Museum of the Terracotta Warriors
and Horses of Qin Shihuang
Lintong, Shaanxi, PR China

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„Erprobung und Optimierung von Konservierungstechnologien für Kunst- und Kulturgüter der Provinz Shaanxi, VR China“

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Virtuelle Realität:
„Panorama- und Objekt-Movies“
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Virtual Reality:
‘Panorama- und Object Movies’
and
‘Virtual Colour Reconstruction on 3d Models of Terracotta Warriors’

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21. April – 23. July	Exhibition in the ‚Kunst- und Ausstellungshalle' in Bonn: ‚Xi'an – Imperial Power in the Afterlife, Burial Goods and Temple Treasures from China's Ancient Capital'
24. – 28. April	Visit of the Chinese Delegation in Munich; Delegations members: Zhao Rong, Fan Yanping, Wu Yongqi, Yin Shenping, Han Jinke, Han Wei, Wang Dongfeng, Wang Liang
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02. – 29. Nov.	Working stay from Mr. Rong Bo and Zhang Zhijun in Munich.
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Interview mit Hr. Hennies für das “WDR”, 17. 2. 2006
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Furthermore a range of newspaper articles on the exhibition in the KAH in Bonn.

Virtual Reality I

Summary of the results: panorama and object movies

With the help of Virtual Reality (VR), apparently three-dimensional photorealistic scenarios can be created. It is possible for the viewer to independently choose his own angle, to alter the size of details from the respective scenes, and to move freely in different directions. Virtual Reality thereby allows for views or angles which reality is only hardly able to offer or not at all.

VR technology can be excellently used for the representation of objects of art, museum halls and excavation sites, since, by utilising digital photos, a maximum of realism can be achieved. Virtual Reality therefore can serve as an instrument which makes art easier to experience. Thus, new perspectives can be opened to the viewer of virtual media. Visitors of exhibitions or museums, for instance, are able to take a virtual trip to the remote or inaccessible site of an excavation or exhibits from perspectives, which are otherwise difficult to access.

It was the intention of this project to demonstrate by the example of the tomb of the First Chinese Emperor Qin Shihuang, the possibilities offered by the application of virtual reality. In the process, the objective was to design and carry out a “virtual tour” through panorama movies as well as to visualise an apparent 3D scene in the form of an object movie.

Since visitors to the Terracotta Army in China are barred from entering the pits of the warriors and horses themselves, they have to restrict themselves to looking down into pit from the edge. By means of a panoramic view constructed in the pit, it is possible to study the clay warriors at close range. With the help of the panorama video, it is possible to virtually enter the pits. For the presentation on a monitor, several panorama movies from the First Emperor’s tomb complex were merged to form a “virtual scene”. Starting from a front page, it was possible to navigate to three different panoramas which made possible to “look into the pit” from especially impressive places in pits 1 and 3.

An object movie makes it possible to virtually move around object one likes to view. The respective subject can be looked at from different perspectives. By means of an object movie, seemingly plastic and highly resolved representations temporal processes can be created. When the mouse is used for viewing, the line of sight can be individually altered.

Thereby, it is possible to navigate freely in the scene as well as to minimise or maximise a detail and to explore the virtual world minutely.

In order to make art from the First Emperor's tomb, which, from our point of view, is far away, experienceable in Europe, an object movie of the kneeling archer with the "green face" as well as of a bronze goose was created. With the help of these two interactive media, it is now possible to seemingly move around the bag and the warrior. Thus, a spatial experience is made possible, and to a much greater extent than is the case with a two-dimensional photo.

Many works of art lie dormant in depots, and the public has only limited access to them. If an object movie was created of such a work of art, it would at least be possible to view the virtual replica on the screen. Thereby, little known or forgotten art of a collection could be brought to public attention to a greater degree. A sculpture placed in front of a wall can only be viewed from the front and the sides. The disadvantages of this form of presentation can be compensated by the "total view" of an object movie.

The employment of VR applications would be the obvious choice as an auxiliary means for the viewing of works of art, which may not be able to replace the study on the object itself; however, unnecessary strain for the object can thus be avoided. Especially the realistic and interactive utilisation of panoramic and object movies, for instance, makes it possible to examine a work of art in its virtual form – even across great distances – via the Internet.

In museums or archaeological collections, panoramic and object movies can be employed in the exhibition as a support. Moreover, these movies could be provided with additional language, image and text information. In a presentation next to the object of art by means of a monitor or beamer, it would be thus possible to convey additional contents on the work of art represented such as the name of the artist, the materials used, time of origin etc.

State-of-the-art mobile telephones, for example, are already provided with the possibility to play movies or videos, respectively. In the future, it would be possible for a visitor to a museum, who is looking at an object of art, to have a related movie with complementary information and representations transmitted onto his cell phone. In conjunction with spoken texts, photos and other animations, movies, stored on CD or DVD, can be sold in the museum shop.

Figure 1: Equirectangular panoramic view of Pit No. 3

Virtual reality – panoramic and object movies of sculptures of Qin Shihuang's tomb

Felix Horn, Meng Zhongyuan

Introduction

Virtual reality (VR) can be employed as an auxiliary means to make art experienceable in a better way. In the process, the application of virtual worlds makes it possible to view works of art from perspectives or angles, which in the real world are only hard to reach or impossible. Thus, the visitor to an exhibition or a museum is able to virtually move to the far away and usually inaccessible site of the excavation. Likewise, the employment of virtual reality allows us to view the exhibits from perspectives otherwise hard to access.

The approach of this project was to demonstrate by the instance of the tomb of the First Chinese Emperor Qin Shihuang the possibilities offered by the application of virtual reality. By the example of Terracotta Warriors and bronze birds from the First Emperor's tomb, the application of VR is to be demonstrated. Our target was to design and carry out a "virtual tour" through panoramic movies as well as the visualisation of an apparent 3D scene in the form of an object movie.

Panoramic[1] and object movie

What do the terms panoramic and object movie[2] mean? For a panoramic view in the real world, a human needs to stand on a vantage point while turning his own axis. Translated to the virtual world, the viewer of a panoramic movie is shown the surroundings of a fixed standpoint in a panoramic view. The horizontal and vertical line of sight can be altered at will.

When looking at a work of art, e.g., a sculpture, the interested art-lover surrounds the object of art on a circular path. An object movie makes possible a virtual motion around the object one wishes to look at. The respective subject can be viewed from different perspectives. With an object movie, seemingly plastic and highly resolved representations as well as temporal processes can be accomplished.

The representation of such movies is implemented with the help of special viewing software[3], in which the line of sight can be individually altered with

[1] The term panorama is a made-up word composed of the Greek components "pan" (= all) und horama (= view) and approximately means "total view".
[2] Due to their way of virtual representation, panoramic and object movies are also termed as panoramic VR or object VR, the abbreviation VR standing for Virtual Reality.
[3] Viewing software of this type ("viewer") is the QuickTime Player by Apple Company. QuickTime is a cross-platform multimedia format fort he creation and transmission of

the mouse. Thereby, it is possible to navigate freely in the scene as well as to minimise or maximise a detail and to explore the virtual world minutely. In the process, the viewer sees a rectangular detail of the panorama. When he moves the detail further with the mouse, further parts of the image series are transmitted to him so that a fluent change of perspectives ensues. Moreover, the greatest possible resolution of the view is initially not shown. By pressing the player's Zoom key, the image detail is maximised and the illusion of approaching a particular is created.

The employment of VR applications is the obvious choice as auxiliary means in dealing with works of art. Especially the realistic and interactive utilisation by the viewer is a great advantage of panoramic and object movies. The direct and immediate study on the object of art, however, cannot be replaced thereby.

The utilisation of virtual reality, however, can contribute to art being spared unnecessary strain. Thus, studies in stylistics, for instance, could – even across large distances – be pursued via Internet on the virtual object of art.

Panoramic movie

Visitors to the Terracotta Army in Lintong are allowed to look at the clay warriors and horses only from the edge of the pit; they are, however, barred from entering the pit. A panoramic movie created in the pit opens the possibility to study the warriors at close range.

The representation of panoramas on the computer is divided into three different types of projection: cylindrical, spherical and cubic form. In the case of the cylindrical projection, the panoramic image is shaped like the external wall of a cylinder, while the viewer is at the centre. In horizontal direction, a rotation by 360 degrees is possible; the vertical viewing angle is restricted to less than 120 degrees. The spherical and cubic projection allows for a horizontal rotation by 360 degrees and is not restricted as far as the vertical angle is concerned.

In the Museum of the Terracotta Warriors and Horses, Pit No. 1 was selected for the creation of panoramas. Due to the good lighting conditions, especially the front area of pit is suited as a location for the photos.
Several individual photographs have to be taken as source material for a panoramic movie. For the creation of the photos, a digital SLR camera[4] was used together with a wide-angle lens[5]. By using a special panorama head mounted onto the tripod, an accurate adjustment of the pivot point was possible.

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movie, sound, animation, graphics, text and music. The Player contains a plug in for browsers such as Netscape etc., making QuickTime Movies integratable in a web site.
[4] SLR = Single Lens Reflex.
[5] Camera: Nikon D100, objective: Nikon 18 mm.

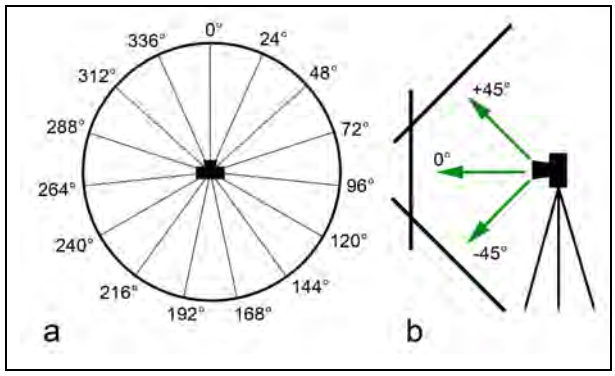

Figure 1: *Image rows*

a) Photographing a row of 15 pictures each, one every 24°; b) Taking 3 rows at inclinations of + 45°, 0°, – 45°

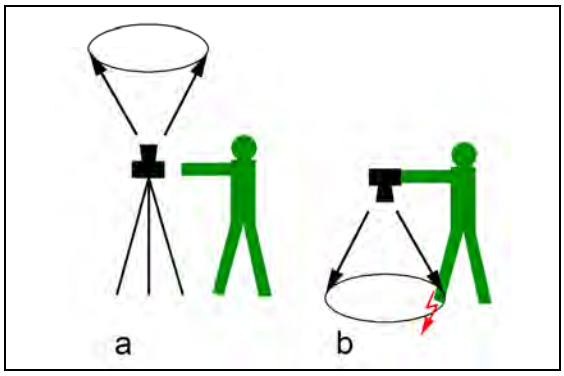

Figure 2: *Top and bottom photo*

a) Taking a single shot of the top (+90°), b) Take a photo of the ground (–90°), attention: keep your feet out!

Figure 3: All 47 images of the spherical panorama; *first row*: series at +45°, *second row*: series at 0°, *third row*: series at –45°; *fourth row*: vertically upward and downward.

It was possible thereby to exactly align the camera on the tripod so it could be rotated around the nodal point[6]. This was required in order to avoid parallax errors, which otherwise become visible after the photos are stitched together. With the help of a little water-level or with a spirit level built in into the tripod head, the camera can be horizontally aligned.

In order to capture the entire environment in a pan of 360 degrees, depending to the objective used, 12-16 photographs are required. For this purpose, the camera is being rotated on the tripod in defined angle sections. In the process, it is important that the individual images have an overlapping area of ca. 30%, in order to be able to later stitch them together more easily with the stitching software[7]. For a spherical panorama (360 x 360 degrees), three series had to be photographed: one in horizontal direction, and one in which the camera in each case is inclined upward or downward by 45 degrees

[6] *Nodal point*: corresponds to the optical centre of the objective.

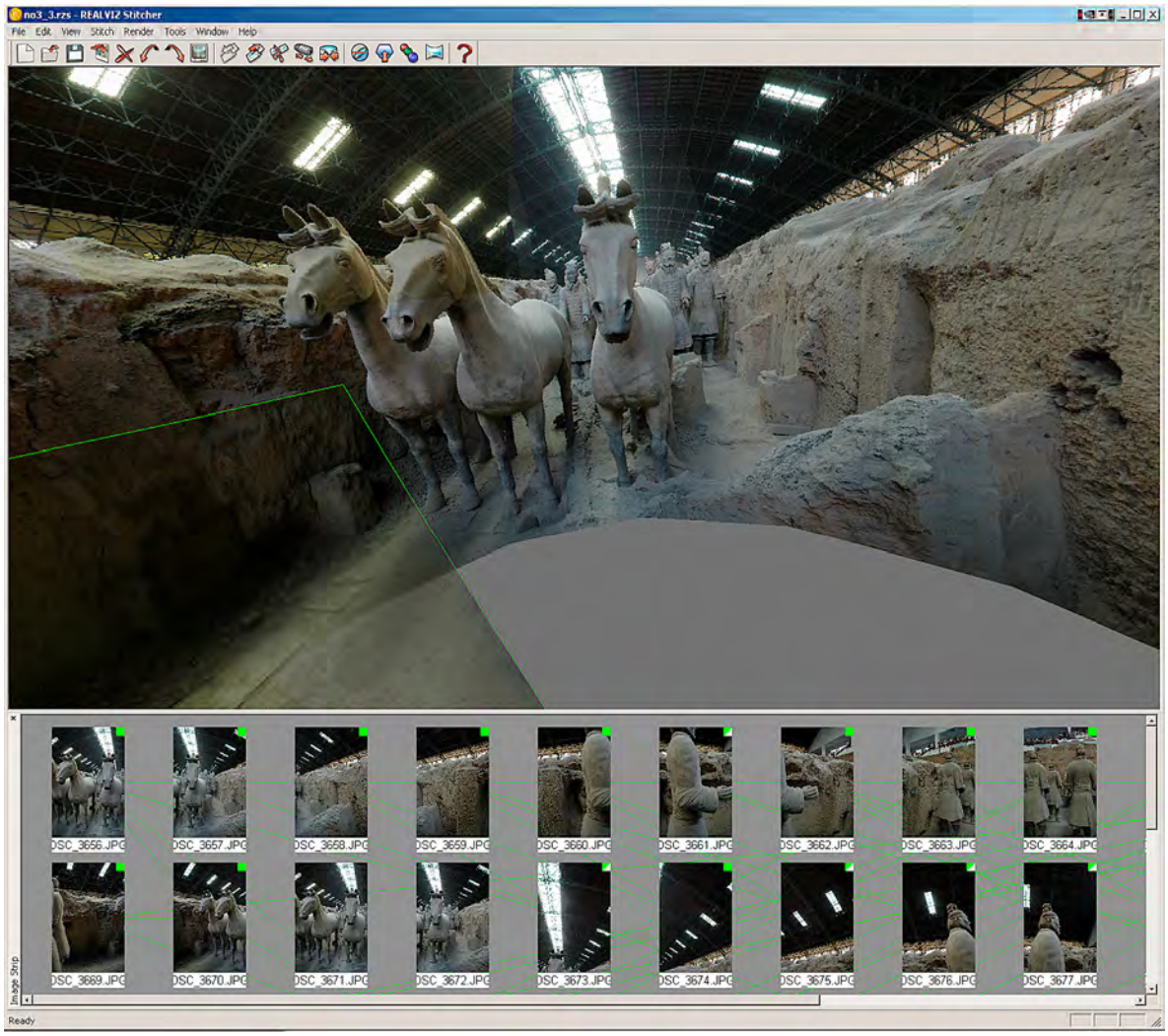

Figure 4: Assembling of the panoramas out of individual images with the stitching software (Realviz Stitcher).

from the horizontal (Fig. 1b). Finally, in each instance an individual image was in created upward from the ceiling (Fig. 2a) and vertically downward from the ground (Fig. 2b). For the image taken vertically downward, the tripod must be removed. The camera should in this case preferably be held in hand in unchanged position.

With the wide-lens objective[8] used, in one pan of the camera 15 photos were generated in steps of 24 degrees (Fig. 1a). For three image series required, thus 45 photographs were created. Together with the photos for ceiling and ground, 47 images were created altogether (Fig. 3).

Special attention when taking the series of photos had to be paid to the all the camera angles being maintained for all the images. By means of a

[8] Note: with digital cameras, pay attention to focal length extension through the sensor. With the camera used (Nikon D100), the focal length extension factor amounts to ca. 1.5. An 18 mm wide-lens objective thereby is provided with a focal length extension of 27 mm.

constant value for lighting, distance, illuminants etc., it was guaranteed that the photos could be stitched together at the computer without any problems. Altered settings within an image series may cause margins in the overlapping area of the images. In the worst case, it is no longer possible to stitch together the individual images. Therefore it was important to make sure that the camera was operated manually without any automatic, and without altering the distance settings during rotating.

When all the shootings were accomplished, the digital images were transmitted to the computer and imported into the stitching software[9], stitched together and rendered[10] (Fig. 4). The result is a panorama in (QTVR-) multimedia movie format, which can be viewed by means of an appropriate viewer (Fig. 5). As a rule, the details of the movies required post-processing in order to achieve a good result.

If several panoramic movies are created in one location, there is he possibility to link the individual files with each other by means of so-called “hot spots”[11]. Thereby, it becomes possible to move in different places of an excavation site, and to take a “virtual” look around there.

Within Pit No. 1 in the Museum of the Terracotta Warriors, panoramic images were created in five different locations, which can be combined to form a “virtual tour”. Different light conditions during the shootings due to the respective time of day and weather, however, led to very different results and moods in the panoramic movies created. Therefore, the individual movies can be combined with each other only to a limited extent.

[9] Programme for the creation of panoramas: *REALVIZ Stitcher* v. 4.0.
[10] In computer technology the term for the calculation of an image.
[11] A hot spot represents a short cut by means of a hyperlink, as e.g. on Internet sites.

Figure 5: View of the spherical panoramic movie from Pit No. 1 in the Museum of the Terracotta Army (Apple QuickTime).

Object movie

When presenting excavation items in a showcase, only a limited number of perspectives are possible. Moreover, the glass pane prevents them from being looked at from short distances: it is impossible to study them at close range.

