Digital Micro-Photogrammetry

New ways to dialogue with future researchers

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Abstract: The return of photogrammetry in researches and studies about cultural heritage has been possible thanks to the development of the digital photography. With the evolution of the digital photographic equipment and so the overcoming of the analogical shooting, now the application field of the digital photogrammetry is wide and varied.

The study presented shows how the Structure from Motion (SfM) can achieve high level of details, in relation of the shooting equipment used. The Micro-Photogrammetry, used during a survey campaign in Cappadocia - Central Anatolia, has constituted an additional and completing part of the studies, allowing both the conclusion of the study on the conservation state of the object and improving new ways for the screening of the study object.

In the case study reported, on the rupestrian residential systems (the World Heritage Site of Göreme), has permitted an easy study and learning on the manufacturing of the inner surface of the rooms and has provided, through the production of 3D models, an analysis on the equipment and instruments used for these kind of manufacturing.

The study shows significant results and various possibilities on the multi-disciplinary methodology of study in complex subject, like the rupestrian architecture. Moreover the results of the manufacturing process have been investigated and the performance is expounding showing the level of detail obtained on each sample. The whole of this study shows an innovative framework on the SfM technique and creates new ways of dialogue between the interested researchers on the topic of the study and conservation of cultural heritage; never forgetting the possibility and the opportunity to create and share the state of art with a specific database for the future generation of researchers.

Keywords: digital photography, photogrammetry, survey, stone manufacturing, database

Introduction

The work presented is about an experience of digital micro-photogrammetry applied to different kind of stone manufacturing in the territory of Göreme - Cappadocia.

The data gathered from a digital photographic campaign could be used to study, archive, share and compare not only the photos but also digital models of the studied objects. These virtual reproductions may become physical if printed with 3D printers, in this way they are useful to create new ways of dialogue between the researchers and the scholars interested in the topic and in the conservation of Cultural Heritage. This is made never forgetting the possibility and opportunity to create and share the state of art with using a specific database and organizing well-structured archives for the future generation of researchers. Last, but not least, the possibility to develop teaching and learning solutions using 3D printed models, is clearly a very interesting opportunity for schools and museums. It allows a direct mix between technology and tradition and the values of Cultural Heritage. It brings to the students, to the tourists and to the simply curious people the potentiality of contemporary technologies and the strong communication of heritage.

The region of Cappadocia - Central Anatolia

Geographical Overview

The Cappadocian Area is a historical region of Turkey, separated from the Black Sea, on the North, by the *Pontus* and from the Mediterranean Sea by the Taurus Mountains on the South. It is located between the Armenian Highland on the East and the territory of *Lycaonia* and *Galatia* on the West.

The relief consists of a high plateau rising over the 1000 meters in altitude, pierced by volcanic peaks. Due to its inland location and the high altitude, this region has got a continental climate, with hot dry summers and cold snowy winters; rainfall is sparse and so the region is largely semi-arid.

The territory of Cappadocia is characterized by a singular morphology of valleys and peaks: canyon, cliffs, pinnacles, pyramids and the so called “fairy chimneys”. Its geographical configuration, composed in layers of tuff, is the result of a geologic development with significant volcanic eruptions, robust erosion operated by water and winds as well as freeze/thaw cycles with extreme temperature range.

The process at the origin of this unique morphology started 60.000.000 years ago, when the earth crust corrugated creating the Taurus Mountains, dividing the Mediterranean Coastal region of the Southern Turkey from the Central Anatolian Plateau.

Over millions of years this slow erosion by nature has changed the structure and the texture of the rocks creating this fascinating lunar landscape. Moreover this changes allowed men to excavate the tuff, a stone easy to be carved and worked, initially creating shelters to protect themselves from the weather conditions, animals and other kinds of dangers, and then houses, churches, productive buildings and also furniture (mostly consisting in niches, shelves and tables).

The need of an elevate number of accommodations was due to the settlement of Christian religious communities that, fleeing Rome’s persecution had arrived and started intense anthropic activity. They started establishing monastic communities, building churches and monasteries, creating frescoes paintings in cave chapels, remaining isolated and retired in this peculiar area, involving Christian people in living there.

Göreme and its rupestrian heritage

The work presented here takes care of the Cappadocian village of Göreme, in the province of Nevşehir. Göreme was inhabited from the Hittite era, between 1800 and 1200 BC, and it was located between rival empires: Greeks and Persians. This precarious political position meant that residents needed hiding places and safe recovers; they found them carving the rocks.

Göreme is a small town, but it has a wide selection of natural and cultural wonders that can be appreciated just taking a walk around the village or visiting the *Göreme Open Air Museum*, with a collection of caves and fairy chimneys, a sequence of very nice underground churches, some of them decorated with simple geometric motifs, and others with wonderful frescoes from the 11th to the 13th centuries (Fig. 1).

The area of the museum has been added in the UNESCO World Heritage List in 1985.

The documentation work

This work is a part of a wider project of architectural survey, restoration and monitoring of the actual state of the rupestrian settlements in Göreme.
Taking a look at the rupestrian heritage present in this area, is easy to notice its actual state of conservation, well preserved in certain zones as well as completely abandoned in others.
This enormous patrimony appears impossible to be entirely saved by intervention of consolidation, restoration and protection; but the documentation of the actual state of conservation appears unavoidable in front of the constant state of danger in which this heritage goes through: the erosion is still present and every year 2cm of rocks are blunt, and so in not so many years the conformation of this land will become completely different from how it is and how it was (Fig. 2).
The need of a documentation appears necessary in different scale of work: at a panoramic-scale, with a mostly photographic equipment, in order to have a wide area survey; at an architectural-scale using indirect 3D Laser Scanner surveys, or topographic surveys and at a detailed-scale with photogrammetric and micro-photogrammetric surveys of the excavated rooms.
As a matter of fact the peculiarity of these Cappadocian settlements is also in the way the men of that time, used to chisel their walls. During a panoramic check about the studied area between the research group, many different type of chisels have been identified, the differences regard both the morphology of the instrument used and of the way they chisel up walls.
From this observation came the decision to apply the micro-photogrammetric survey on the inner surfaces of the carved room of houses and churches around Göreme.
This photographic survey, operated on more than 20 samples of stone manufacturing, is here presented taking in consideration 4 most significant examples.
This methodology gives to the scholars the possibility to capture a high detailed (in colours and shape) sample of the stone surface without damaging the original wall.

