use of these 4-propellered helicopters gives the possibility of flying over restricted areas of territory and taking photographs or videos useful to the successive processing of multi stereo matching, of photomodellation.

There are three fields that converge together in SAPR (Pilot Remote Aircraft Systems): radio-controlled aircraft, digital photography, and photomodellation. More and more sophisticated algorithms, combined with the increasing ability of calculation and visualization have made the technique of photomodellation more precise and reliable. Together with this, digital photography has now reached results and processing potential that make it nothing like what it was just five years ago, bringing quality and operational dynamism even on smaller and lighter camera-optic systems. In the end the refinement of the technologies of radio and remote control even from tablets have made navigation with drones easier and easier. Starting from the enormous productive 'entertainment' development, the evolution of the drone has spread to a wide variety of activities wanting the affordable and manageable operational ability of remote flight.

The UAV (Unmanned Aerial Vehicles) can therefore resolve most problems faced in sites with difficult access. In other words we can finally proceed with survey not only for the subjects for which accessibility involves uncomfortable and risky pathways, but also for the parts of common subjects that are not reachable without special equipment or particular 'means'.

Laser scanning, digital photography, photomodellation and radio-controlled flight, four determining factors that right now (some slightly earlier and some more recently) are literally revolutionizing the way of understanding architectonic survey.

This revolution is even more deeply felt in those places (or areas of places) that until recently were unknown or were 'victims' of 'hypothetical' reconstructions or required large sums of money in order to acquire reliable data.

The application of new technologies to inaccessible places represents a fundamental test to control the relationship and coordination of various techniques and their rightful place in the more complex 'Survey System', which is nothing more than the ordered set of material regarding a determined architectonic subject.

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