For the creation of an object movie, the kneeling archer with the 'green face' in the Terracotta Army Museum was chosen. There are two types of techniques for the shooting of object movies, the single-row and the multi-row technique. A single-row object movie only consists of one row of images taken with the camera being moved around the object on a horizontal level. If, besides being taken from a horizontal direction, the photographs are

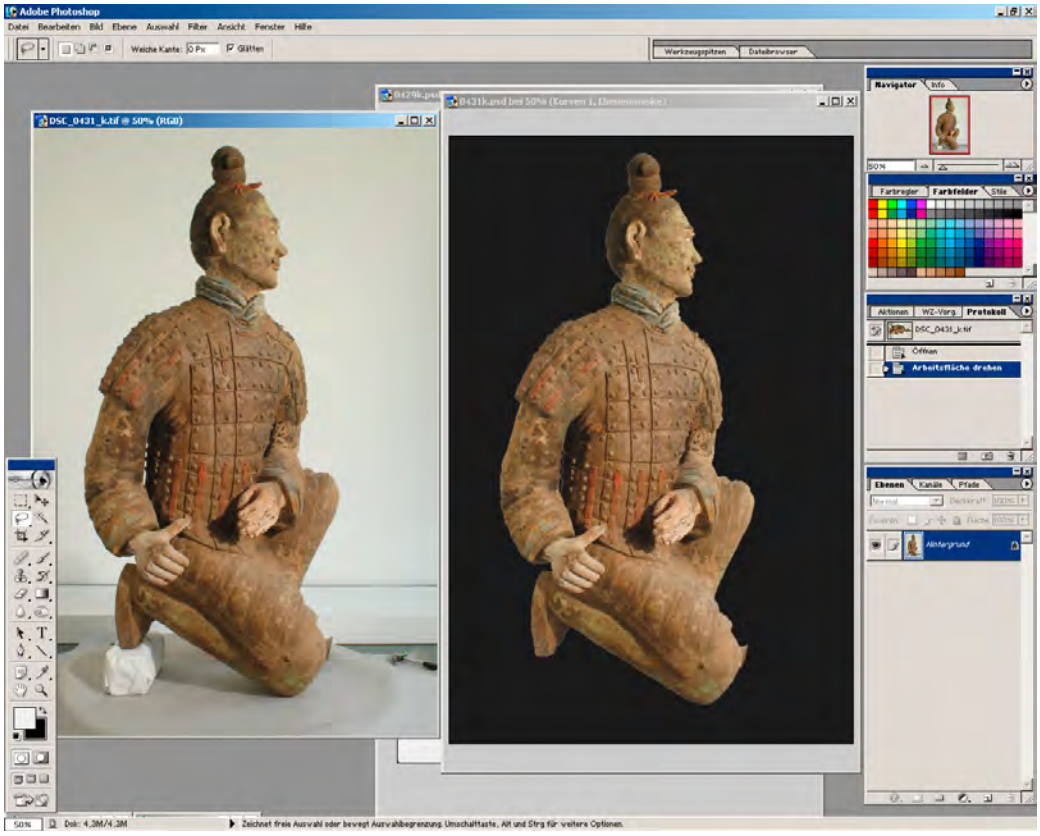

Figure 6: Digital photo of the kneeling archer; replacing the background oft the image using an imaging software, *left*: original photo, *right*: integrated dark grey background.

also taken at an oblique angle from above or from below, the term multi-row technique is used; several rows of photographs are created.

Digital photos are the starting point for the creation of an object movie. For the photographs, a digital single-lens reflex camera, a tripod as well as a rotary disc divided into angles are used. By applying a neutral background for the photo, it is possible to avoid the removal of the background from every single picture in the post-processing.

For the photo shootings, the clay warrior was placed at the centre of the rotary disc. The scene was illuminated with two daylight lamps. The camera was placed in such a way as to make it possible to photograph the clay warrior with the warrior occupying the whole image; in the process, special care had to be taken to avoid that overhanging parts of the figure move out of the picture format during rotation. During the entire image row, the camera remained in the same place. Here as well, it was crucial that the settings for lighting and distance had to be maintained during the entire shootings. The smaller the individual rotary angles are selected, the more photographs can be taken, and the more fluent the object appears when represented in the movie.

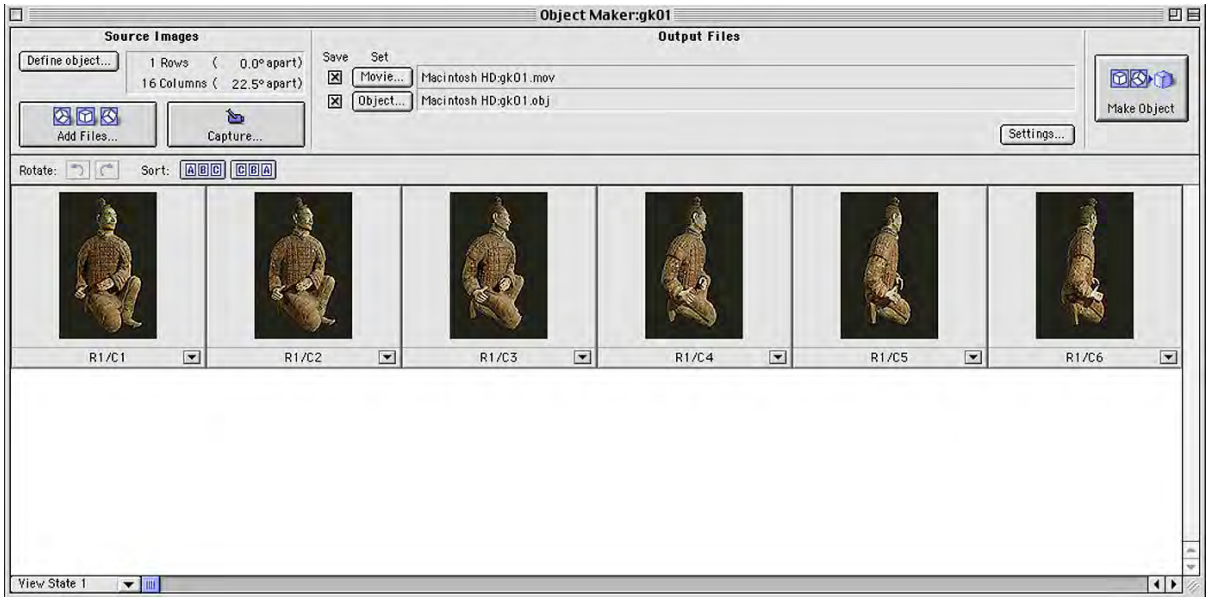

Figure 7: Software during creating the object movies out of the individual pictures (Apple QTVR Authoring Studio).

For the creation of object movies of the kneeling archer, the single row technique was applied. For the photographing, the clay warrior was turned in angle steps of 22.5 degrees. In a full rotation by 360 degrees, 16 photographs were thus created, each of them with a different view. After the shooting, the pictures were transmitted from the digital camera onto the PC.

In the next step, the background was removed from the pictures with image processing software[12], and subsequently replaced with a dark-grey background (Fig. 6).

For further processing, the images were imported into software for the creation of object movies[13] and then stitched together there (Fig. 7). By appropriately adjusting the Settings of the programme, the properties of the object movie such as window size, starting point, auto start etc., can be adjusted. The output format used was QTVR object movie format (Fig. 8). After thoroughly viewing the created movie, errors still present in the images can be removed with the image processing programme. After processing, the photos had to be stitched together once more to form an object movie again.

[12] The digital images were processed with *Adobe Photoshop CS*.
[13] Software for the creation of object movies: *Apple QuickTime VR Authoring Studio* v. 1.0.

Figure 8: The finished object movie of the kneeling archer with the ‘green face’ (Apple QuickTime).

Outlook

What are the advantages of using VR technology in restoration and in the museum? It is possible to create apparent 3D scenes in the form of panorama and object movies at low cost with relatively little effort. Thereby, realistic and unadulterated representations of objects and spaces can be created with high quality. This type of visualisation opens new dimensions when it comes to conveying the impression of space. For the visitor to a museum, new approaches arise by dealing with virtual art, grasping a work of art is thus facilitated. A further advantage of panoramic and object movies is their simple operability when viewed with special viewing software (Movie Player). Especially attractive for the viewer here is the free navigability in a scene.

In museums or archaeological collections, panoramic and object movies can be employed in the exhibition as support. In addition, these movies could be provided with language, image and text information. If the movies are presented beside the object of art with the help of a monitor or beamer, additional contents could be thus conveyed.

Moreover, state-of-the-art mobile telephones are already provided with the possibility to play movies or videos, respectively. In the future, it would be possible for a visitor to a museum, who is looking at an object of art, to have a related movie with complementary information and representations transmitted onto his cell phone. In conjunction with spoken texts, photos and other animations, movies, stored on CD or DVD, can be sold in the museum shop. A further field, in which this technology could be employed, would be for multimedia and TV productions.

Acknowledgement

Many thanks to all the employees in the Museum of the Terracotta Warriors and Horses of Qin Shihuang, and to the colleagues in the Chines-project of the Bavarian State Office for the Preservation of Historical Monuments for their support of our work. Special thanks to Li Hua, Wang Dongfeng, Wang Weifang, Xia Yin for their participation in the location shots in the pit.

A look into the pit – creating a virtual scene from panoramic movies of the tomb of Qin Shihuang

Felix Horn

In the exhibition "Xian – imperial power in the afterlife, grave finds and temple treasures from China's ancient capital" in Bonn, several panoramas were presented in the form of a "virtual scene". Virtual scene means stitching together several panoramas to form a tour. In such a scene, the viewer is able to move from one standpoint to the next, thus gaining an impression of the surroundings at the site. A virtual tour enables the visitor to interactively experience and explore a site or spaces. By means of navigation with hyperlinks, he is able to move through different levels, or decide himself where he wants to move next within the image. The situation of the panoramas thus coupled with one another can be illustrated with an overview map. Other interactive file types may also be integrated with such interactive scenes.

To realise Virtual Reality in the First Emperor's tomb, Apples QuickTime VR (= QTVR) technology is applied[14]. For this purpose, two different types of QTVR media are available: panoramic and object movies.

A *panoramic movie* is an interactive film enabling one to revolve by 360° in spaces or landscapes as well as to direct one's look upward and downward. Here as well, it is possible to maximise the detail to have a better view of particulars.

An *object movie* is an interactive film making it possible to apparently view an object from each side. It is possible to move around the object by 360° and to view it from different angles (Fig. 1).

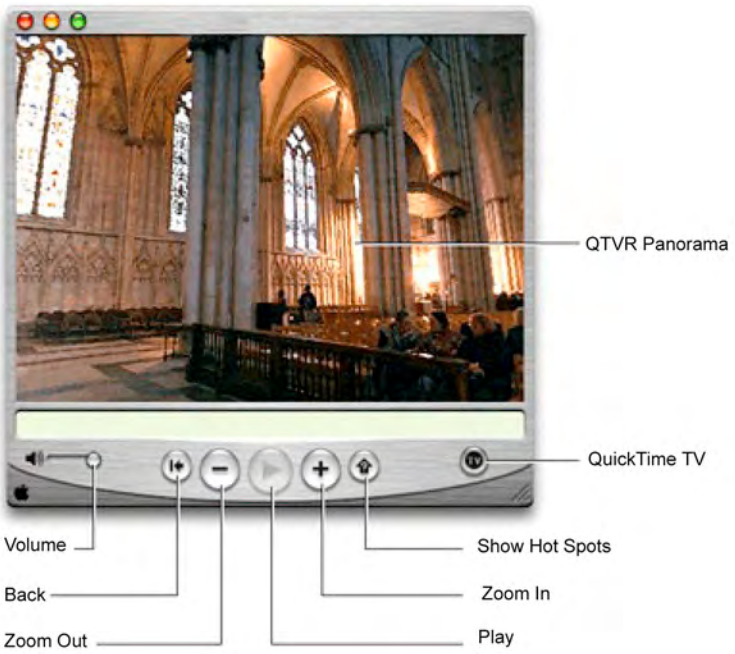

Figure 1: Viewing window of a panoramic movie, below the image there are operating elements.

[14] Die *QuickTime VR* (= QTVR) technology was produced by Apple company. In QTVR, the data are embedded in *QuickTime VR Movies*.

In addition, objects can be animated, e.g., to show different states. According to the quality and resolution selected for the underlying digital images, particulars of the object can be maximised to up to 800 percent.

For the virtual tour in the Bonn exhibition, it was decided to employ only panoramic movies. For this purpose, panoramas created in the years 2004-06 within the pits in different locations were available.

The quality of the panoramic movies created was greatly dependent on the shooting situation. A change in the external conditions had great impact on the result. The time factor played a significant role here. Ideally, it was possible to create the digital photos for an individual panorama roughly within five minutes. Under difficult conditions, the shooting required more than half an hour. Especially a change in the light conditions due to the position of the sun or moving clouds may significantly influence the shooting.

With direct insolation, the hard shadow of a clay figure in an image series thus wandered by several centimetres. Moreover, the many visitors in the background, whose number greatly changed during the day, impeded the creation of the panoramas. If a cloud moved in front of the sun, the shooting had to be interrupted. Beyond that, the shadows caused in the picture by the tripod and the panorama head required later post-processing.

Corrections on a panorama were performed in two different ways. After the individual images were stitched together, major flaws could already be repaired with the stitching software. Even graver flaws were eliminated with various retouching tools in Adobe Photoshop.

Three of the great number of created panoramas, which conveyed a particularly impressive view of the pit, were now selected. For this purpose, two panoramic movies from Pit No. 1, were chosen which provide a round view of the entire pit as well as an immediate view of several teams of horses in aisle T1G18 (Fig. 3). A further movie from an interesting perspective provides a view of Pit No. 3.

For the presentation in the Bonn exhibition, it was now required to stitch together the three panoramas to form a virtual scene. In this scene, the viewer should be able to move from one standpoint to the next. The virtual scene was created with the software *Macromedia Director* by *Adobe*. With Director, a proven multimedia authoring tool for professionals, you can develop high-performance content and deploy it anywhere: on CDs, DVDs, intranets, kiosks, or the Internet.

In Director, Quicktime panoramic movies can be directly integrated, and, with

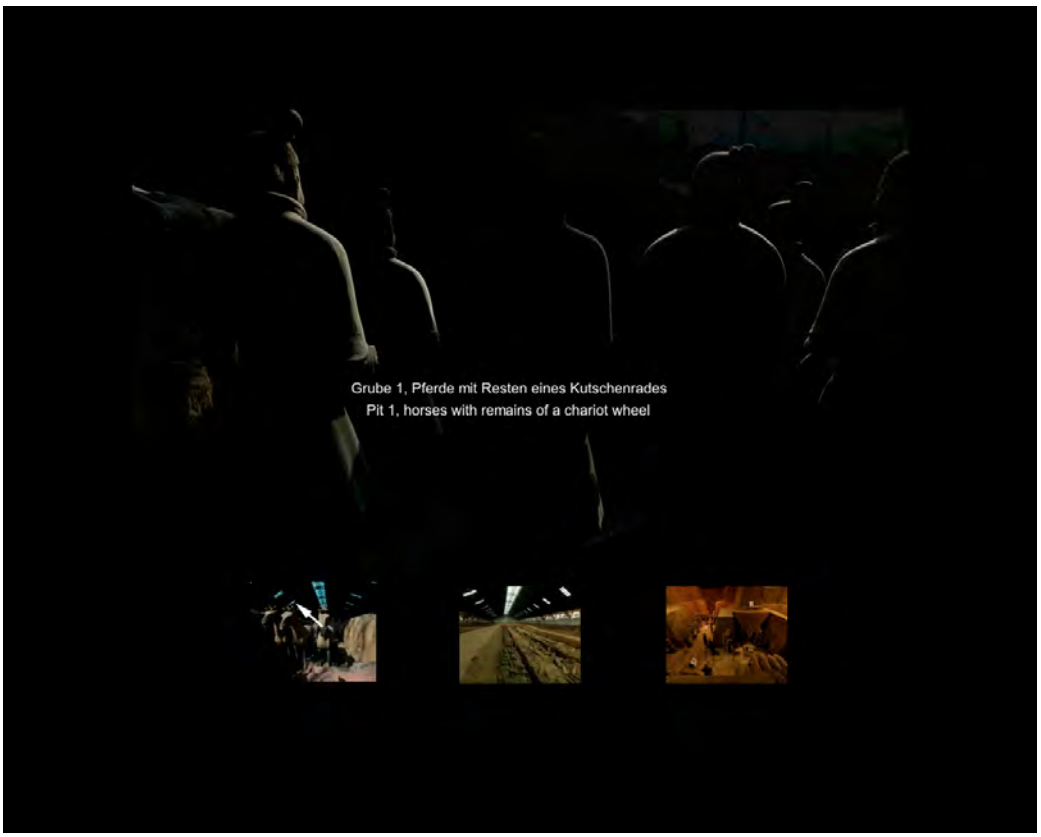

Figure 2: Welcome page of the virtual tour, in the bottom of the image the viewer has the possibility to select from the three panoramic movies.

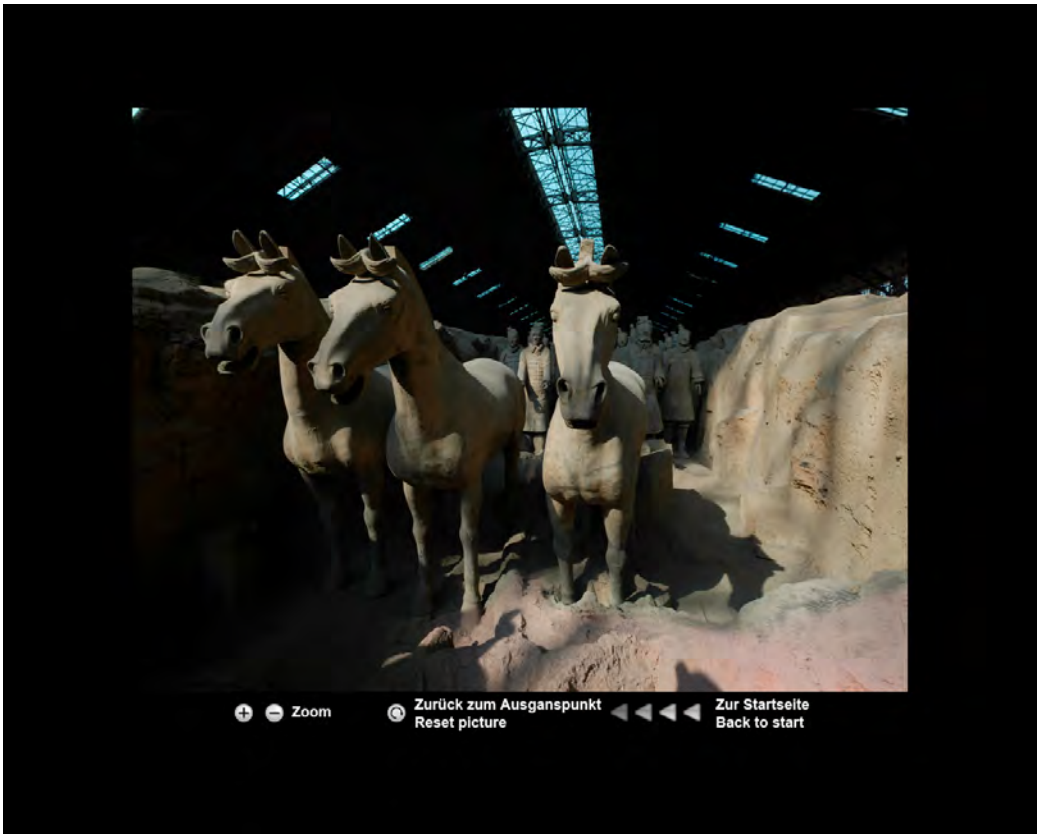

Figure 3: Panoramic movie No. 1, standpoint in Pit No. 1 in front of the horses of a chariot.