Photographic equipment and photogrammetric process

Overlook on the dedicated equipment available after a market survey

Having a look on the equipment the market proposes for this aim, is possible to find three different kinds of lenses, all involved in micro or macro photography. In fact in relation to the brand, similar focal length lenses are called differently micro or macro lenses. This lead to some confusion around the argument: while Canon and Sony name these lenses macro, Nikon calls them as micro, but in both cases they focus on lenses with a 1:1 magnification ratio.
The difference between the adjective micro, macro and close-up, instead has to be used in relation to a different magnification ratio: macro and micro is therefore relate to shots that capture the subject with a factor of at least 1:1, with the result that the subject captured by the camera sensor has got the same dimensions that it really has. By convention, when shooting 1:1 the image will appear in sharp focus - while details in front or behind the subject will not.
There are optical systems capable of higher magnifications, for example 2:1 and even higher such as 20:1 and 30:1. Their effect will be to fix the sensor on the subject with double (or higher) dimensions compared to those

that it actually has. These are the magnification factors which more properly have been defined with the word micro-photography, a technique that can be considered a subset of macro-photography.

Notes on the process

After the previous paragraph one can say that the documentation of the different kind of chisel manufacturing has been carried on and executed by macro-photogrammetry, but it has been decided to maintain the adjective micro to refer to the name of the used lenses.

Micro-photogrammetry can be considered as an evolution both of the traditional analogical photogrammetry and of the digital photogrammetry, well developed in the last years.

Thanks to the high quality of the photographs deriving from the digital reflex cameras of the last professional generation, is possible to obtain images up to 48 mega pixel and so, with a high margin of detail.

Moreover to operate a photographic survey campaign of this kind is necessary to have an appropriate knowledge of photography and the features of the study samples, in a way to set up all the survey operations optimizing the sequences, avoiding data redundancy and planning properly the use of media and human resources. It could be also useful to build a complete picture of the situation in order to execute an exhaustive sampling of all the materials and morphologic components present in the area and to observe the different typology of decay, to eventually make parallel surveys on samples just apparently similar one to another.

The accuracy applied and the completeness of the micro-photogrammetric results compared to a structured-light scanning system survey are primarily to get a final model with true color, then to get it with less expensive equipment and finally the need of a very professional operator. Furthermore, the high quality of the shots to 36 megapixels equates, if not exceeds the precision of a normal scanner.

In addition to this, the pattern coded projection technology, for the acquisition of the surface, is strongly influenced by the local light conditions, and thus by the visibility around the survey portion. As a matter of fact is difficult to use this instrument in very bright light conditions, because too much light makes very difficult for the operator to control the pattern projection and possibly invalidate the data acquisition by the sensor. Finally, structuring the working environment necessary to scan operation can also be a problem in such cases, for the presence or not of the electricity and the right supports.

Data Gathering

In this case study the photographic equipment used has been constituted by a reflex camera Nikon D800e with a lens Micro Nikkor 60mm F2.8, a tripod, a remote control and a support mask (Fig. 3).

This kind of lens allows having very sharp and accurate images of details as they can reach very short distance with the subject. Moreover its focal length allows a good depth of field that helps the photogrammetric software in avoiding problems of alignment using an extended number of pixel suitable in the photogrammetric process.

The use of a solid and stable tripod allows a more rational and practical use of the features of these equipment. The tripod used with a double rail macro head allows accurate moves and precise positioning of the camera, useful for close range photography. Finally the use of a remote control removes any risk of shaking blur that can make some shots completely useless.

To obtain images without disturbance in the definition of the pixel is better shooting in optimal conditions of lighting and shading and setting the ISO of the resulting pictures to be around 50 or 100.
The resulting images have been in .jpg format 5684x4434 with 3937 pixel/mm^2 for a total of 36 megapixels.
It is significant that the photographic campaign should be performed on the portions that best describe the different manufacturing of the walls.
For each sample were taken at least nine photos, but the number can increase if the peculiarity of the surface requests it, as in the first of the samples we will see (Fig. 4).
The support mask is useful to frame the precise area of reference and give measurement information, useful at the end of the photogrammetric process to put in the right scale the 3D model. The mask is square shaped with a cross hole carved in its centre, the square at the middle of the cross is 49x49 millimetres.
This methodology allows locating and identifying the samples at the survey moment and clearly defining a measurable area.

Data Processing

The data processing, made with peculiar SfM software, consists in an initial loading of the photos into the software to create a first alignment called sparse pointcloud. After this a dense pointcloud can be calculate setting some parameters of density and resizing a specific limit box, that could be also aligned with the principal axis of the sample. Then it is possible to calculate the mesh on the dense cloud, giving results far better compared to a surface calculated on the sparse cloud; also in this case the operator has the possibility to set specific parameters.
One last step before the scaling of the model is the calculation of the texture, with an exit data in .tiff format.
In this case study, we can take as a reference the first one of the four samples (Fig. 5).
This fragment has been calculated with this final count:
- the alignment of the photos has defined a sparse cloud of 263.335 (Fig. 6).;
- the process of intensification of the points to create a dense pointcloud has been completed with a total of 12.203.227 points (Fig. 6).;
- the mesh resulting from the dense cloud, consisting in 31.902.082 polygons (Fig. 7).;
- the texture has been calculated in a resulting .tiff file of 8400x8400 pixel.

This procedure has been applied to all the study samples (Fig.8).