Figure 4: a) Welcome page of the virtual tour with language selection in the navigation bar, b) Panoramic movie with a view of Pit No. 3, Chinese voice control is activated.

the programming language *Lingo*[15], which is available here, they can be directly addressed and controlled. At the end, the movies are compiled together with the control, i.e., a so-called projector is created. This means that an independently executable programme is created which can be executed on the PC or Mac without any additional software[16].

Starting from a front page (Fig. 2), one can go to the individual panoramic movies. First a language has to be selected (Fig. 4). This is necessary in order to provide a simple navigation for the international visitor as well. The languages to select from include Chinese, Pinyin, English, French and German.

The language-selection buttons are dynamically activated one after another, i.e., they light up to arouse the viewer attention. This occurs until a language is selected. Afterwards, the caption of the front page and the panoramas are always displayed in the selected language.

After the desired panorama has been selected, it is possible to move within the image with the help of a navigation bar. By means of the mouse, the line of sight can be individually controlled here. Thereby, it is possible to navigate freely in the scene as well as to alter details. In the process, the viewer sees a rectangular detail of the panorama. If he moves it with the mouse, further parts of the image series are transmitted to him so that there is a fluent change of perspectives. A TFT screen was used to display the scene in the exhibition.

[15] 'Lingo' is a programming language for use in the authoring software *Macromedia Director*. This script language is a powerful tool to import media files and to control animations. A great number of multimedia-based contents can be thus combined with each other. A particular advantage of applications created with Director is their platform independence. They are thus applicable in Windows as well as on Mac OS computers.

[16] The programming and design of the virtual scene was implemented by the two colleagues as well as Stefan Meyer and André Traunecker from *Animatrics* GmbH company, URL: < http://www.animatrics.com/ >. Many thanks for this.

Appendix:
Translation into different languages.

Welcome Page:

虚拟现实 – 坑中一瞥
Virtual Reality – View in the Pit
Virtuelle Realität – Blick in die Grube

Caption of the 3 panoramas:

Panorama 1	**Panorama 2**	**Panorama 3**
一号坑车马遗迹	一号坑军团全景	三号坑指挥机关
Pit 1, Horses with Remains of Chariot Wheel	Pit 1, From the Centre of the Army looking around	Pit 3, Headquarter or Guard of Honour
Grube 1, Pferde mit Resten eines Kutschenrades	Zentrum von Grube 1, Rundumsicht über die Armee	Grube 3, Kommandostand oder Ehrenwache

Control buttons:

焦距	重新开始	返回主页面
Zoom	Reset Picture	Back to Main Page
Zoom	Zurück zum Ausgangspunkt	Zurück zur Hauptseite

Virtual Reality II

Summary of the results: Colour reconstruction on a 3D model

The figures from the burial site of the first Chinese emperor Qin Shihuangdi originally were coloured, but today they're mostly without colour. The goal in the project stage 2004-2006 was, to show the original colourful appearance of figures from the terracotta army. With computers, the colouring was reconstructed and completed on 3D-models. An impression of the original colouring was the intention.

Between 2004 and 2006 eight warriors of the terracotta army were scanned: four kneeling and a standing archer, two generals and a standing warrior (Figure 1-8). In addition three bronze birds and a crossbow mechanism (Figure 9) from Qin dynasty were scanned too.

The contemporary colouring was documented and then used as starting point for the colour reconstruction. For the work on the computer the surface of the terracotta warriors were digitalized with 3D scanners. From this, wire-frame models were generated. Those models were the base for the creation of surfaces and textures. For textures, digital photos were used to show their actual condition. The colour reconstruction and the virtual completion was done with a 3D-Paintsoftware and built up on the textures.

Four of the warriors got textures of their contemporary look. Furthermore virtual retouches and colour reconstructions were started on four figures. For the exhibition in Bonn animation videos of a kneeling archer and a general were made. These videos show an impression of their original colouring.

So far, four of overall 12 different types of warriors from the terracotta army were measured. Because of this, the exemplary digital measurement of all the figure types and probably a horse is a goal for the future. After the 3D measurement, those figures should get textured and reconstructed in colouring to show the colour spectrum of the whole army.

Different parts of the process should get optimized: a collection of point in space together with a corresponding pixel (colour value) is aspired, as well as a sensible reduction of data with an adequate level of detail.

Also planned is the compilation of disordered polygon models in ordered surfaces and to test different new methods to texture 3D-models.

The position of the kneeling archers is described as ‘ready to shoot’ in literature. What they held in their hands is still not doubtlessly clear. By reconstructing a crossbow the question should get answered. Numerous informations about crossbows and arrows of the Qin dynasty were already collected. The analysis of that information was only done in parts until now.

Scanned figures

Kneeling Archer T21G18-08

Date of scanning:	2004
3D scanner:	ATOS II, Firma GOM
Number of single scans:	–
File format:	stl
Error correction 3D model:	Yes
Texturing:	No
Colour reconstruction:	No

Proposed work:

— Colour reconstruction

Figure 1: T21G18-08.

Kneeling Archer T21G18-07

Date of scanning:	2004
3D scanner:	ATOS II, Firma GOM
Number of single scans:	–
File format:	stl
Error correction 3D model:	No
Texturing:	No
Colour reconstruction:	No

Proposed work:

— Texture mapping with digital photos

— Colour reconstruction

Figure 2: T21G18-07.

General T9:1 / 02747

Date of scanning:	2004
3D scanner:	ATOS II, Firma GOM
Number of single scans:	–
File format:	stl, wrp, 3ds max
Error correction 3D model:	Yes
Texturing:	No
Colour reconstruction:	Yes

Colour reconstruction:

— Following the analysis of polychromy of the figure

Proposed work:

— Enhancement of the colouring of the figure

Figrue 3: T9:1 / 02747.

Standing Warrior T21G10-13 / 02755

Date of scanning:	2004
3D scanner:	ATOS II, Firma GOM
Number of single scans:	–
File format:	stl
Error correction 3D model:	No
Texturing:	No
Colour reconstruction:	No

Proposed work:

— Colour reconstruction

Figure 4: T21G18-13.

Standing Archer 02817

Date of scanning:	2005
3D scanner:	QT Sculptor, (IGD)*
Number of single scans:	194
File format:	stl, wrl, 3ds max
Error correction 3D model:	Yes
Texturing:	Yes
Colour reconstruction:	Yes

* Fraunhofer Institute for Computer Graphics

Figure 5: 02817.

Texturing:

— With digital photos in the present condition (not very detailed)

Colour reconstruction:

— Following the analysis of polychromy of the figure

Proposed work:

— Enhancement of the colouring of the figure

— Reconstruction of a crossbow

Kneeling Archer T21G18-01 (green Face)

Date of scanning:	2005
3D scanner:	QT Sculptor, (IGD)*
Number of single scans:	180
File format:	stl, wrl, 3ds max
Error correction 3D model:	Yes
Texturing:	Yes
Colour reconstruction:	Yes

* Fraunhofer Institute for Computer Graphics

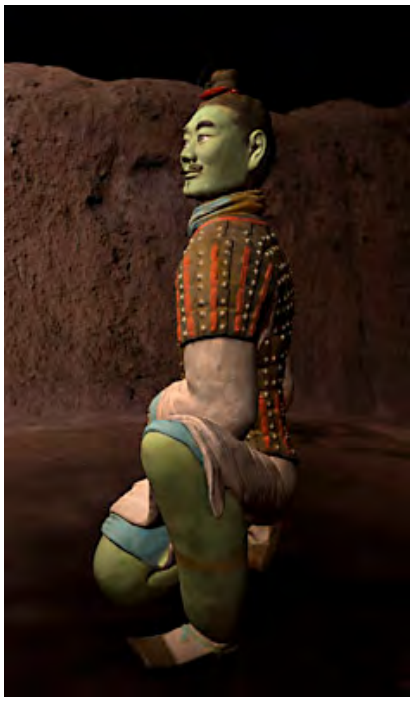

Figure 6: T21G18-01.

Texturing:

— With digital photos in the present condition

Colour reconstruction:

— Following the analysis of polychromy of the figure

Proposed work:

— Documentation of damages on the 3D model

— Reconstruction of a crossbow

General T2G2:97 / 00847

Date of scanning:	2005
3D scanner:	QT Sculptor, (IGD)*
Number of single scans:	150
File format:	stl, wrl, VRML
Error correction 3D model:	Yes
Texturing:	Yes
Colour reconstruction:	No

* Fraunhofer Institute for Computer Graphics

Figure 7: T2G2:97 / 00847.

Texturing:

— With digital photos in the present condition (not very detailed)

Proposed work:

–

Kneeling Archer T21G18-03

Date of scanning:	2005
3D scanner:	QT Sculptor, (IGD)*
Number of scans:	168
File format:	stl, wrl, 3ds max
Error correction:	Yes
Texturing:	Yes
Colour reconstruction:	Yes (head only)

* Fraunhofer Institute for Computer Graphics

Figure 8: T21G18-03.

Texturing:

— With digital photos in the present condition

Colour reconstruction:

— Following the analysis of polychromy of the figure (head only)

Proposed work:

— Finishing the colour reconstruction

Trigger mechanism of crossbow

Date of scanning:	2005
3D scanner:	QT Sculptor, (IGD)*
Number of single scans:	28
File format:	stl, 3ds max, NURBS
Error correction 3D model:	No
Texturing:	No
Colour reconstruction:	No

* Fraunhofer Institute for Computer Graphics

Proposed work:

— Reconstruction of a crossbow, animation of the functionality

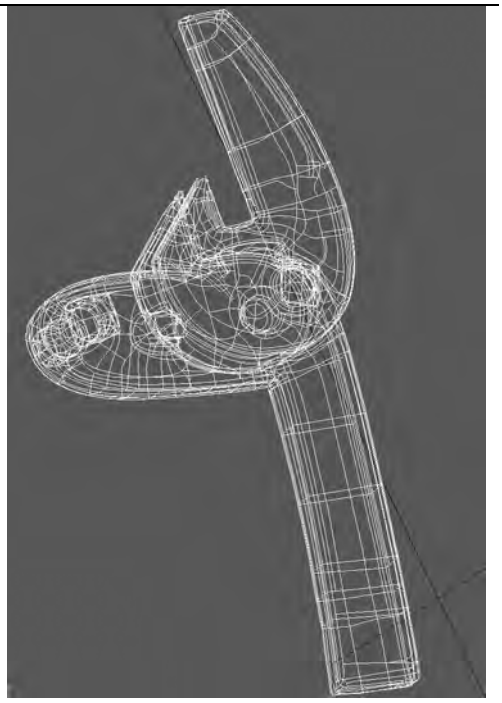

Figure 9: Trigger.

Virtual colour reconstruction of figures from the terracotta army

Felix Horn

Preparations of results and documentation of colouring

For the planned colour reconstruction on 3D models the primal colouring should be based on the original colouring as accurately as possible. For performing such colour reconstruction it's important to understand the buildup of the colouring and also to develop an understanding of the colour schema. To this end investigations were carried out in respect of the colours and condition of the figures chosen for 3D-scanning.

The high ranking officer T9:1 and the kneeling archer with the green face T21G18-01 were intensely studied. The reconstruction of polychromy on the kneeling archer seems to be less problematic, because it's mainly in good condition. On the surface of the officer only small remnants of colour are present. Photos of the remaining colour on figures of the army were taken. For this, a high resolution STL- camera (Nikon D 100) was used.

Using the colour chart *ColorChecker DC* from the firm *Gretag Macbeth* and the software *inCamera* by *Pictographics* it's possible to create colour correction profiles for the digital photos (Figure 3 & 4). These ICC-profiles ensure a natural colour reproduction and can be added to the photos.

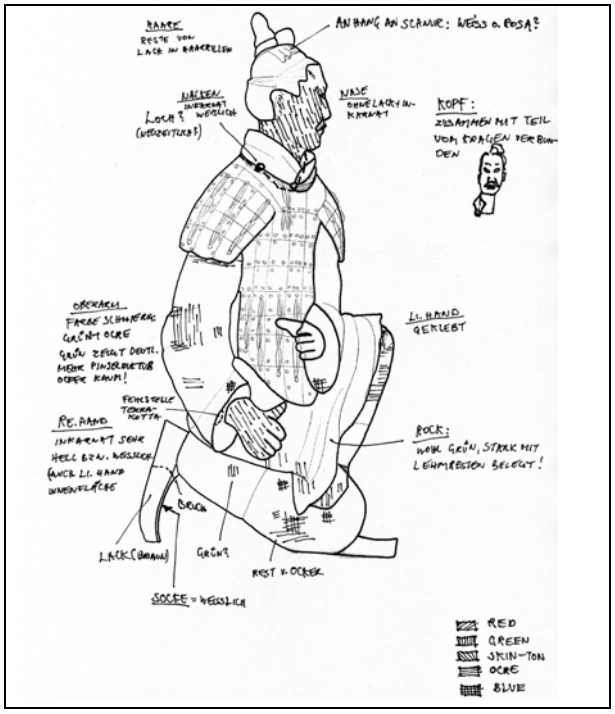

Figure 1: Report of polychromy, Kneeling Archer T21G18-01.

Figure 2: General T 9:1; report and documentation of polychromy.

Figure 3: Colour correction on the example of the kneeling archer T21G18-08; *lower right*: the colour chart *Colorchecker DC*.

Figure 4: General T9:1; remnants of blue colour remaining on the chest armour, edge of the braid.

The remaining colour on the figures was also manually mapped and commented (Figure 1 & 2). By means of the taken photos and the maps of the remaining colour, the colour reconstruction of single figures was started.

3D reconstruction on the figures of the first emperors' burial site

From October 11th to 15th 2004 a measuring campaign to digitalize the figures of the terracotta army was accomplished together with Mr. Guido Heinz, employee of the Römisch-Germanischen Zentralmuseum in Mainz. For this four, figures in the museum of the terracotta warriors and horses in Lingtong were scanned: two kneeling archers, a general and a standing warrior.

Scanned figures:

- Kneeling archer T21G18-08
- High ranking officer (general) 02747
- Standing warrior T21G10-13 / 02755
- Kneeling archer T21G18-07

In addition the bronze swan no. 27 from the cavern of the waterfowls (Pit no. 7) was digitalized. The 3D scans were accomplished in the storage room of the workshop building of the museum. The reason for this was that many of the figures are stored there, that the room is easy to shade and that sufficient bus bars are available (Figure 5).
For measuring the figures a fringe projection scanner was used. For digitalisation a 3D scanner *ATOS II* from the firm *GOM* was used (Software 5.2.07). The measuring system worked with two cameras and a fringe projector, which was controlled by a notebook with Linux operating software. The surfaces of the figures were scanned and the three dimensional structure was documented. A 3D scanner, unlike two-dimensional scanners, can measure the topology of an object. The outcome of this is a realistic three dimensional image of the figure of a warrior.

During scanning a large number of disordered points in an area accrue, a so-called "point cloud". The single dots of the point cloud don't describe a connected surface. That's why the point amount is processed through triangulation to a reticule structure. The accruing three-dimensional model is also called wire frame model (Figure 7).
At the beginning of the measurements, points with a marker were placed on the figure to which should be scanned. 30 to 40 photos of the figure were then taken with a digital camera. Following this, the photos were transferred to a computer where they were analyzed through photogrammetric software. With such software, a 3D model could be made from the marker points on

Figure 5: Scanning the General T 9:1 in the storage room of the Museum of the Terracotta Warriors.

the figure. This model makes it possible to put the single scans together at the computer and to calculate a complete model. Next the scanner was calibrated by scanning and analyzing special measuring crosses and –rulers. The scanning of the figures started with a frontal scan followed by scans from the sides. The head was scanned in higher resolution than the body, because it’s important for the expression and appearance of the figure.

Figure 6: 3D model of the General T 9:1; fawn coloured wire frame model, blue areas are not scanned areas (= holes).

For this, different lenses were used with the camera and the projectors of the measuring system, to vary the size of the measuring area. The head was scanned in a measuring area of 20 x 30 cm and a resolution of 1.3 million pixels. The body was scanned in a measuring area of 6 x 80 cm and also 1.3 million pixels. After every single scan the result was checked on the computer to ensure it was satisfying and every desired detail can be seen, based on the chosen position of the scanner. Eventually the scanner must be adjusted again and the scanning process repeated.

Depending on the areal surface of the figures between 30 and 80 single scans were necessary to measure the whole figure. Once the best possible scans of a figure were taken, the data was added and respectively rendered to a first working model. The final registration of the points and the rendering of

the models were done at night, because the computer operates for hours at full capacity doing this.

The geometry of the scanner makes it very difficult or impossible to scan undercuts and deep indentations. Especially the bottom side of the kneeling archer, the headgear of the general and the bases were hard or impossible to measure (Figure 6).

Holes in the wire frame models could be corrected at the computer with different 'hole-filling algorithm'. During post processing of the data the missing parts could be reconstructed through the surrounding area.

The 3D models made are all in the STL-format (*.stl), which is the usual format for non-textured wire frame models. It is possible to convert the

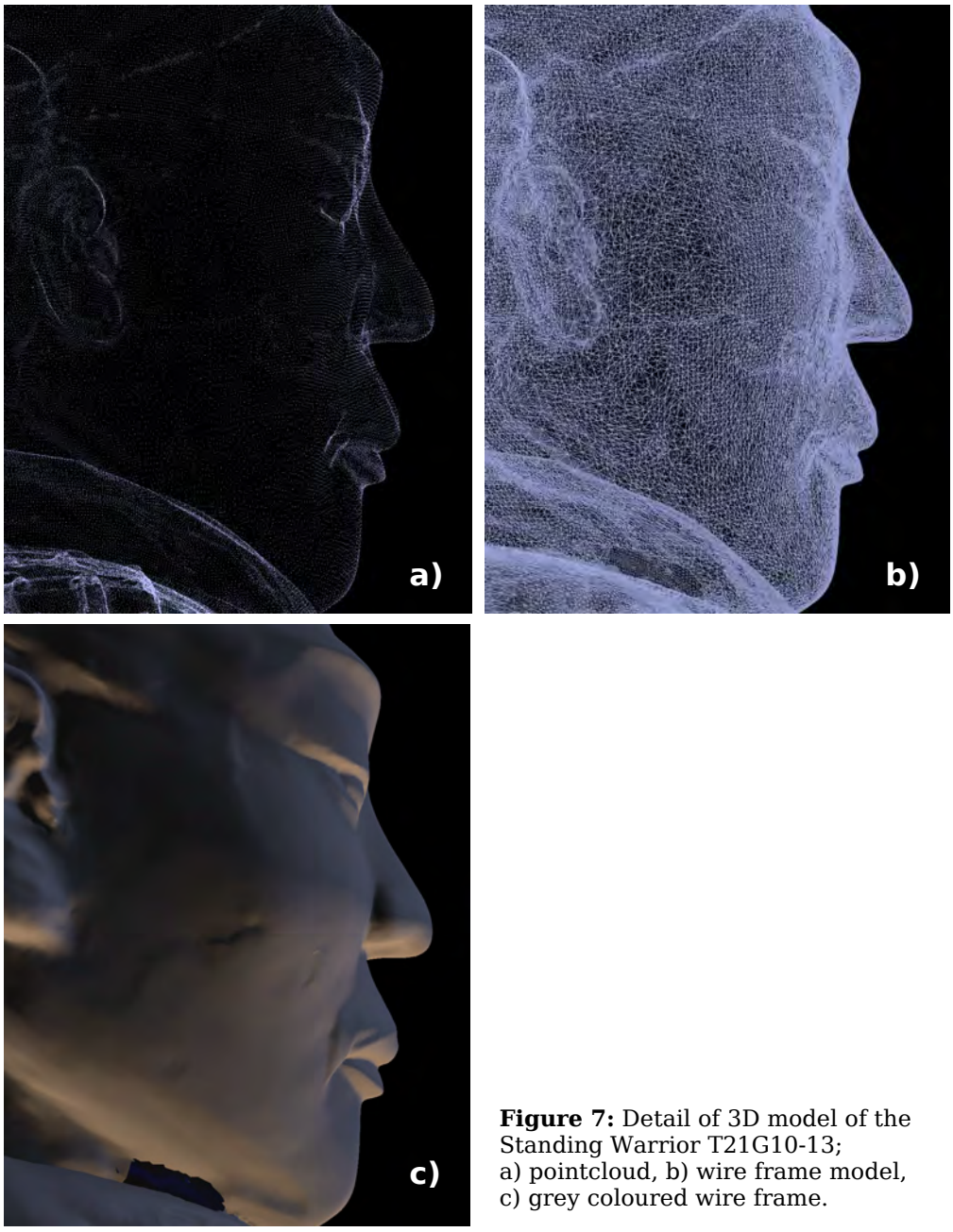

Figure 7: Detail of 3D model of the Standing Warrior T21G10-13;
a) pointcloud, b) wire frame model,
c) grey coloured wire frame.

Figure 8: Head of the Kneeling Archer T21G18-03, 3D model coloured fawn, large imperfection of the polychromy can be seen on the left side of the face.

models into another file format. It should be noted that while converting the data, small mistakes accrue and 'readable' models are made.

The next step is the colour reconstruction. For this, the files need to be imported to the 3D processing program 3ds Max. To import STL-files is still problematic, probably because of the high polygon count of the models.

From the data gained and the following analyses on the original figures textures should be created. These textures should then be transferred to the surfaces of the three dimensional wire frame models. To design the surface of the 3D models so called 'texture mapping' is used. This method places digital photos or surface characteristics on a 3D object. During the application of the texture, thus the adaptation of the photo file on the 3D-model, every part of the wire frame model is assigned to the matching part of the digital photo.

Digital photos, done in different perspectives, were used to visualize the warriors. It was important to acquire the whole surface while the photos were taken. Also important was to have constant lighting, so that there were no visible borders while the single photos were added. To ensure this, and to avoid shady parts, numerous photo lights were used.

Virtual colour reconstruction of figures from the terracotta army

Felix Horn

3D acquisition of the clay warriors

Between 5th and 13th June 2005 there was a data evaluation to digitalize the figures of the terracotta army, together with the company 'ArcTon GmbH'. Mr. Martin Schaich and Mr. Lars Langheinrich accomplished the 3D acquisition. The digitalisation was carried out in the Museum of the Terracotta Warriors and Horses in Lintong. Two 3D scanners were used. The following figures were scanned in the storage room of the restoration / conservation building:

- Standing archer 02817
- Kneeling archer T21G18-01
- Kneeling archer T21G18-03
- General 00847

Furthermore an excavated crossbow mechanism from the Qin Dynasty was measured and afterwards a 3D model was made. Two fringe projection scanners made by the company 'Polygon-Technology' were used for measuring (Figure 1 and 2). The scanners are from the Fraunhofer Institute for Computer Graphics (IGD) Darmstadt and provide fast, accurate and high resolution scans of complex objects and structures, especially for use in the field of restoration/conservation, archaeology and in preservation of monuments and historic buildings. The measuring system works with a fringe projector and optionally, with one or two cameras.

Scanning with two different resolutions should result in an ideal acquisition of the figures. For this, the measuring systems were configured on two different measuring ranges.

For measuring the head of the warriors a smaller measuring range and a shorter scan distance was chosen resulting in a higher accuracy and resolution (Table 1 and 2).

Figure 1: The two QT Sculptor measuring systems (two different types, right: QT Sculptor P-TM 1024).

Figure 2: Scanning of the kneeling archer T21G18-03 in the storage room of the terracotta army museum.

Characteristics of the sensor head			**Resolution for 100 / 500 / 1000 mm picture field**	
Sensor head	Resolution grid size	Shot speed in seconds	Lateral resolution [mm]	Depth resolution [mm]
Standard	1024 x 768	2.4 sec.	0.10 / 0,49 / 0,98	0.020 / 0.098 / 0.20

Table 1: Resolution, measuring time and accuracy of the sensor head.

	Large measuring range	**Small measuring range**
Measuring distance	1.0 – 1.6 m	0.5 – 1.0 m
Resolution (average)	0.5 mm	0.3 mm
Accuracy (average)	0.1 mm	0.05 mm

Table 2: Measuring range of the scan system.

Head and body of the terracotta warriors were scanned using different resolutions (Table 4). For the less complex body of the warriors a larger field of view and a lower resolution could be used. The very detailed elaborated heads were scanned with a higher resolution. The scan of the crossbow mechanism was also done in higher resolution.

Depending on the complexity of the figures different measuring effort was necessary resulting in a diverse number of scans (Table 3).

As the terracotta warriors couldn’t be moved it was not possible to scan the base. Other parts like undercuts weren’t accessible for the scanner too. Especially the base of the kneeling archer, the general’s headgear, partial areas between arm and body of the figures were difficult or impossible to measure. In areas that could not be reached while scanning unavoidable holes in the scanned data are the consequences. Those parts were reconstructed during the post processing.

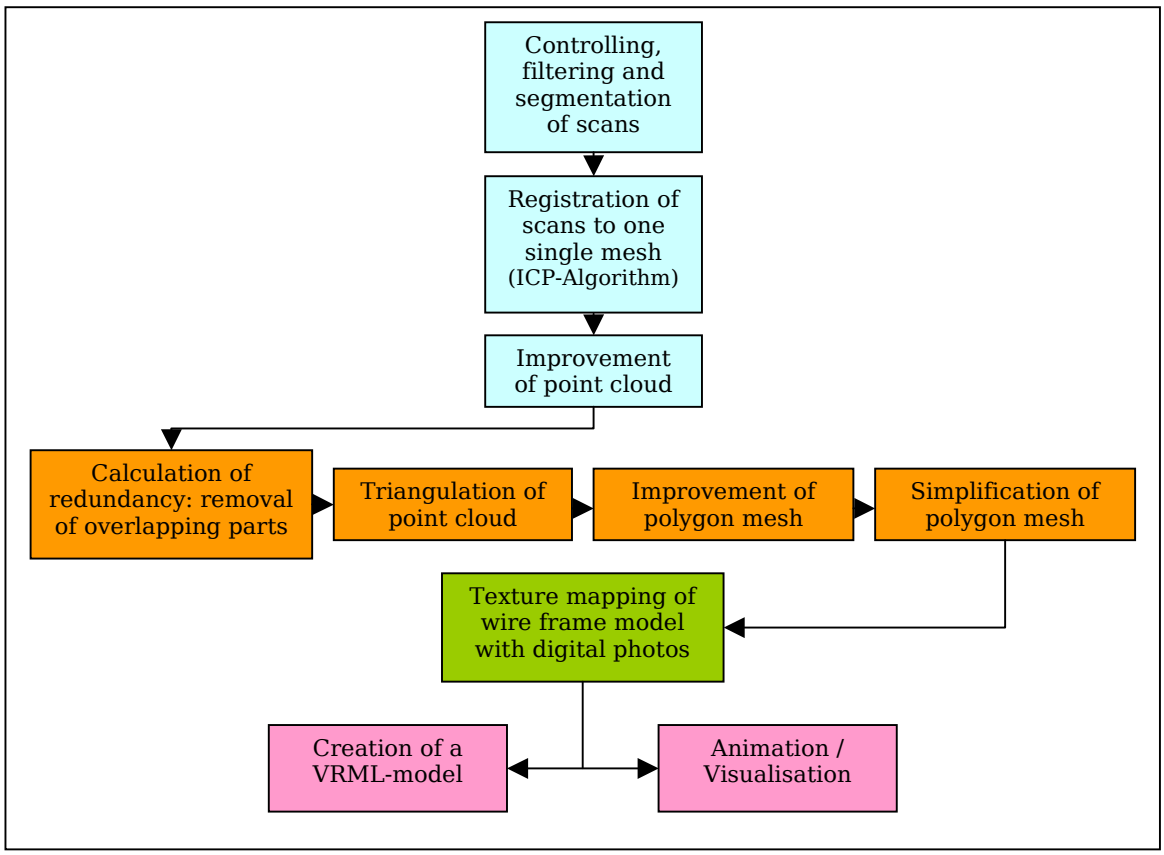

Figure 3: Schematically workflow (diagram by ArcTron GmbH).

To have the possibility to control the accuracy of 3D models, the single scans were put together on site. Missing parts could be measured again the following day.

It's a complex procedure from the digitalisation of the figures to a photo-realistic textured 3D model. During the registration process the measurement data are combined, with unnecessary points being eliminated. A consistent three-dimensional polygon mesh is generated and photo-realistic textured through taken digital pictures[1].

Description	**No.**	**Number of single scans**	**Used scans**	**Number of vertices**
Standing archer	02917	200	194	25 million
Kneeling archer	T21G18-01	240	180	35 million
Kneeling archer	T21G18-03	220	268	22.6 million
General	T2G2:97 or 00847	220	150	31.5 million
Crossbow mechanism		48	28	2.9 million

Table 3: Number of single scans, number of used scans and number of points per measured object.

[1] For the terracotta warriors listed in table 3 this work was done by the company ArcTron GmbH.

The first step was to put the single scans of each warrior together to a point cloud. This happened with a manual registration process. During this process, single scans are getting dedicated to equal areas through identical points.

Only the amount of scans necessary for the complete covering of the whole figure was used. Redundant scans, which are made during the measuring process, aren't used during the future processes.

Figure 4: Point cloud of the kneeling archer T21G18-01. Last registered scan is shown red. (Grafik ArcTron GmbH).

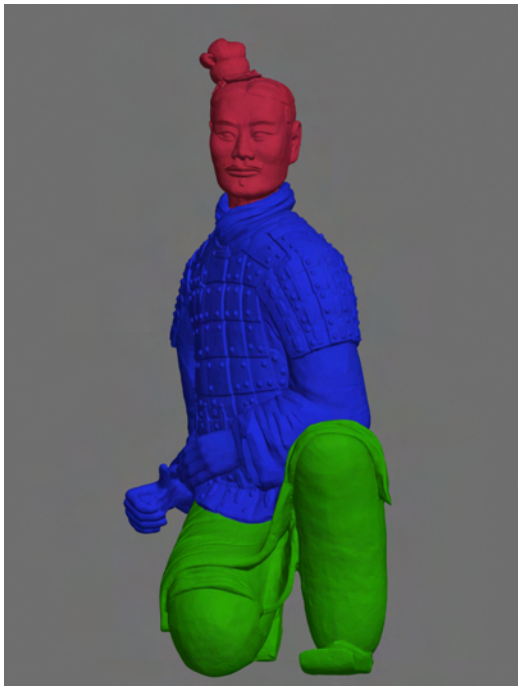

Figure 5: Kneeling Archer T21G18-01, wire frame model made of three parts: Head (*red*), upper part (*blue*) and lower part of the body (*green*).

The accuracy for the single scans registration to a point cloud depended on the configuration of the scanner and the number of scans used per point cloud (Table 3).

The number of polygons was reduced after the refinement of data. This is shown using the example of the kneeling archer T21G18-03. The original number of polygons was 950.000 and could be reduced to 714.000 (Table 4).

Kneeling archer T21G18-03	
Number of scans:	220
Number of vertices:	22.6 billion
Accuracy *Head:* *Body:*	 0.09 mm 0.14 mm
Number of polygons (overall): *Head:* *Body*:	950.000 360.000 590.000
Number of used scans:	168
Number of polygons after improvement:	714.000
Number of texture images:	51

Table 4: Details of the number of scans, vertices, polygons, texture scans and accuracy.

To afford an object orientated processing of certain parts of the 3D model, the archers were split into several single objects. As a result the amount of data of a single part of the figure was reduced and a chance for an accurate model was given. The model of the kneeling archer T21G18-01 for example is split in 3 objects: head, upper and lower part of the body. The single parts are linked to a complete model (Figure 5).

After the reduction of vertices in overlapping parts, triangulation of the point cloud to a closed polygon model, optimization and decimation of data precise and accurate wire frame models with a high level of detail were made.

Description	**No.**	**Number of polygons**
Standing archer	02817	867.000
Kneeling archer	T21G18-01	1.010.000
Kneeling Archer	T21G18-03	714.400
General	T2G2:97 or 00847	804.000
Crossbow mechanism	–	72.000

Table 5: Number of polygon after optimization of data.

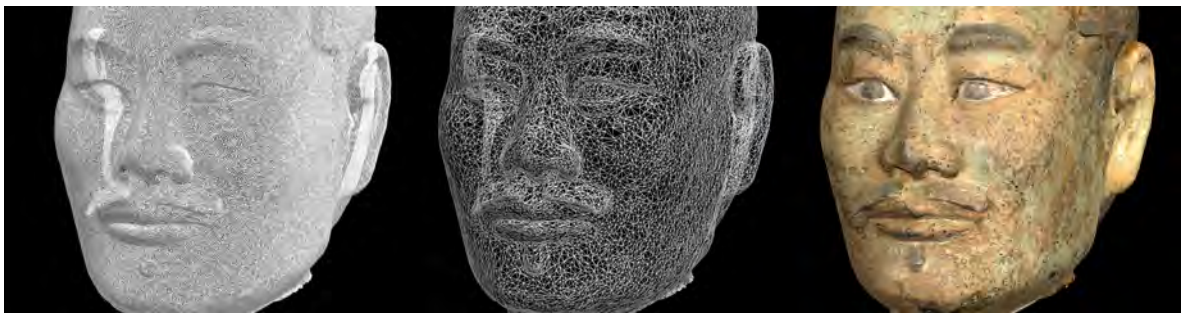

Figure 6: Head of 3D model of the warrior T21G18-01, *left*: wire frame model, *middle*: wire frame model with reduced number of polygons, *right*: textured wire frame model.

All 3D models made are available in the STL-format[2] (*.stl). STL-format is the usual format for non-textured wire frame models and used a standard in the rapid prototyping industries.

The 3D model of the crossbow mechanism as a simple geometrical object was transformed from a polygon model to a CAD-model through reverse engineering. As a result the crossbow mechanism is available in the STL-format and also as a 3D-studio-max file (*.max) with NURBS-surfaces.

Texturing of the 3D models

For creating photo realistic textured 3D models, the figures were photographed with a high resolution digital camera[3]. Photography lighting was used to ensure even lighting conditions with less shading and to improve details in high contrast colours. Due to lack of time it wasn't possible to have every measured figure photographed in high detail. Only the two archers were documented with numerous detailed photos, because of their relatively well preserved paint layers. The General and the standing archer were photographed with only a few large format images (Table 6).

Description:	**No.**	**Number of pictures**
Standing archer	02817	8
Kneeling archer	T21G18-01	44
Kneeling Archer	T21G18-03	51
General	T2G2:97 / 00847	9

Table 6: Number of photos used for texture mapping.

[2] **STL** = **St**ereo**L**ithography, also known as abbreviation of **S**tandard **T**riangulation **L**anguage.
3 A 6-megapixel Camera Nikon D100 was used for photographing.

In the next step the 3D models were then textured with high resolution digital photos. For this, 3D models with full resolution or respectively with a high level of detail were used.

To accomplish this, the digital photos were straightened through identical points on the digital photo and the 3D model. Then they were mapped onto the polygon model through a projection.

Due to the wire frame models being textured, a photorealistic image of the object could be made. This was successful for the two kneeling archers. The General and the standing archer were textured with low resolution pictures. The textured models were made in the format VRML (*.wrl). The textured pictures are saved as JPEG files (*.jpg). The kneeling archers are subdivided into three under objects, so the pictures for texturing are subdivided into three single pictures: the head, upper and lower part of the body (Figure 6).

As a result of the texturing a photo realistic 3D models was created. These can be viewed in usual VRML viewers and from this; they can be further processed too.

Figure 7: Textured photos for the 3D model of the kneeling archer T21G18-01, made of three subobjects; *left*: Texture image for the lower part of the body, *middle*: image for the upper part of the body, right: Texture of the head.

Importing and following processes in a 3D processing program

For the next step, the files should be imported into the 3D processing program 3DStudio Max for virtual colour reconstruction. During the process it transpired that the high resolution and textured 3D models were made of too many polygons (‘high poly’), which meant that importing to the 3D program is only partially possible; the software isn’t intended for processing such a large number of polygons.