3D printing and prototyping

After the conclusion of the data processing, a further step has been made to obtain a tactile model of the stone sample: the mesh has been re-created in its original dimensions with a 3D printer (Fig. 9).
This operation has been carried on with a MakerBot Replicator, a PLA-polymer 3Dprinter that works with a filament diameter of 1,75mm. This printer can produce a maximum volume of 25,2 W x 19,9 D x 15,0 H cm (7.522 cubic centimeters), has got three moving axis and a layer resolution of 100 microns. To go through the 3D printing, the model obtained from the SfM process has been decimated into dedicated software to reduce the number of the polygons (to a total of about 15.000.000 faces) and enhance the mesh quality.

At the end of the process, the reproduction of the stone samples in scale 1:1, allows to experience the sensorial perception made in situ, also for someone never been there. This is possible thanks to the high quality of the photos, first of all, but also to the quality of the process and of the instruments (software and hardware) used to complete it. Finally it is also possible to fix the state of the ruins at the moment of the survey, in a more tangible way.

Features of the study samples

The four samples here presented are all taken from rural and domestic places and rooms. None of them derived from a religious place, maybe for this reason there are no tracks of decorations motifs on them.
The first sample of the study is characterized by well-defined signs of a sharp tip chisel bumps, the signs are quite separate one from the other and quite deep.
The 3D model obtained with micro-photogrammetry is in a high quality one, so it is possible to study its shape using sections (Fig. 10); moreover the help of the 3D printing allows fixing the actual state of conservation in a 1:1 scale that could be easily transferred into a laboratory and shared with other scholars and researchers.
The second sample of stone-manufacturing has been chosen for its signs of almost vertical chisel bumps very well marked and separate one from the other. The wall seems not presents any traces of colour or drawings, but due to the changing of this stone, that crumbles just touching with hands, it is possible that the original shape was different.
The third example of stone-manufacturing is of a different kind compare to the first and the second ones. In this case is not easy and maybe not possible to recognize a peculiar type of chisel bumps or tips: the finishing touch is rough but uniform on the entire surface, and also here, there are not visible traces of drawings, colour or other kind of finishing.
The fourth sample is more like the second one: the bumps of the chisel are well marked and defined. Their direction is more tilted to the right and going down to the left, with an angle of about 45°. Also in this last sample there are no traces of colour or other kind of finishing. Here, like in the first one, is easily recognizable the instrument tip.

Discussion: a suggestion for a reverse engineering process

Starting from the micro-photogrammetric survey and the following reconstruction of the samples' models a process of reverse engineering has been started with the aim of reproduce the chisel's tip.
The first step consists in isolate the sample's mesh all around the sign of the instrument, choosing the clearest one (Fig. 11).
After this, it has been necessary to look at the remaining part of the mesh from the opposite side, to explore the outside of the instrument.
From this new point of view the morphology of the instrument starts to appear clear and so the work can proceed aligning the surface with the three main axes, in a way to study in depth its shape and better control the reconstruction hypothesis. Then the residual mesh has been completed with a simplified hypothesis of a shape proper of an instrument of this kind (Fig. 12).
The result could be an important means to be studied with scholars of different research areas (Fig. 13).

Conclusions

At the basis of this processing it was the idea of the possibility to capture and “bring away” a very detailed sample of the stone surface without damage the original wall. Moreover it was possible to act a monitoring over the spots of interest. The high level of detail of the samples gives the possibility to check and verify minimal differences between the models, checking also the ongoing decay and the transformation of the surfaces.

The new frontiers of the digital photogrammetry, together with the recent quest for technologically advanced experiences during visits to museums, art galleries or archaeological and cultural heritage sites, are now the starting point to re-think the way we experienced the cultural heritage, but also the possibility we have to study it.

These different kinds of manufacturing present a common quality. Thanks to their state of conservation and to the high precision of the contemporary technique of digital photogrammetry, the instrument tip results highly recognizable: the possibility to shot photographs at high resolution, like 36 to 50 Megapixel, realizes the opportunity to start and carry on new kind of researches, studies and expand the area of interest of many Scholars and it also gives the possibility to have new kinds of dissemination possibilities for the new generation public of the web and museums.

From this starting point, this research can move from the mere micro-survey and 3D reconstruction, through the conjecture of the ancient instruments and will be finalized in the future with a dissemination proposal for the present generation museum and the recent web social network.

The new challenges of the digital photogrammetry are now more complex than in the past and probably we are just close to a further evolution of this tool in the next future.

The combination of digital survey with versatile modelling tools can be the occasion to experiment some dissemination possibility, like passing from a trace to a reconstruction, going from the resulting carved sign of a manufacturing back to the original hardware used for the engraving.

Figures

Fig. 1 – View of an area near to the Open Air Museum - Goreme (Copyright: Andrea Pasquali)

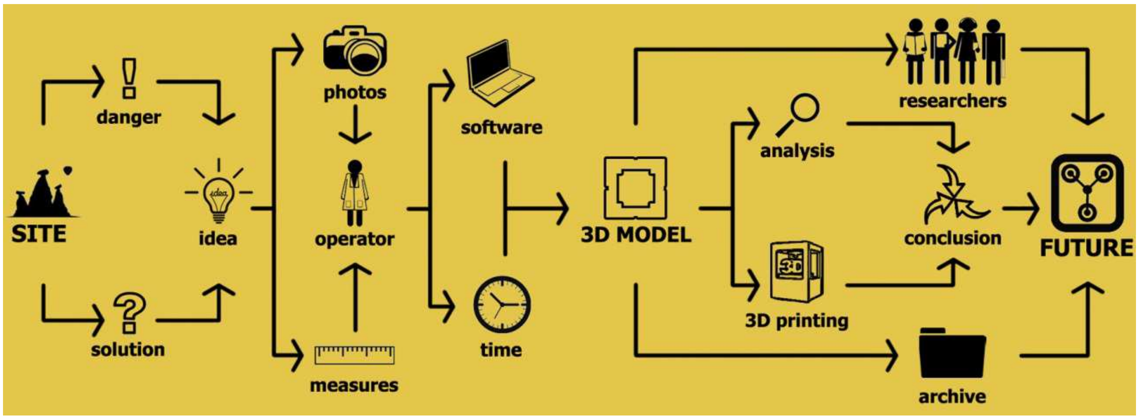

Fig. 2 – Graphic of the documentation work: starting, workflow and final aims (Copyright: Andrea Pasquali - Angela Mancuso)