An important step in the following process was to reduce the data / the number of faces. With the 3D software used it was possible to reduce the file size of the wire frame model. The warrior T21G18-01 was made up of one million faces at the beginning and was then reduced to approximately 300.000 faces. The texturing of the models wasn't changed during the data reduction

Kneeling archer T21G18-01	**Before data reduction**	**After data reduction**
File size	App. 73 MB (73.142 kB)	App. 19 MB (19.021 kB)
Number of vertices	501.928	150.579
Number of faces / polygons	999.945	299.790

Table 7: File size, number of vertices and faces before and after data reduction.

The processing of the figures with the digital graphics program was done in two steps. Imperfections and dirt on the surface were retouched, followed by the colour reconstruction of the warrior (Figure 8). The retouching is done in the colouring of the given aged colour values. The reconstruction is done in approximately original colours. To virtual retouch imperfections painting-software is necessary, which allows to painting directly onto the 3D model. For retouching, several layers were used. The advantage of this technique is, that e.g. partial retouches can be tested and seen combined with other colours and effects, without changing the original. Using different paint and retouching tools guarantees an individual treatment.

The virtual retouching optically soothes the look of the warrior. This conservational attempt should show how the figure would look after a real cleaning and retouching.

The colour reconstruction is very close to the original look of the warrior. The 3D visualization of the colour reconstruction should show how the warrior originally looked like.

For a realistic view of the figure, light sources were put in the scene. A three dimensional form is perceived by the human eye because of differences in brightness and the colour grading on the surface. An illumination as natural as possible is generated so as not to have a synthetic looking surface

Figure 8: 3D model of the kneeling archer T21G18-01; a) wire frame model, b) wire frame model with texture mapping, c) textured and retouched model, d) textured model with colour reconstruction.

Depending on the kind, position and adjustment of the illumination, different dispositions can be made. These can accentuate the character of a 3D model. The last step is to get the definite pictures, calculated from the scene with the 3D model. This process, which transforms the 3D model to a picture with light, shadow and colours is called rendering. The result shows how the terracotta warrior used to look.

Figure 9: Bronze crossbow of the carriage No. 1, on a scale of 1:2.

Crossbow reconstruction

For the virtual reconstruction of the crossbow different information was put together on the computer. In Pit No. 1. an imprint of a crossbow in the soil was studied and photographed. Also a bronze crossbow from one of the conserved bronze chariots on a scale of 1:2 was studied and measured (Figure 9 & 10). To document size, state and colouring, digital photos were made. We also started to analyze Chinese literature of this topic, together with Chinese colleagues.

The position of the kneeling archers is described in the literature as “ready to shoot”. It’s still not clear what they held in their hands though. The intention of the reconstruction is, to bring the positioning of the weapon together with the posture of the kneeling archer. The functioning of the crossbow could be visualized through an animation, based on the virtual reconstruction.

Figure 10: Chariot No. 1 with charioteer, on the right side the crossbow and a quiver.

Virtual colour reconstruction performed on the 3D model of a selected figure from the Terracotta Army

Felix Horn

Figure 1: Colour reconstruction of General T9:1 performed on the three-dimensional model.

Utilising 3D measuring methods and state-of-the-art computer technology, and taking into consideration scientifically obtained data, computer animations can be created. With the help of these 3D visualisations, complex interrelationships are communicated in a clear and understandable way.

On the majority of figures from the tomb of the first Chinese Emperor Qin Shihuangdi which have been excavated so far, only sparse residues of the colouring are left or none at all. The figurative sculptures predominantly show merely the brown and grey shades of the terracotta. A large part of the original colouring is lost today. Only a few figures still display large polychrome surfaces.

Therefore, it was the purpose of this paper to demonstrate the possibilities of the virtual processing of 3D models by means of the figure of General T9:1 of the Terrakotta Army, and also to visualise the exquisitely colourful original appearance of the clay warriors.

The application of “virtual realities” opens completely new possibilities for the reconstruction and documentation in restoration, archaeology and historic preservation.

With the help of the computer, the polychrome colouring was to be reconstructed on the three-dimensional model of a warrior from the Terracotta Army. The processing of digital models opens new possibilities which cannot be achieved on the original. The most divergent conditions can be visualised.

General T9:1

The colour reconstruction demonstrated using the example of General T9:1. In the Terracotta Museum, the General has the consecutive number 02747; he was found in the north western corner of Pit Number 2 in the test excavation area T9.

In the process of virtual colour reconstruction, the appearance of the figures is to be approximated to the way they originally looked. The reconstruction of the colour, however, requires a certain portion of the original polychromy to be still present. If, at first glance, no more polychromy seems to survive on a figure (Figure 3), it is still possible to find minor residues after an extensive search.

The General T9:1 has a powerful appearance; he exudes inner tranquillity and calm. At the same time, he seems to be intently facing the imminent tasks. His accurately trimmed moustache and goatee impart him with a dignified air.

Like some other officers and generals of the Terracotta Army, the General is wearing what is called a pheasant cap[1]. This kind of headgear combines outer form and inner symbolism. Thus, in the Warring States Period, two pheasant feathers represented (ca. 475-211 BC) a symbol of audacity, valour and determination[2].

The General's clothes consist of two coat-like garments worn on top of one another, which are covered by armour. These two layers are also known as double long gown. Surviving colour residues show that the outer gown was in stark contrast to the inner gown as far as the colour is concerned. The garments in this case are an expression of joy of life conveying authentic aliveness.

His armour, which features no arm protection, covers the chest and back[3]. The edges of the armour were adorned with colourful patterns. Besides, the armour was decorated with eight bowknots consisting of ribbons, three of which are located on the chest plate, three on the back plate, and one on each shoulder.

The General's right hand is shaped as though the fingers were clasping an object or a weapon, respectively. Of the left hand, only the fingertips are protruding from the sleeve.

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[1] Pheasant cap, Pinyin = *he guan*, Chinese 鶡冠.

[2] „*The feathers of the male Brown-eared Pheasant Crossoptilon mantchuricum were used as a battle adornment by generals between the Warring states and the Qing Dynasty*." From: MADGE/MACGOWAN 2002.

[3] According to WANG XUELI, it is a type 1c armour: "*commanders' armour*", but *without protruding sleeves.* Generally, he distinguishes two types of armour: 1. *Commanders' and corporals' armour* and 2. footsoldiers', cavalry of charioteers' armour.

Figure 2:
Colour reconstruction[4] of the General T9:1, created by Chinese colleagues.

Figure 3: General T9:1, Pit 2, Museum of the Terracotta Warriors (photograph).

[4] See AH 83, colour chart I, p. 217.

It appears as though his trousers were covered by the double long gown, and therefore are not visible. The legs were protected with a kind of shin guard. The horizontal line in the centre of these shin guards probably was the interface between the upper part of the fabric and the lower part made of leather.

The General's footwear consisted of upward bent, rectangular-shaped poulaines, which were probably coloured black or brown.

Clothing in historical China

For the execution of the colour reconstruction, it was decisive to understand the way the clothing was built up. Therefore, an attempt is made to categorise the General's clothes and to study the fundamentals of Chinese clothing.

The hanfu is regarded as a something like the archetype of Chinese clothing[5]. The term *hanfu*[6] can be translated as "clothing of the Han Chinese" and signifies the historical clothing of this population in the early 17th century. As can be shown by means of archaeological finds, the basic form and appearance of the hanfu garment had almost completely evolved as early as the Shang Dynasty[7] (ca. 1766 – 1050 BC). In this period, the hanfu garment consisted of a knee-long gown with narrow cuffs held together by a belt.

The hanfu in ancient China was also known as *Yi Shang*. The outer garment *yi*[8], which usually does not feature any buttons, is worn on the outside, the inner garment *shang* is worn below. The history of the hanfu spans over more than 3000 years, and according to legend, it can be traced back to the Yellow Conqueror, a mythical figure of ancient China.

In the Western Zhou Dynasty[9] (1045-771 v. Chr.), the differences in social standing are reflected in the shape of the hanfu. Apart from a few alterations, the hanfu garment of the Zhou Dynasty corresponds to the style of the Shang Dynasty in its form and appearance, its general cut, however, was wider.

The standard form of the hanfu collar was called *Jiaoling Youren,* and can be translated as "transverse collars, to be tied to the right". Here, the left side of the garment is always folded over the right side. The hanfu garment has a gender-neutral shape as well as a simple and functional cut.

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[5] Term: *Hanfu*, Wikipedia – The Free Encyclopedia, online under URL:< http://en.wikipedia.org/wiki/Hanfu >, [date: 24.02.2006].

[6] "Clothing of the Han Chinese", Pinyin: *hànfú*, Chinese 汉服.

[7] Shang Dynasty, Pinyin: *shang chao*, Chinese: 商朝.

8 *Yi* (依) represents a kind of coat or gown, and *Shang* (裳) an undergown.

[9] Zhou Dynasty, Pinyin: *zhou chao*, Chinese: 周朝.

Due to the changes brought about by the conquest of the Han-Chinese areas by the Manchu, the hanfu began to fall from use at the beginning of the Qing Dynasty.

The *shenyi*[10] is a variant of the hanfu garment; literally translated, this term means "deeply enwrap the body with clothing". As opposed to the hanfu garment, the outer piece (*Yi*) and the inner piece (*Shen*) are sewn together here, therefore the shenyi garment is also called "long gown[11] consisting of one piece".

Before the Shang and Zhou Dynasties, people usually wore two-piece garments consisting of gowns and coat (= hanfu). The shenyi garment or "one-piece garment" began to become established roughly in the beginning of the Warring States Period[12] (474 – 221. BC). The long gown was worn by both men and women during the Warring States Period until the Han Period[13].

The long gown or shenyi can be encountered on wood or clay figures used as funerary objects, as well as in silk paintings from the Warring States Period[14]. The long robe follows the hanfu garment in its characteristic; the front piece is folded left over right and held together with a belt. The dying and weaving techniques of this period were highly developed already, as can be shown by the instance of many complicated and sumptuous patterns.

During the Xia and Shang Dynasties, a dress code began to be established in Chinese society. In the Zhou Dynasty, this system was perfected: there was an increased differentiation according to the various classes[15], as is shown by the distinct shaping of the clothing and the personal jewellery. According to each occasion, different clothing variants evolved, for instance for festivities, ceremonies, cultic and religious occasions, weddings, war clothing etc. Differences in dress were an indicator for the social standing of the person wearing it. The width of the sleeves, the length and colourfulness of the dress

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[10] "Long gown", Pinyin: *shenyi*, Chinese: 深衣.

[11] The German word *Jacke ("jacket")* seems to be little suited fort he description of the clay warriors, since, according to definition, a jacket only covers little more than the hip. The term coat or gown is more suited fort he generals' garment. The term "gown" is therefore used in the following.

[12] Warring States Period, Pinyin: *zhangguo*, Chinese: 战国.

[13] History of Ancient Traditional Chinese Clothing**,**
< http://library.thinkquest.org/05aug/01780/clothing/history.htm > [date: 04:06.2006].

[14] Shenyi: Qin-Han period and Three Kingdoms period,
< http://www.china-fun.net/clothing/development/20060822/110117.shtml >, [date: 04:06.2006].

[15] „*Since the inception of the dress code in the early Eastern Zhou, all classes were governed by strict rules of dress to maintain social distinction and therefore social order*. " SHEN 1995, p. 52.

as well as its adornments (patterns!) reflected the social standing, as did accessories[16].

The fabric utilised for the long gown probably was linen. The hem of the garments was made up of textile ribbons. These decorative ribbons were monochrome or patterned and were used to hem in the edges of the edges of the garments. The ribbons could be decorated with woven, stitched or painted patterns.

Precious garments were frequently hemmed in with what is called brocade (*jin*) and damask (*qi* or *wenqi*) made of silk.[17] These two fabrics were of great importance among the figuratively patterned silk fabrics in the pre-Han period.

Like the other features of the dress, the type and shape of the pattern were an indicator for the status of a person[18]. Patterns for the decoration of the clothing usually consisted of geometrical forms, featured stylised representations of plants, animals and humans, or a combination of several of these elements.

Make-up of the dress

When looking at first Chinese emperor's Army, it shows that in the Qin Period as well a person's social status was revealed by his clothing. The differences were, however, probably not as significant as in the previous period. As far as the clothing of the Terracotta Warriors is concerned, marked differences can be observed. Depending on the soldiers' ranks, a differentiated shaping of the headgear, the dress and the armour[19] can be detected.

Whereas the simple foot soldiers' equipment and gear was kept simple, functional and plain, in the case of officers and generals a larger degree of extravagance and adornment can be discerned. Thus, the armour offered more protection at the upper body and feet according to the higher position within the army.

As already mentioned, the General wears a pheasant cap. It is attached to the head with a band, which runs over the upper head, and is tied together at

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[16] Accessories: this means headgear, hair ribbons, amulets, pendants, beltbuckles and braids etc.

[17] "*Apart from the so-called brocade (jin), a polychrome warp-faced compound tabby weave, the so-called qi-damask (qi or wenqi) is of outstanding importance in the weaving of figured silks in pre-Han China*." KUHN 1995, p. 81.

[18] "*She was a member of the shi (knight) class, just above the class of commoners cording to the Book of Rites, a person of this class was not allowed to wear patterned weaves*." SHEN 1995, p. 52-53.

[19] According to military rank, the warrior's proportion and body size are treated in different ways. A higher position within the Army is expressed through a larger size and body volume.

both ends with an overhand knot, which under the chin is tied in the form of a bowknot.

Whereas simple soldiers and lower officers only wear a long gown, high-ranking officers and generals are clad with double long gowns, i.e. two garments are worn over one another.

General T9:1 wears a double-layered gown, also called double long jacket[20]. The double gown is divided into an outer garment, which is over the inner garment which is worn on the inside. With both roughly knee-long gowns, the left side is folded over the right one, creating collars crossed to the right.

By the sleeves as well as at the bottom hem, the outer gown is wrought markedly shorter. It recedes by several centimetres, the difference amounts to about 5 to 6 cm. Through the shortened dimensions, the undergarment becomes visible. An intentionally contrasting colouring of outer and inner gowns reinforces the spatial effect.

This system of a “receding clothing“ can be found especially in the Han Dynasty and may have been a fixed rule, according to which the outer garment was to leave a part of the inner gown visible. It can be surmised that this principle already existed in the Zhou and Qin Periods.

On the General’s figure, the receding of the different layers of clothing is accentuated not only by means of colouring, but – as clearly visible with other figures from the Terracotta Army as well – has been modelled with clay (Figure 5). At the bottom edge of the garment, the shorter outer gown forms a clearly visible stepping in contrast to the longer gown situated below. No distinct stepping is discernible at the bottom edges of the sleeves. Here, rather, the border is accentuated through a change in the run of the folds at the transition of the double-layered gown.

A marked arrangement of the folds is discernible at the lower arms of the Terracotta Warriors (Figure 6). Whether the folds are caused by pushing up the sleeves or due to a special cut, a stitching, for example, has been impossible to figure out so far. It is obvious that the folds are caused by a voluminous layer of fabric, which can be recognised by the form of the folds. The sleeves of the undergarment could probably be worn in three different variants according to requirement: in full length (covering the hands), pushed up at the lower arm, or folded backward.

[20] Besides the term “long gown”, the term “long jacket” can also be found in the literature. Here, however, the term “long gown” is used.

Figure 4: Face General T9:1, colour residues at the edge of the right eyeball, fillings at both corners of the mouth.

Figure 5: General T9:1, reverse side, modelling of the double-layered gown.

Figure 6: Arrangement of the folds at the underarms.

Colouring of the General

The basis for the virtual work at the computer was the exploration of the colour residues still present on the figure. By examining the findings, information on polychromy as well as on the state of preservation has been gathered, and documented on the basis of detailed photographs (Figure 7-12) and sketches[21]. With the help of the information thus obtained, the figure's colouring was to be reconstructed in connection with further sources.

The General's appearance today is characterised by the aged, grey-brown look of the terracotta (Fig. 3-6). Extensive residues of polychromy can no longer be discerned. In indentations and at the surface borders, merely minor colour residues can be found.

Thus, at the inner edge of the braid of the chest armour, bright-blue colour residues can be found (Fig. 7 & 8). At the General's right sleeve, there are green colour remnants. Likewise, there are purple and white colour traces. At the edge of the chest armour, there is a remnant of purple colour (Fig. 10a), and below the bowknot, on the right shoulder, green colour has survived (Fig. 10b).

The issue of the colouring of the pheasant cap is difficult to answer, since there are no more residues to found on it. Originally, the pheasant caps consisted of leather stripes drenched in qi lacquer attached to the head with ribbons. Therefore, a brown hue is presumed, which is supported by a colour reconstruction of General T9:1 (Fig. 2) from Pit 2 created by Chinese archaeologists: here, the pheasant caps show a brown colouring, the ribbons are kept in the colours red or orange[22].

Since real armour was made of leather, the General's had a brown hue. It was imparted to the individual armour plates by means of qi lacquer, which, put on as priming, was left visible. The individual armour plates were connected with each other by means of red threads, of which a sparse residue of red colouring points to the chest armour. For the decorative bows on the front and reverse side of the armour, the colours red and white were attested – likewise only in small remnants. Brown colouring for the armour, as well as red or respectively red and brown colours for ribbons and decorative bows is also confirmed by the colour reconstruction by the Chinese colleagues.

As could be shown on the basis of preserved colour residues, the shin guards were coloured purple on top and green on the bottom. The upward-bent poulaines were probably coloured brown or black, since they were supposed to represent leather.[23]

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[21] See Appendix, Fig. 37-40, p. 85 et. seq.

[22] *"The caps are mostly brown, occasionally also red, the ribbons are orange-coloured."* AH 83, 2001, p. 237. It has turned out, however, that according to the Chinese understanding of colours, *orange* rather signifies a bright red.

[23] The Chinese colleagues' colour reconstruction also shows brown shoes. See Fig. 2.

Figure 7: General T9:1, chest armour, edge of the braid.

Figure 8: Bright blue colour remnant. (Detail Figure 7).

Figure 9: General, left shoulder.