Fig. 3 – Photo-Matrix of some of the samples on site (Copyright: Angela Mancuso)

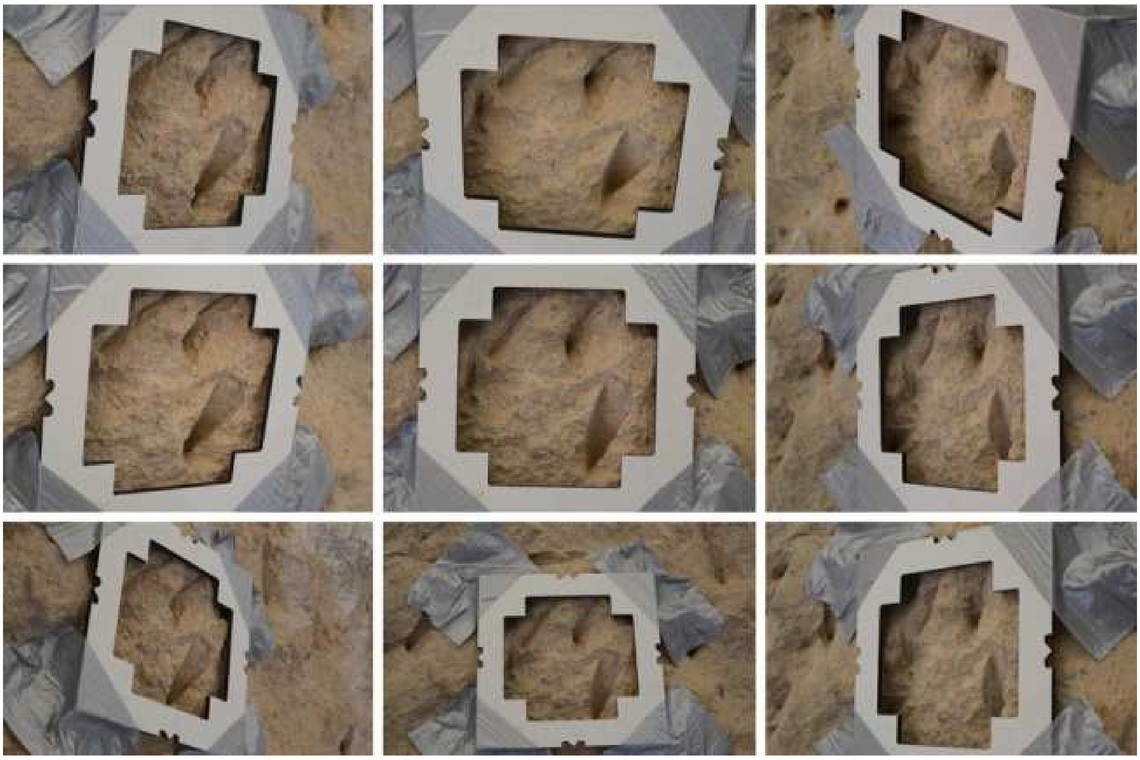

Fig. 4 – Example of Photographic survey (Copyright: Andrea Pasquali - Angela Mancuso)

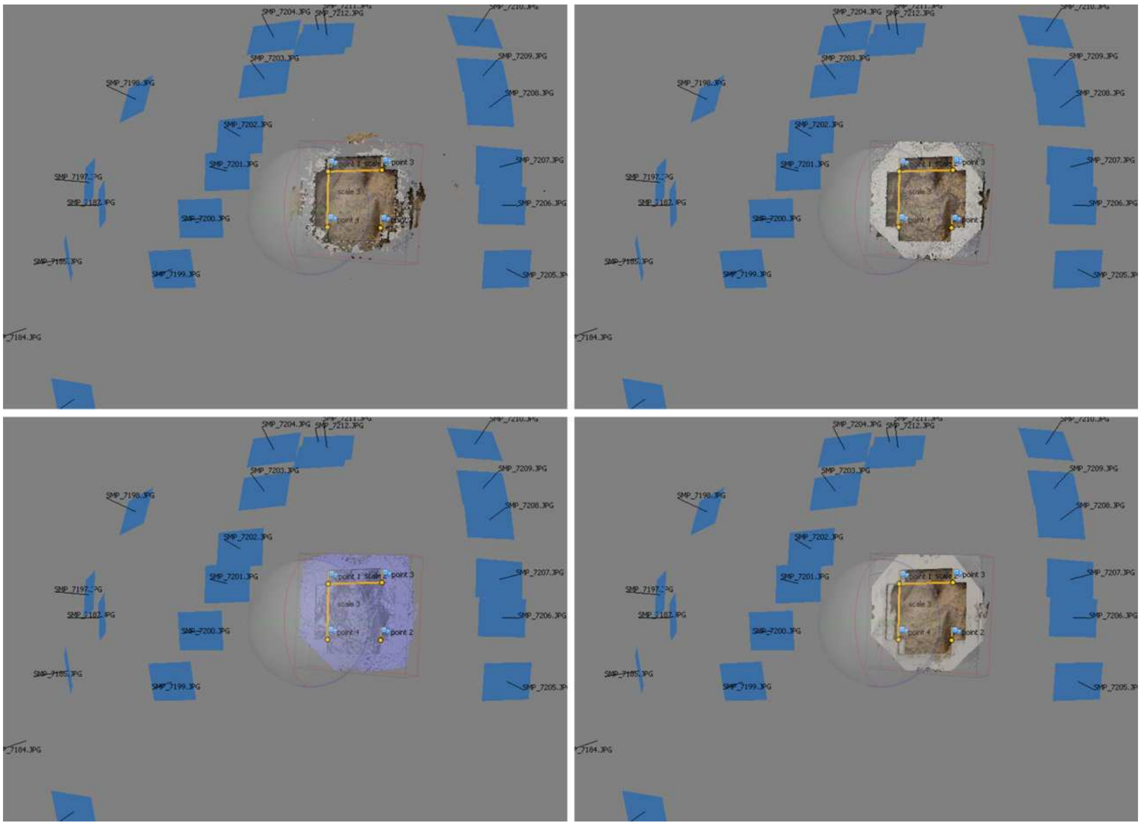

Fig. 5 – Workfow on SFM software: sparse pointcloud, dense pointcloud, mesh, textured mesh (Copyright: Andrea Pasquali - Angela Mancuso)

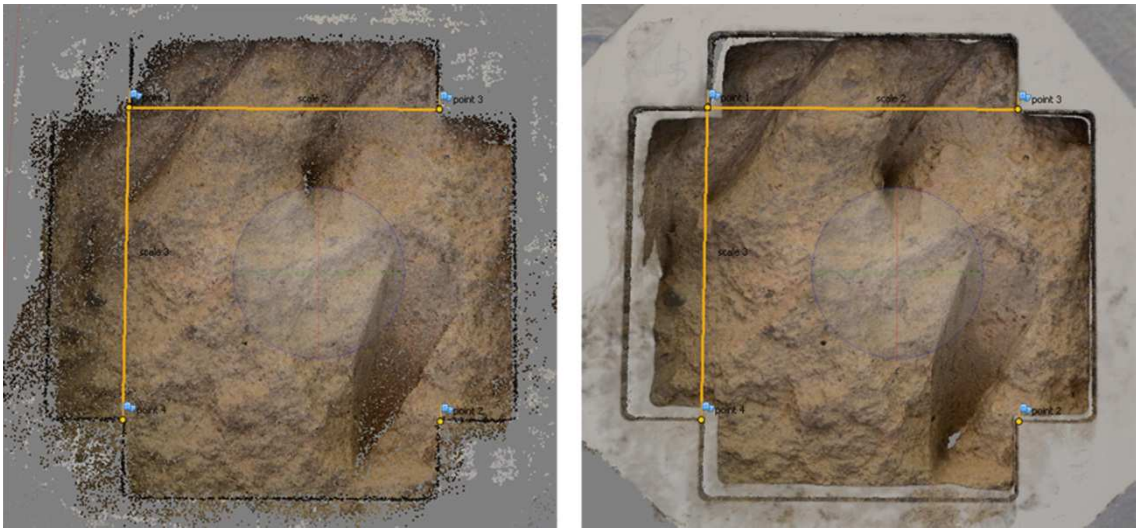

Fig. 6 – Comparison of sparse cloud and the textured ortophoto obtained (Copyright: Andrea Pasquali - Angela Mancuso)

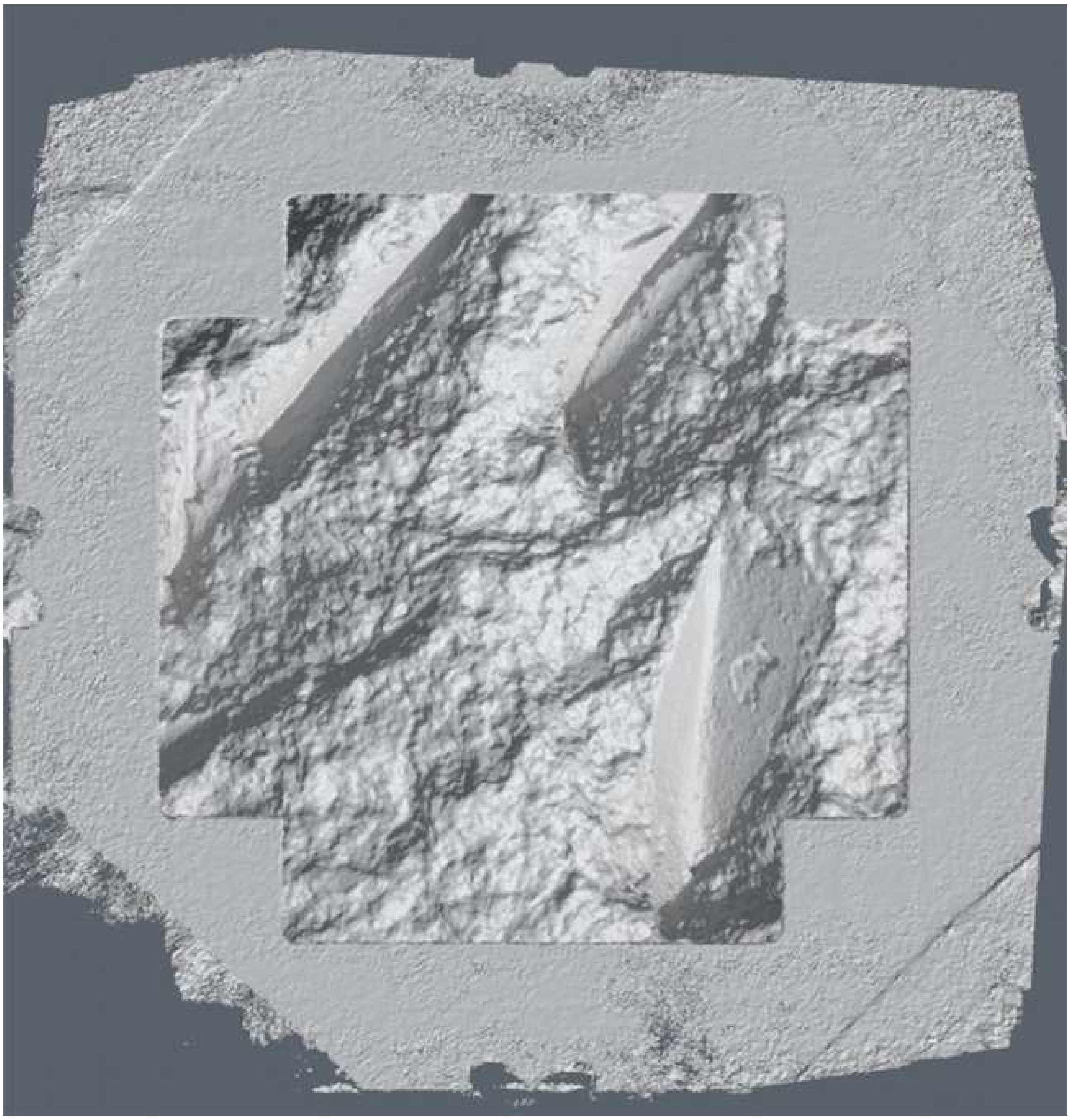
Fig. 7 – Render of the 3D model: mesh without texture (Copyright: Andrea Pasquali - Angela Mancuso)