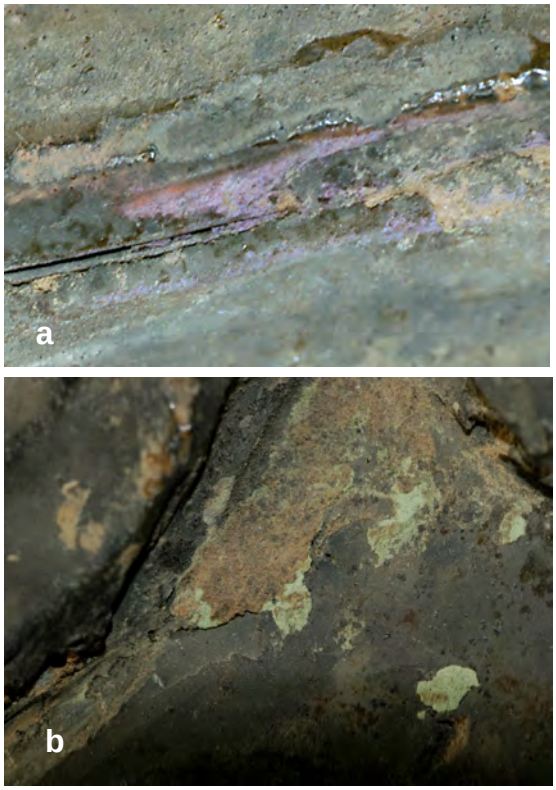

Figure 10: a) Edge of chest armour, purple; b) bowknot, green colour remnants (detail Fig. 9).

Figure 11: Right bottom bowknot, red and white colour remnants.

Figure 12: General's right sleeve, green colouring.

The interpretation of the polychromy is difficult, and must be seen critically due to the small quantity and size of the colour residues. The interpretation, moreover, is made difficult through the various restorations undergone by the figure such as cleansing, pasting, caulking and retouches (Figure 4-5).

The polychromy still existent today only makes possible the reconstruction of the figure's basic colour scheme. An assessment of further colour details cannot be accomplished due to small quantity of small-size colour residues.

On the basis of the developed colour scheme, it was attempted to find a systematic for the make-up of the General's clothing. The colour distribution encountered served as a basis for this as well as the clothing plastically rendered on the figure, which presumably represents a realistic depiction of the historical dress.

Based on the examinations of the General, it is presumed that the make-up of the clothing consisted of three layers. Besides two outer layers of the double gown, the bottom-most layer is probably made up of shirt[24] or undergarment (Figure 13).

The distinction here is made not so much according to the modelling of the clay, than rather on the basis of the residues of the surviving polychromy. Thus, in the interior of the General's sleeves and the collars, minor residues of white colour can be found.

In the process of examining the General, the colour sequence *green, purple* and white can be observed at the collar as well as at the sleeves from the exterior to the interior. At the bottom end of the inner long gown, no polychromy residues were found, therefore, no determination of the colouring was possible here.

The sequence of the colours at the collar, the sleeve ends, and at the bottom edges of the long gown can certainly be interpreted in different ways.

Figure 13: Dress make-up of Generals T9:1; the armour was omitted.

[24] 'Shirt', Pinyin: *zhongyi* (literally: centre garment). "The high officers and the charioteers steering *the quadrigas, however, apparently wear shirts below the long gowns. They protrude by 4 to 5 cm from below the jackets, some of them even by 10 cm. They mostly reach down over the knees* […]." AH 83, p. 201.

Assuming a three-layered build-up of the clothing (double long gown as well as undershirt), and provided that collar and sleeve cuff have the same colours[25], the colour of the inner gown must have been purple, the outer one's green and the undershirt's white.

The outer one of the two long gowns appears to have been wrought more thinly. Probably it only had little padding. The inner long gown looks more voluminous and thicker[26]. It appears to have been a padded or rather wadded gown. Its sleeves are about 10-15 cm longer the ones of the outer gown.

It is impossible to find out whether the outer garment (= outer gown) had a braid or a small cuff. Engravings in surface of the terracotta as they have been discovered on other Terracotta Warriors fort he delimitation of the hem ort he cuff could not be detected. On the basis of small residues of the colouring, there was no way to determine whether there was a braid which was offset in terms of colour. The sleeves have a straight cut, a narrow sleeve end and they end at a hand's breadth from the wrist.

Figure 14: Colour chart, above detail colour residue from a digital photograph, below colour values measured.

The evaluation of the various colour residues was carried out at the computer. In the process, the colour residues recorded in calibrated[27] digital photographs were measured[28] by means of the pipette function of an image processing software[29]. The colour values recorded were filled in into 2 x 2 cm large fields. The colour fields of a photograph were arranged below one another in order to gain an impression of the colour value (Fig. 14). Subsequently a mean value was created from several similar colour fields by means of 'mixing'; i.e. by means of what is called the sprinkle function, the appearance of a pigment mixture could be emulated.

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[25] *'The colours of the clothing vary in thousand different ways, but the collars and cuff sleeves principally have the same colour.'* WANG XUELI, no page indicated.

[26] AH 83, p. 195, long jackets: *'The clay warriors' jackets have a heavy appearance and are therefore probably wadded jackets.'*

[27] For a colour-true rendering of the polychromy, ICC profiles were created by the company *Gretag Macbeth* with the help of the colour chart *ColourChecker DC* in order to correct the colouring.

[28] See Appendix, Fig. 41, p. 89.

[29] The software *Photoshop CS* by the company *Adobe* was utilised.

In the next step, the contour drawing of the General created by means of a graphics tablet (Figure 15a) was coloured. With the help of the information obtained, it was possible to create a colour drawing rendering the reconstructed colours (Figure 15c). For spots of the figure without evidence for colours such as the eyes, lips, beard and shoes, contract-proof digital photographs of other coloured clay warriors were used as reference.

a) **b)** **c)**

Figure 15: General T9:1, preliminary drawing for the colour reconstruction on the 3D model, a) digital photograph, b) contour drawing, c) colour drawing for the reconstruction[30].

[30] The colour drawing was created by Mel Eibl.

Pattern on the General's clothing

Corresponding to General T9:1's high position in the formation in Pit 2, his armour, besides being well plated, is also excellently wrought from an artistic point of view. The edges of the armour were decorated with exquisitely colourful patterns, which was to imitate an edging of the borders with colourful ribbons[31]. This kind of decoration can be compared with the woven ribbons frequently found at the collar, sleeve opening and hem of the Shenyi clothing.

Generally, it can be said about the ornaments on the Terracotta Warriors' clothing that they usually are symmetrically built-up, and that the patterns show marked colour contrasts. Thus, they appear luminescent and vivid. So far, the patterns could predominantly be found on figures of higher ranks such as officers or generals.

As had shown after an examination of the findings for the General as well as of further colour fragments, two patterns had to be created for the virtual colour reconstruction (Figure 16). The colour residues on the figure gave no clues on a possible pattern at the edge of the armour. However, there are finds of negative imprints of the colouring in the ground, which make it possible to reconstruct the geometrical forms and colours.

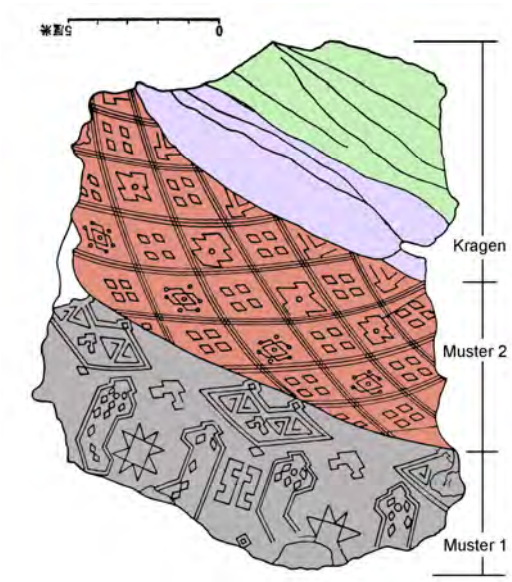

Figure 16: Colour fragment, Nr. B-101, General T9:1, neck area.

Of special importance fort his purpose was a colour fragment from General T9:1. This 18 x 14.5 cm-large fragment (Figure 20) with the number B-0101 was conserved as imprint in the soil in Pit 2, and was recovered. It probably stems from the rear part of the collar[32]. The alignment of the pattern confirms that this colouring residue stems from the onset of the back armour at the General's collar. Especially valuable for the reconstruction have been photographs and drawings of this fragment, since its top shows the colouring of the collar: green and purple above. In the centre and bottom part of the fragments, two different patterns can be seen (Figure 16).

[31] An edging of this kind with a patterned ribbon can be found on a wood figure from a Chu tomb, 4th ct. BC. See: AH 83, Fig. 15, p. 294.

[32] The location of the fragment at the 'right hem of the chest armour must be due to a mistake in writing. In the pertaining drawing (Fig. 63, No. 3) the fragment' ornament, from the collar, neck area' is correctly attributed. See AH 83, p. 256-257.

Carrying out the reconstruction was essentially based on the surviving colour residues on further generals. These colour residues were documented by means of digital photos[33]. Scanned images and drawings[34] from publications were also utilised for the reconstruction. During the evaluation of the photos, measures and angles (Figure 18) could be determined which made possible a reconstruction of both patterns. In the process, it was possible to observe that the forms of the patterns can be reduced to a basic raster or a simple geometric construction[35]. It became obvious that both reconstructed patterns can be based on a lozenge[36] as well as on a rectangular grid.

Reconstruction of pattern 1 (scattered pattern)

These patterns are composed of different elements, which are scattered over the surface. Therefore, it can be termed as scattered pattern. The following elements are recurrently applied in this pattern: eight-pronged star[37], hexagons, lozenges and broken lozenge forms[38], *Fu* sign[39], *huang*-like patterns – filled with meanders and broken forms[40] and zoomorphic elements.

The following digital photos and drawings of surviving colour fragments were used as a basis for the reconstruction of the lozenge pattern:

- Digital photos, remains of polychromy in soil, Pit 1, General T22G9:1 (002741).
- Fragment in plaster, Nr. B-101; digital photo 5529.Tif (also AH 83, p. 255, No. 1).
- Remains of polychromy from General T20G10:97 (according AH 83, S. 257, according to new information T22G9:1).
- Line drawing, AH 83, S. 256, Abb. 63: 'ornaments on officers' armour from Pit 2', No. 2, T4:1, ornament on chest armour.
- Line drawing, AH 83, S. 258, Figure 64: 'ornaments on the armour of officer T20G10:97 from Pit 1', No. 3, chest area.

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[33] Especially valuable information for the reconstruction was provided by digital photos of the General's polychromy T22G9:1 (consecutive number 002741) from Pit 1, which has survived in clay until today.

[34] Equally valuable clues were provided by the hand drawings by my colleague Frau Blänsdorf. See C. Blänsdorf: *The polychromy of clothing and armours of the generals form the terracotta army*, Annual Report 2005, p. 5-54.

[35] Geometrical constructions such as angle division, or the division of a line into halves or thirds etc.

[36] The lozenge grid was constructed with an angle of 30 degrees to the horizontal and a 60 degree angle to the vertical.

[37] The eight-pronged star stands for a celestial body or a star. Depending on its use, it could serve as a symbol for sun, moon or a constellation, and therefore have the most varied meanings.

[38] These could also be termed as broken lozenge patterns.

[39] The sign *Fu,* a sign of honour and nobility, is made up of two *Chi* symbols, which are located back to back.

[40] See AH 83, p. 257.

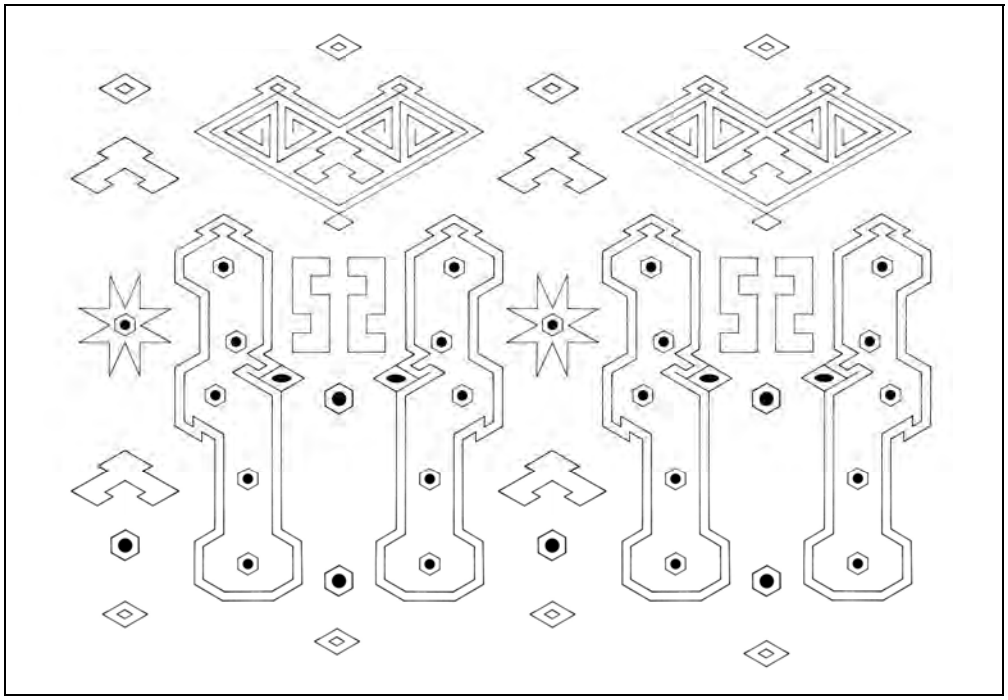

Figure 17: Scattered pattern (pattern 1), contour drawing with elements already constructed.

The construction of the geometrical elements of the scattered pattern was carried out assuming that the entire pattern is based on an even lozenge raster as well as on a rectangular grid. All oblique borders of the geometrical elements were constructed such that they are in a parallel position to each other.

The decisive factor for the reconstruction of pattern No. 1 was the colour fragment (Figure 20) with the number B-0101. On top, it shows the colouring of the collar: purple above green. In the centre and bottom portion, patterns No. 1 and 2 are discernible especially well (Figure 16 & 20). Digital photos of large colouring residues on General T22G9:1, which have been preserved in the soil and still are in Pit No. 1 today, have also been very conclusive (Figure 18 & 19).

The measures and angles obtained from the photos[41] and drawings (Figure 18) were evaluated. For several differing values, a mean value was calculated. Departing from the values obtained, the individual elements of the scattered pattern were constructed (Figure 17). Corresponding to the examination of fragment B-0101, and to the colouring extracted from the photos of the colouring residues of General T22G9:1, the geometrical elements were coloured.

The line drawing of pattern No. 1 was used as model for the painting of a copy of General T20G10:97.

[41] Before the measuring, the digital photos were equalised as much as possible.

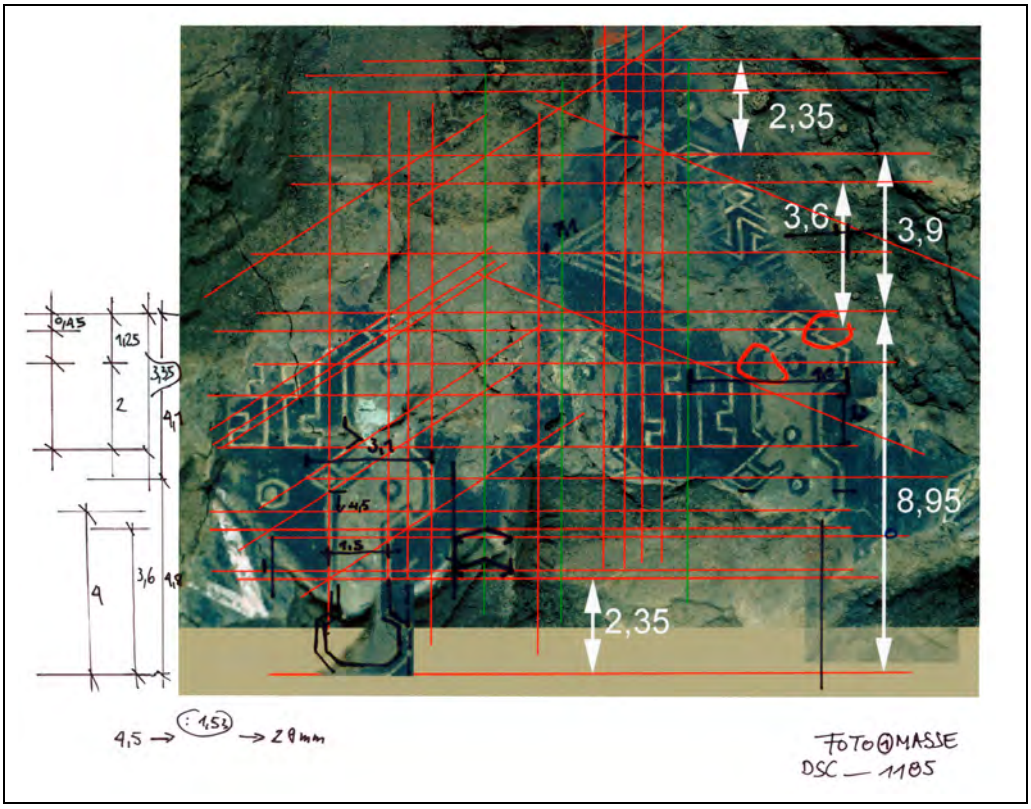

Figure 18: Polychromy of General T22G9:1 (see Figure 18), extraction of measures and angles for reconstruction.

Figure 19: General T22G9:1, Pit 1, colouring in soil, (digital photo: DSC_1185.jpg).

Reconstruction of Pattern 2 (lozenge pattern)[42]

Pattern No. 2 is also composed of the following elements: lozenges with protruding ends, quadruple lozenges, broken lozenges[43], halved lozenges and halved quadruple lozenge. The basic scaffold of the lozenge pattern consists of three series of reclining lozenges.

The following digital photos and drawings of surviving colour fragments were used for the reconstruction of the lozenge pattern:

- Fragment, Pit 1, T22G9:1, stripes with lozenge pattern, AH 83, p. 254, no. 2, digital photos.
- Fragment, no. B-101; lozenge pattern, colour chart VI, AH 83, p. 255, no. 1.
- Colour drawing, AH 83, p. 256, Figure 63: 'ornaments on officers' armour from Pit 2', no. 1, Figure T4:1, braid.
- Contour drawing, AH 83, p. 256, Figure 63: 'ornaments on officers' armour from Pit 2', no. 3, Figure T9:1, Ornament of collar, neck area.

The reconstruction was carried out assuming that the pattern is based on an even lozenge raster (Figure 22). The lozenges here enclose an angle of 30 degrees to the horizontal; they have an acute interior angle of 60 degrees as well as an obtuse interior angle of 120 degrees. The construction of the various lozenge elements was carried out on the computer in such a way that they follow the lozenge grid.

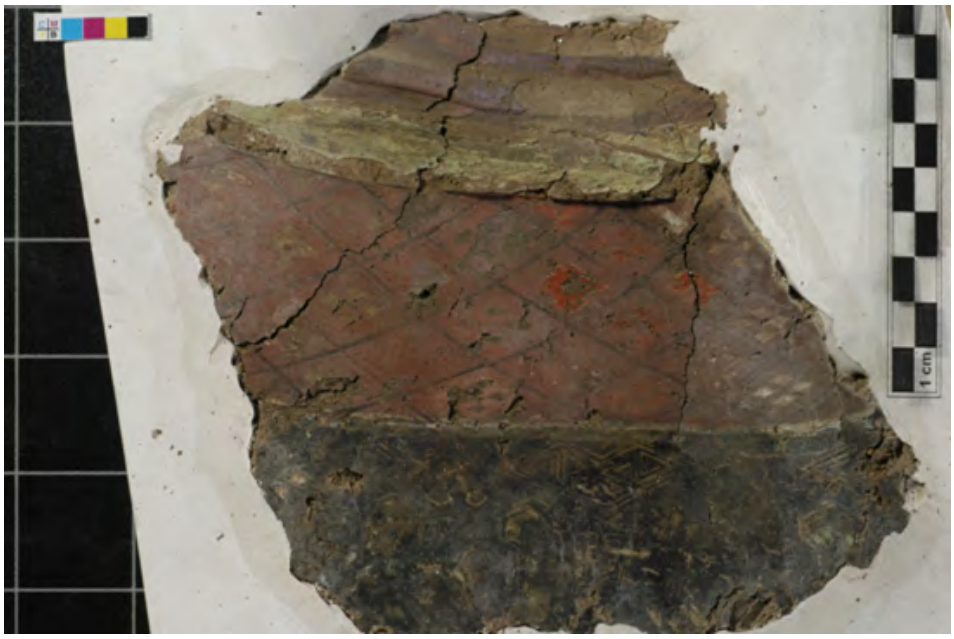

Abb. 20: General T9:1, colour fragment, 18 x 14.5 cm, from the armour in the neck area, (no. B-101).

[42] In the literature also called *diamond* or *hu* pattern.

[43] Also termed as "ear-cup" by ZHAO FENG, due to its similarity to a Chinese ear-cup. ZHAO FENG 1999, p. 48.

In the next step, the contour drawings of the lozenge patterns were coloured. The colouring of the background of the lozenges, of the lozenge elements as well as the lozenge grid could be well discerned on Fragment B-101: the background is red and brown, the lines are coloured black. The colour distribution at the "lozenges with protruding ends" follows a recurring system[44].

WANG XUELI writes on the colouring of lozenge patterns:

> *"The colours used for these patterns are applied in a markedly contrasting fashion, e.g. the rivets on the little plates of the red-brown General's armour were painted vermilion. Alternatively, it was also common to join white and bright purple, with white, bright purple and red often used on auburn. In order to avoid a shambles, a bright red lozenge grid pattern is used at the edges of the armour, here again in contrast to the auburn armour. The lines of the lozenge pattern are black, but the filling is coloured, the background is white, vermilion, deep auburn or golden. In the case of the spiral-decorated lozenges, the heart is vermilion and the sides are white, or they have yellow lines and red sides. The doubly broken lozenge patterns have red lines and white dots, or white lines and red dots, or red lines and red dots, or yellow lines and white dots, or white lines and yellow dots."*

After colouring the contour drawing, a basic element had been created, which, lengthwise, can tiled after one another as often as desired (Figure 23). With this rapport, the colouring of the armour could be textured on the 3D model of the General.

[44] The colouring of the "lozenges with protruding ends" was taken from C. Blänsdorf. See C. Blänsdorf: *The polychromy of clothing and armours of the generals form the terracotta army*, Annual Report 2005, p. 34, Fig. 40.

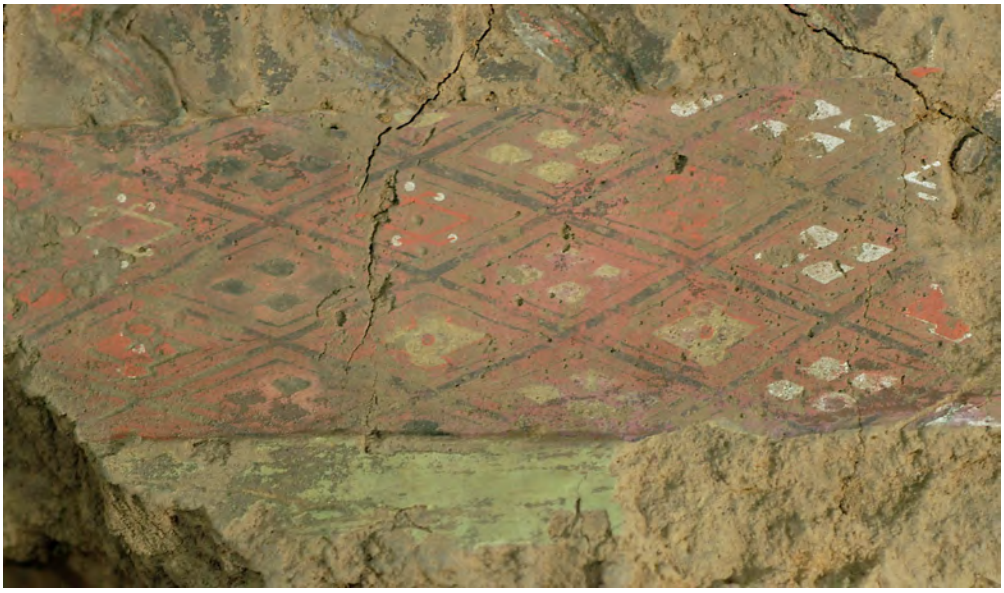

Figure 21: General T22G9:1, colour fragment, Pit 1, strip with lozenge pattern (DSC_1218.jpg).

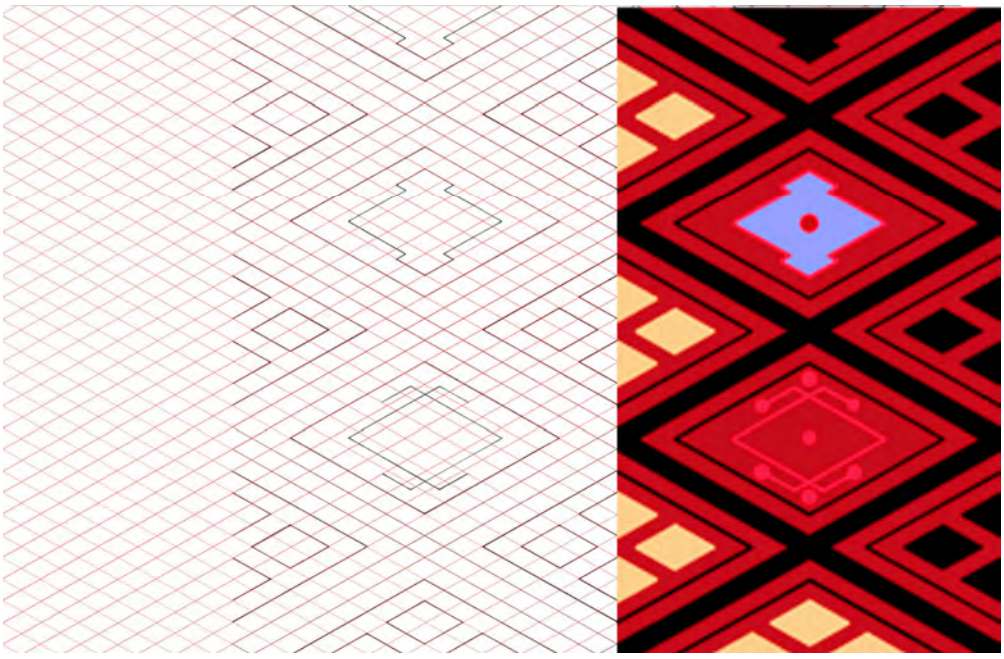

Figure 22: General T9:1, reconstruction of the lozenge pattern (Pattern 2); *left*: basic raster, *centre*: elements 'hooked into' the lozenge grid, *right*: colour reconstruction.

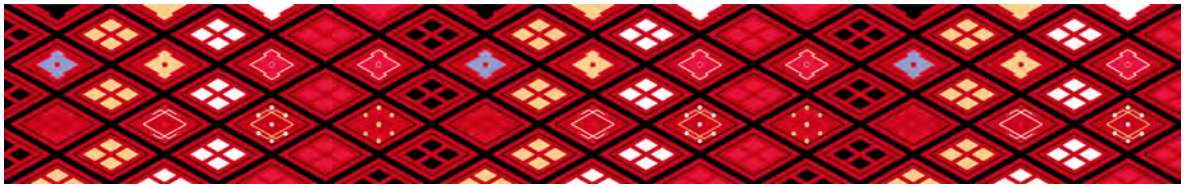

Figure 23: Reconstruction of Pattern 2, several basic elements ('rapport') can be tiled in horizontal direction.

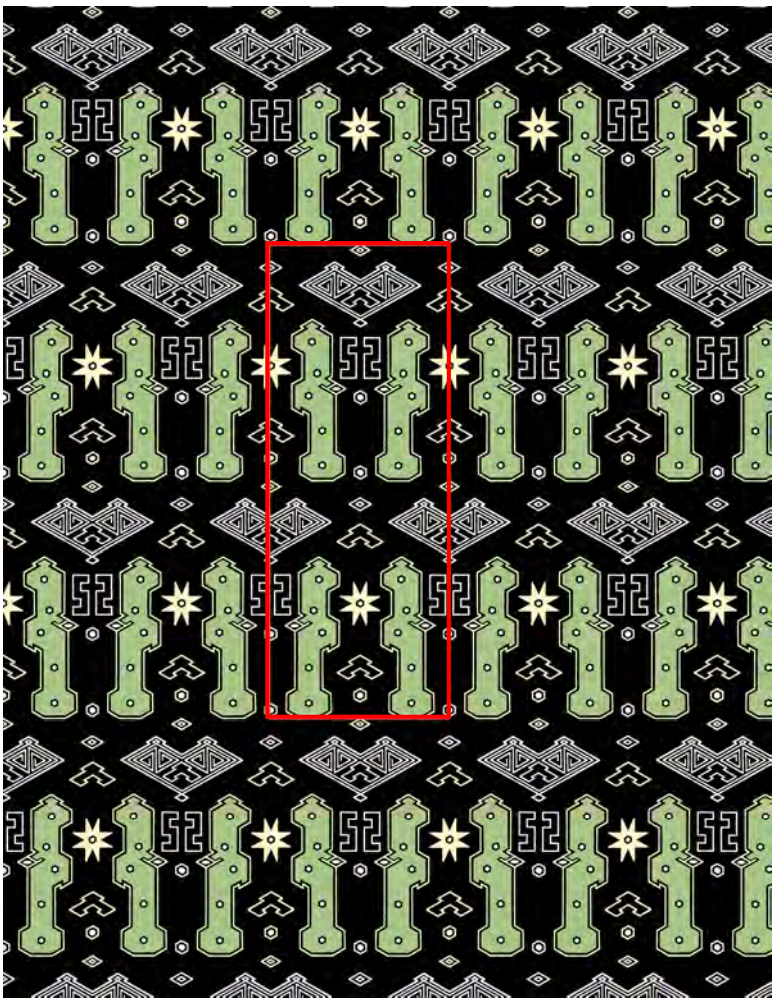

Figure 24: General T9:1, reconstruction of Pattern 1, rapport (red) put together in vertical and horizontal direction (= tileable pattern).

Figure 25: Reconstruction of the scattered pattern, rapport.

Figure 26: Application of Pattern 1 on a curvilinear three-dimensional object.

Figure 27: Application of Pattern 2 on a curvilinear three-dimensional object.

Digitalisation of the surface

In order to process the Terracotta Warrior's surface on the computer, it must be available in digital form. For this purpose, the General's contour was scanned with a 3D stripelight scanner[45], to create a spatial grid model of the figure in this way (Figure 28). A stripelight scanner was used for the 3D measuring. The scanning was carried out in the Museum of the Terracotta Army in Lintong.

Figure 28: Wire frame model of General T9:1, created during scanning the original figure.

Figure 29: Wire frame model, covered with uniformly grey colour.

[45] The digitalisation of the figure was carried out in collaboration with the Römisch-Germanische Zentralmuseum in Mainz with Hr. Guido Heinz.

Complementation of the colouring

The next step was to process the figures with a digital 3D graphics programme in order to reconstruct the warrior's colouring (Figure 30, 35 & 36). The colour reconstruction was carried out in the hue of the approximate original colour. In order to virtually complement the surface of the figure, painting software is required which makes it possible to work immediately on the 3D model. Several layers were used to execute the retouches. It is the advantage of the layer technique that, for instance, partial examinations can be first tested and observed in combination with other colours or effects, respectively, without altering the original image. The employment of different painting and retouching tools allows for a working method individually adapted to each missing portion.

For the application on the 3D model, the two reconstructed patterns must be tileable. This means that they can be continued at will in horizontal and/or vertical direction. If this is possible, the patterns can be applied to the 3D surface rather simply as texture (Figure 26 & 27).

By means of the virtual colour complementation, it was possible to approximate the General to his original appearance.

Rendering of the 3D model

In order to realistically represent the figure, several light sources were built into the scene in the next work step. A three-dimensional form can be spatially perceived by the human eye only through differences in lightness and the colour nuance thereby created on the surface. To avoid the impression of synthetic surfaces, the lighting situation was made as natural as possible. Depending on the type, position and alignment of the light sources, it is possible to create varying moods, which appropriately accentuate the character of a 3D model.

In the last step, the definite images are calculated from the scene with the 3D model. For the visualisation of a scene with three-dimensional objects, it is possible to not only calculate individual images, animations[46] can also be created. The decisive factor for the quality of an animated film is the number of individual images (= frames), which are shown in the animation in one second. When rendered with 24 images per second, the illusion of motion is created in the viewer. The process in which the 3D model is converted into an image with light, shades and colours, is also termed *rendering*.

[46] Animation, from Lat. *animare*, "to give life"; a sequence of individual images, which, during playing, create the illusion of motion.

The rendering software, also called “renderer”, is crucial in the rendering of an image. The result of the rendering procedure can be influenced by a multitude of the most varied settings. Besides the image quality, the rendering time is also determined thereby. Based on the options used, the latter may take seconds up to several hours[47]. To animate the clay warriors, the ray tracing procedure[48], which is marked by its high image quality, was employed for calculation.
The visualisation of the colour reconstruction on the 3D model is to give an idea of the original colouring. The animations of the warriors thus created can convey an impression of the original appearance of the clay warriors as well as of the entire army. The question, however, whether the First Emperor Qin Shihuangdi ever beheld his imposing colourful army himself, will probably for ever remain a mystery.

Figure 30: General T9:1, colour reconstruction of the 3D model.

[47] This depends on the type and number of computers used.
[48] For the calculation with the 3D software *3ds max* of the company *Autodesk*, the renderer *Mental Ray* was used.

Acknowledgement
I would like to thank all the persons who helped me accomplishing this wonderful project in the last three years! Without their help, this would not have been possible.

Dank an Florian Schmoldt, Mel Eibl, Maximilian Stummer, Leszek Plichta, Claudius Urban , Tanja Krampfert, Ando Avilar, Thomas Harbers, Guido Heinz, Martin Schaich, Lars Langheinrich, Gerda Koppatz, Johannes Pietsch, Wang Dongfeng, Wang Liang, Zhao Kun, Zhou Tie, Li Hua, Xia Yin, Fu Qianli, Mao Xiaofeng, Shen Maosheng, Meng Zhongyuen, Rong Bo, Wang Weifeng, Zhang Zhijun, Rolf Snethlage, Martin Mach, Catharina Blänsdorf, Carolin Roth, Sandra Bucher, Beata Oginski, Matthias Kocher, Ilse Sanya, Mieke Pfarr, Anne Horn and all the others!

Figure 31: Pelt mapping of the head of a 3D model

Figure 32: General T9:1, detail of the wire frame model.

Figure 33: General T9:1, detail of the wire mesh model, textured with grey colour.

Figure 34: General T9:1, wire mesh model covered with uniformly grey colour.

Figure 35: General T9:1 painted and textured with patterns, rendering with two light sources.

Figure 36: General T9:1, detail of chest armour.

Appendix

Documentation of remains of polychromy and damages

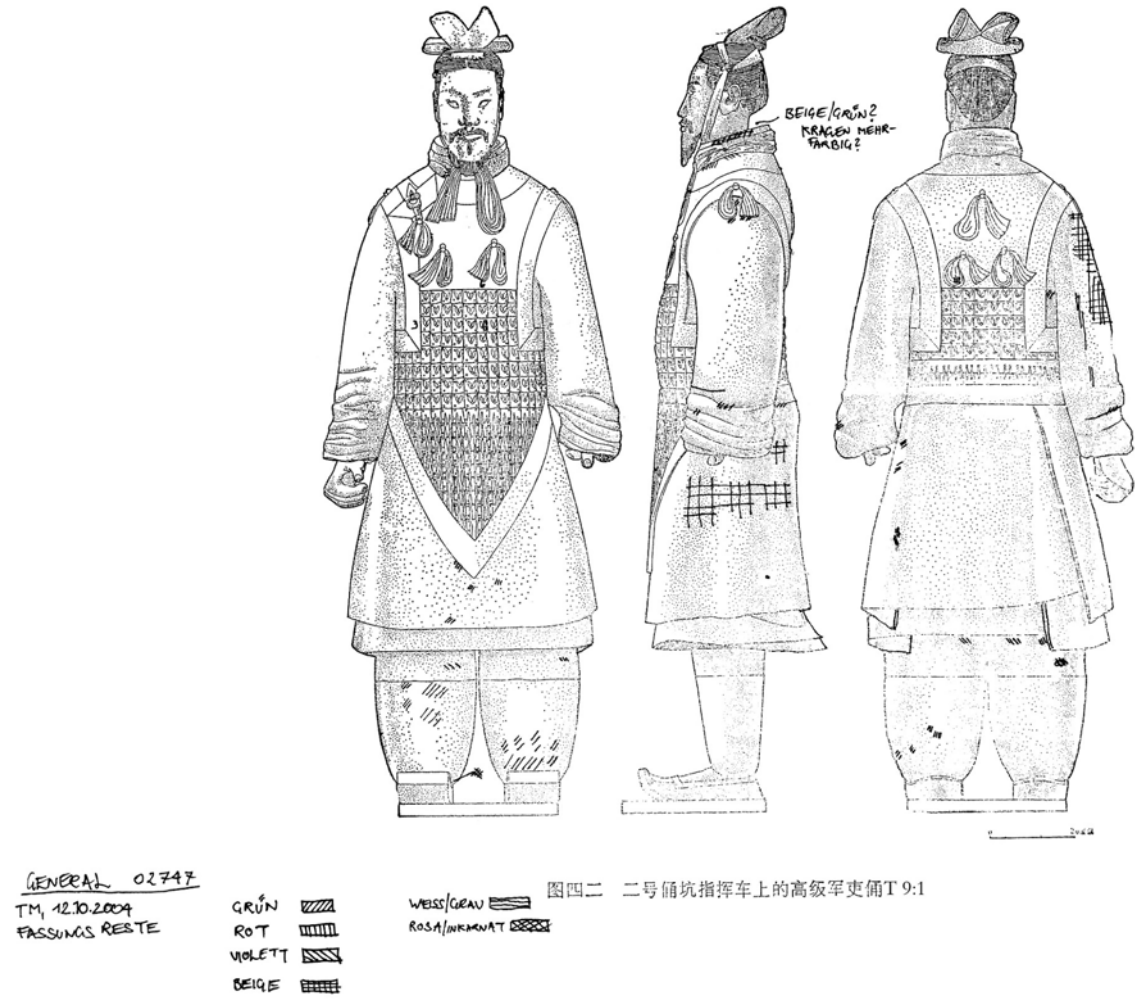

Figure 37: General T9:1, Documentation of remains of polychromy.