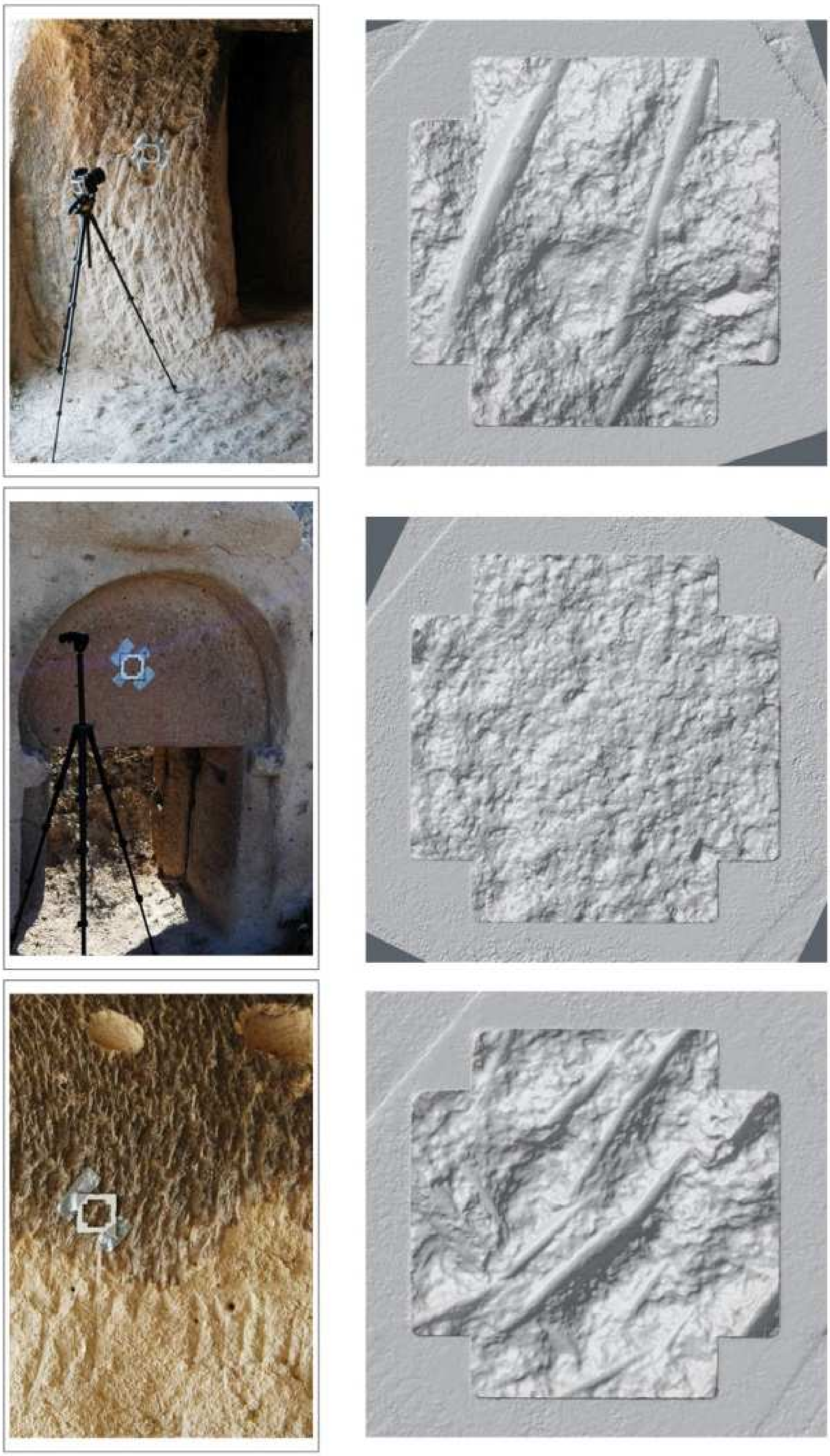

Fig. 8 – Collocations and 3D models of some samples (Copyright: Andrea Pasquali - Angela Mancuso)

Fig. 9 – 3D printed of the stone manufacturing samples (Copyright: Andrea Pasquali - Angela Mancuso)

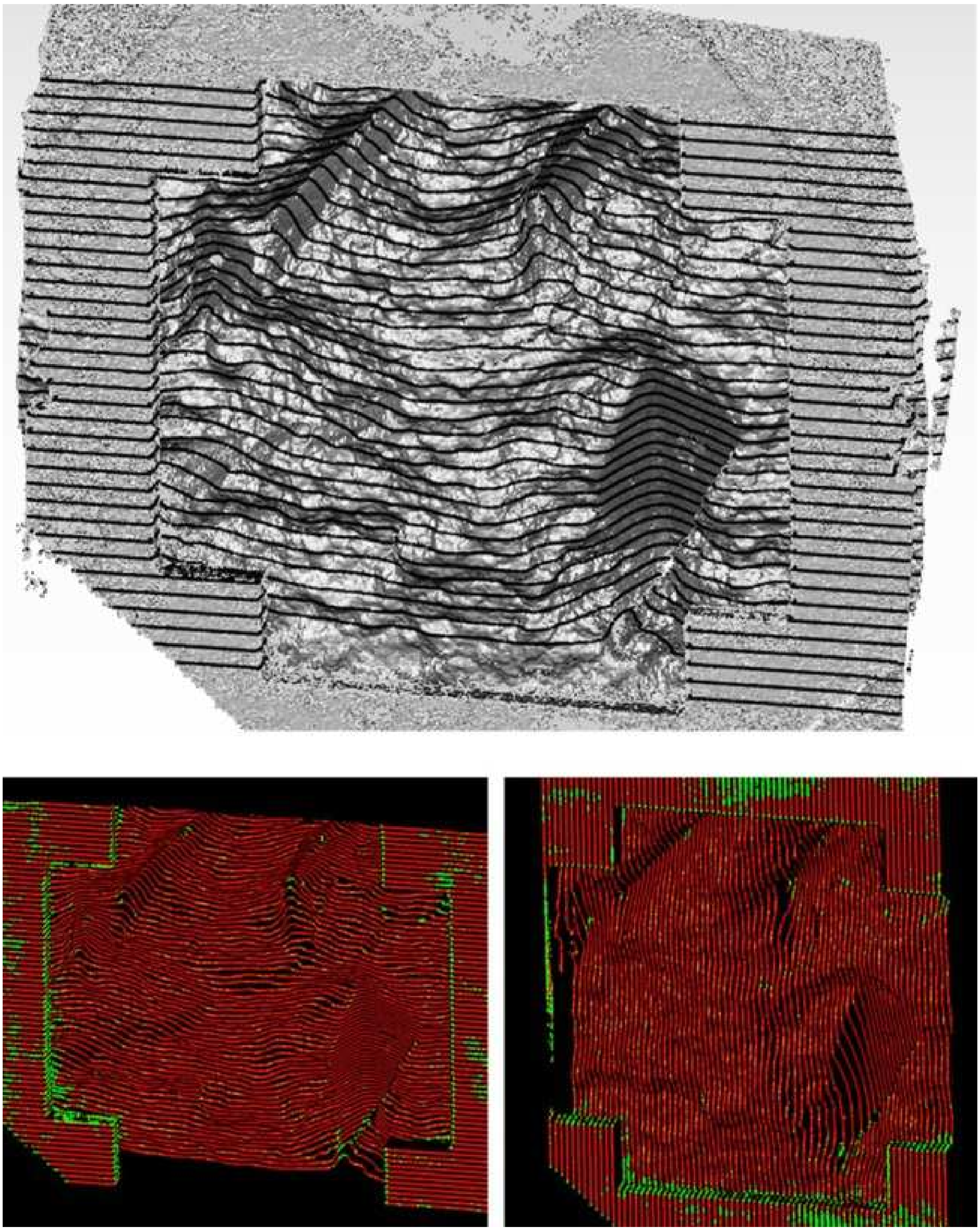

Fig. 10 – 3D model analysis by mesh editing software (Copyright: Andrea Pasquali - Angela Mancuso)

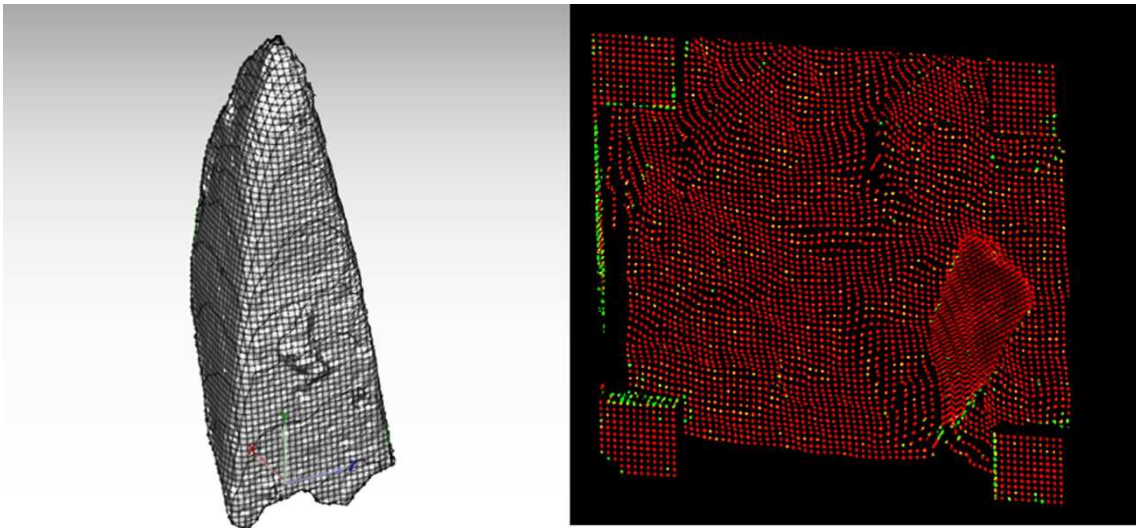

Fig. 11 – Study on a part of the 3D model (Copyright: Andrea Pasquali - Angela Mancuso)

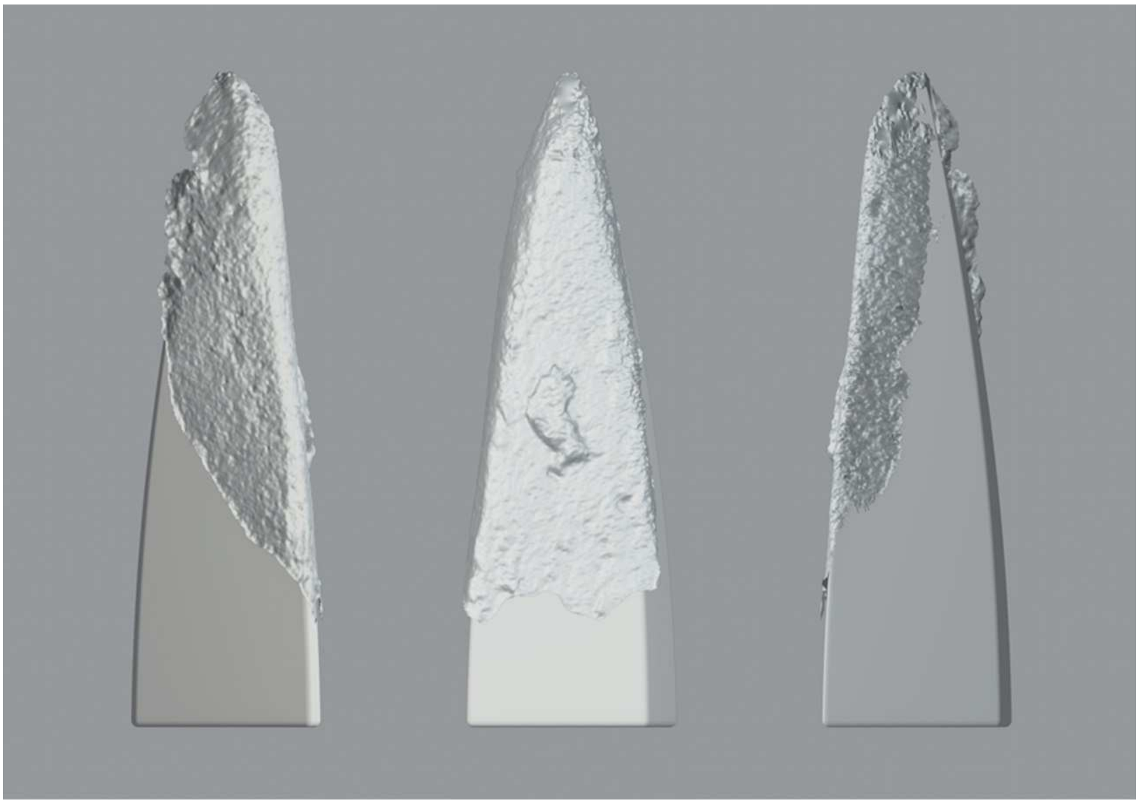

Fig. 22 – Scientific reconstruction of chisel top (Copyright: Andrea Pasquali - Angela Mancuso)

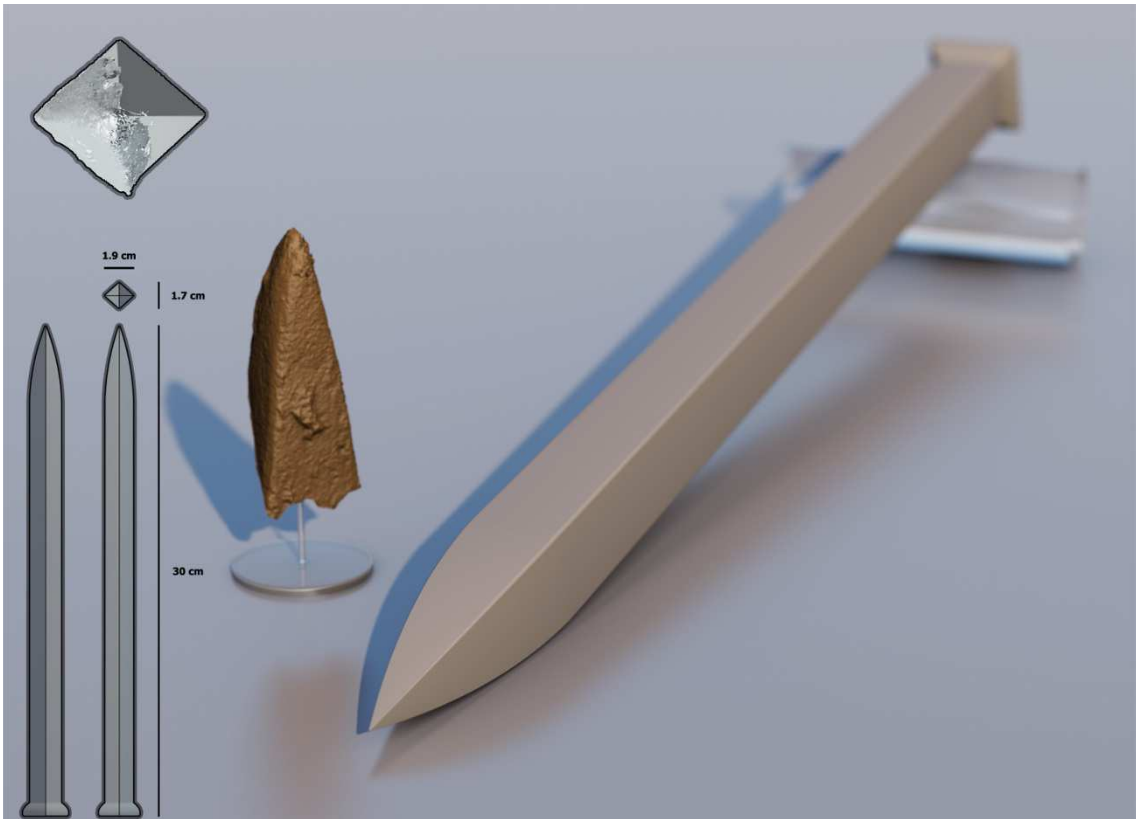

Fig. 33 – Suggestion of chisel reconstruction and dimensional data (Copyright: Andrea Pasquali)

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Imprint:

Proceedings of the 20th International Conference on Cultural Heritage and New Technologies 2015 (CHNT 20, 2015)

Vienna 2016

http://www.chnt.at/proceedings-chnt-20/

ISBN 978-3-200-04698-6

Editor/Publisher**:** Museen der Stadt Wien – Stadtarchäologie

Editorial Team: Wolfgang Börner, Susanne Uhlirz

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