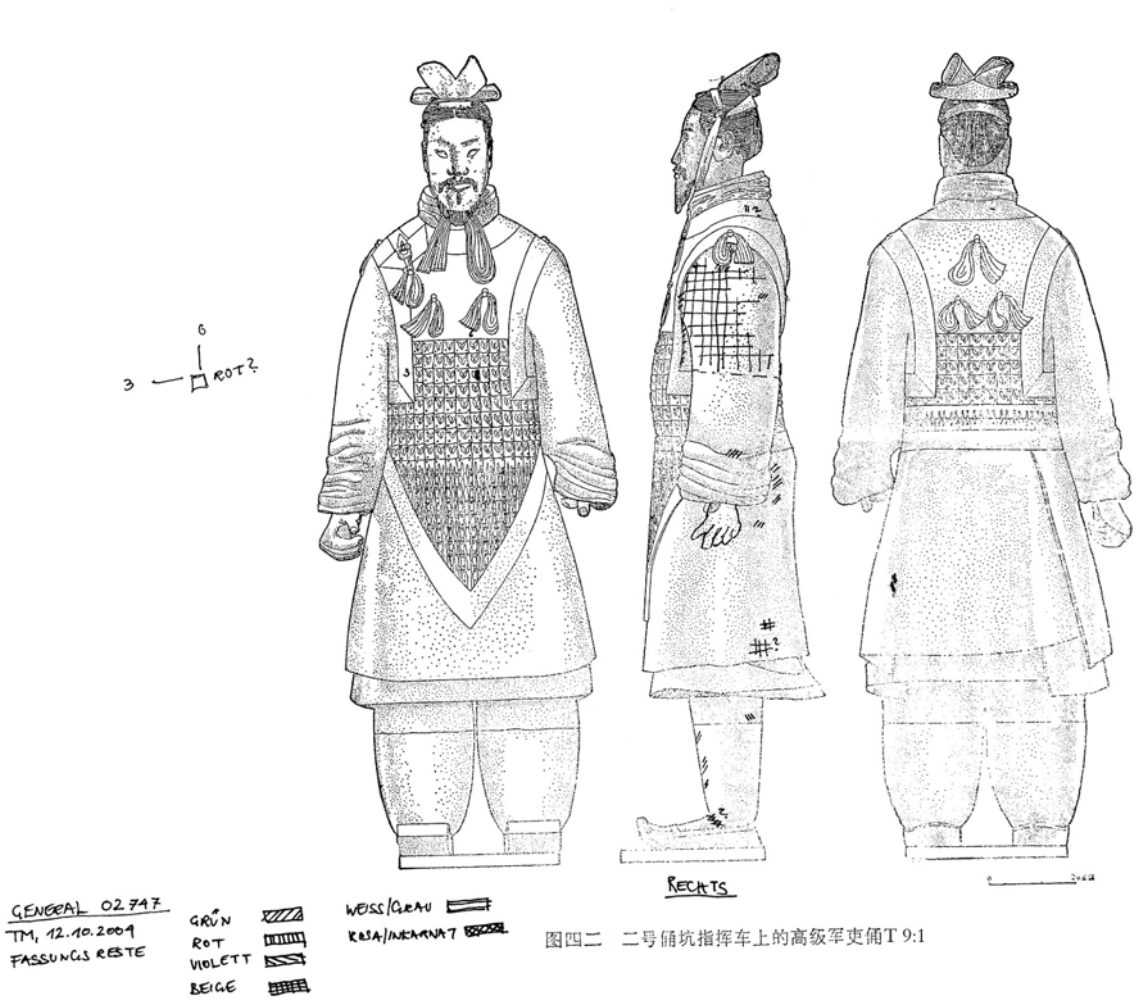

Figure 38: General T9:1, Documentation of remains of polychromy, (polychromy of the right side of the figure is shown from left view.)

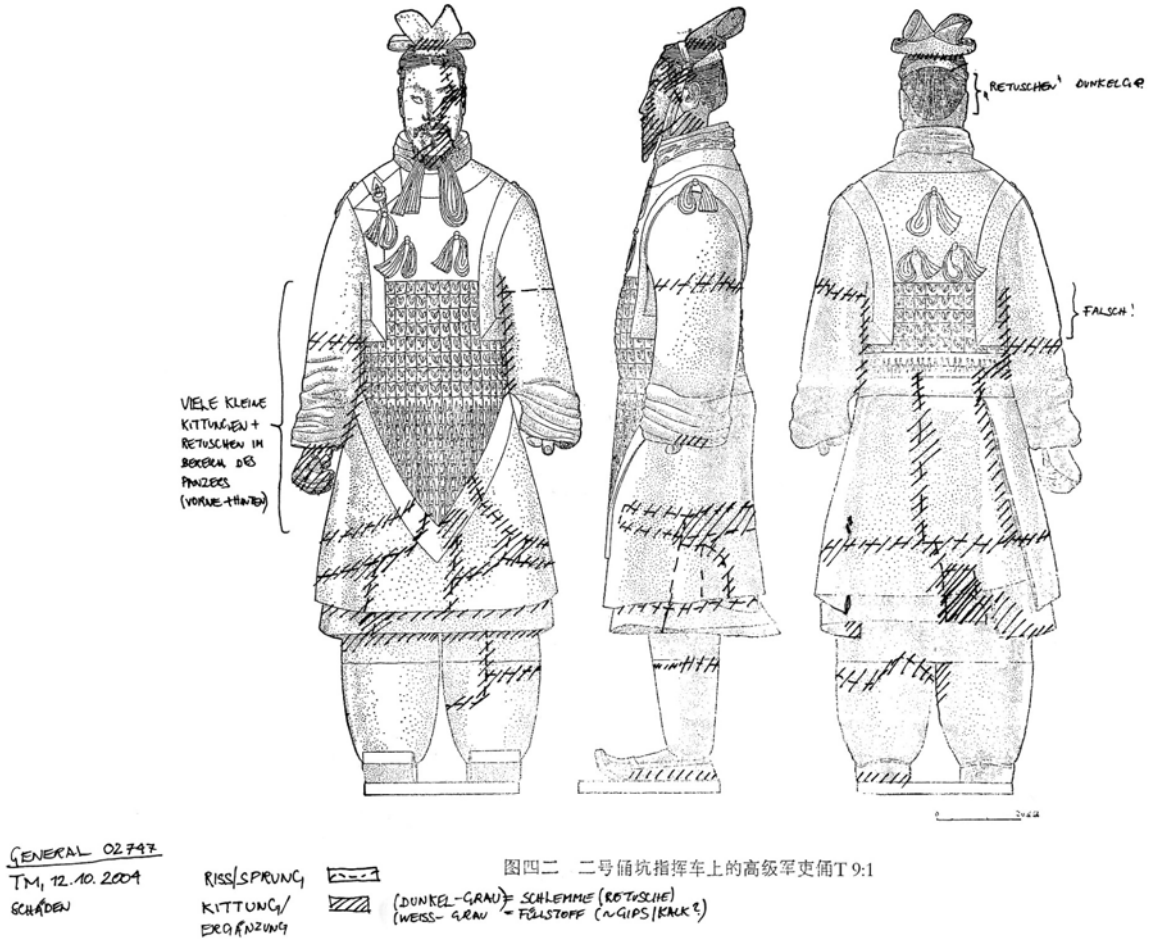

Figure 39: General T9:1, documentation of damages: glued joints and fillings.

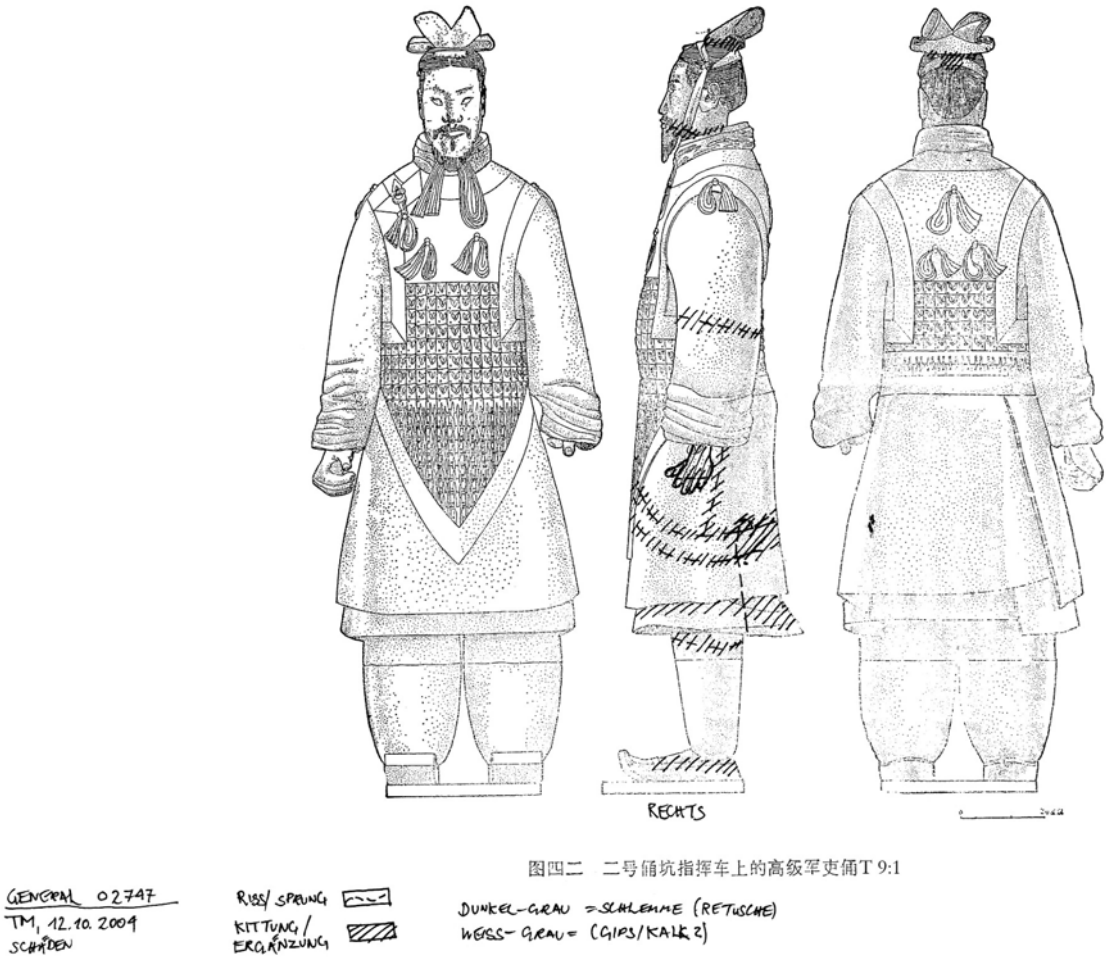

Figure 40: General T9:1, documentation of damages: glued joints and fillings (damages of the right side of the figure are shown from left view.)

Mapping of colouring

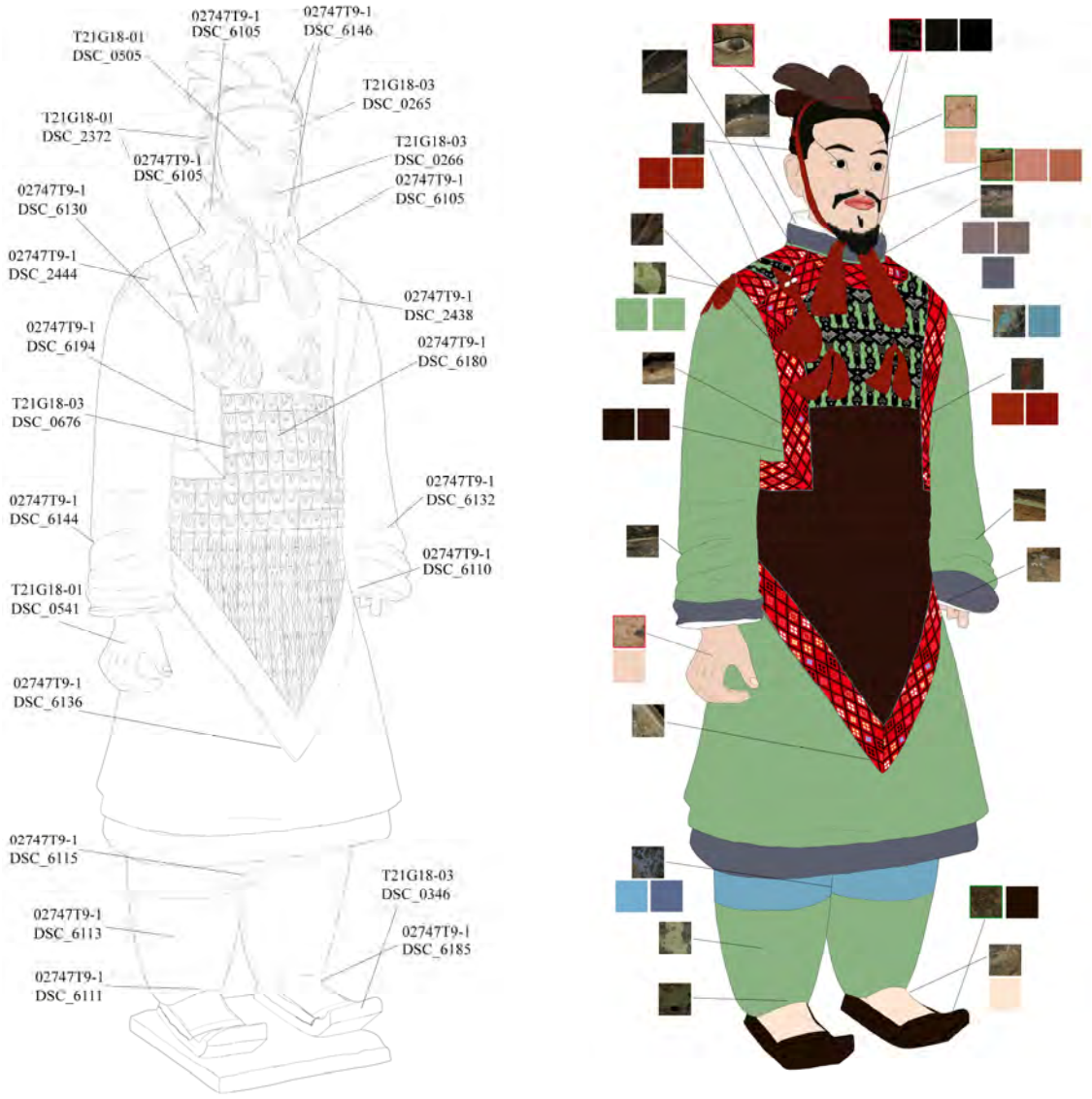

Abb. 41: General T9:1, documentation of polychromy with digital photos, *left*: number of figures together with the number of the photo; *right*: details of remains of polychromy together with the measured colour values.

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ZWISCHENBERICHT FÜR DEN ZEITRAUM: 01.01.06 BIS 31.12.06

Förderkennzeichen: 01GWS038 Abgabetermin: 30. 04. 2007

Vorhaben:
Erprobung und Optimierung von Konservierungstechnologien für Kunst- und Kulturgüter der Provinz Shaanxi / VR China

Darstellung der wichtigsten wissenschaftlich-technischen Ereignisse und anderer für das Vorhaben wesentlicher Ereignisse (z.B. personelle Veränderungen)

1. Personelle Veränderungen

Frau Sandra Bucher hat am 15.11.06 ihren Mutterschaftsurlaub angetreten.

2. Arbeitsaufenthalte, Delegationen

2.1. Nov./Dez. 2006 – Arbeitsaufenthalt chinesischer Kollegen vom Museum der Terrakottaarmee in München

Die Schwerpunkte des Arbeitsaufenthalts vom 3. bis 29. November der chinesischen Kollegen Herrn Rong Bo und Herrn Zhang Zhijun im Jahr 2006 waren die folgenden Themen: Klimamessungen in der Krypta St. Seebald in Nürnberg sowie Messung und Auswertung der Salzgehalte im Mauerwerk eines Bauernhauses in Schupf bezüglich der Höhen- und Tiefenverteilung.
Bei einer Exkursion nach Bamberg besuchten die chinesischen Kollegen zusammen mit Hr. Prof. Snethlage und Hr. Horn am 20. 11. 2006 Prof. Dr. Rainer Drewello. Am Lehrstuhl für Konservierungswissenschaft und Denkmalpflege der Otto-Friederich-Universität Bamberg wurde der Einsatz von modernsten 3D-Technologien wie 3D-Scannern, 3D-Software und Texturierungsprogrammen in der Denkmalpflege und die virtuelle Rekonstruktion von Kulturgütern vorgestellt.
Herr Wang Dongfeng, der bereits in den vergangenen Jahren mit Frau Bucher zusammen an der Bergung und Konservierung der Steinpanzer gearbeitet hat, setzte in der Zeit vom 3. November bis 15. Dezember die Arbeiten zur Entfernung der Korrosionsschicht von den Drähten fort und bereitete die bereits konservierten Fragmente vor, in dem einen neue Transportsicherung aufgebracht wurde.
Fast alle in München gelagerten Fragmente, insgesamt 29 Terrakottafragmente sowie ein großes und ein kleines Steinpanzerfragment wurden von den chinesischen Kollegen nach China zurücktransportiert. In München verblieben sind einige bereits beprobte Fragmente für die Untersuchung der Terrakottaeigenschaften sowie bemalte Terrakottafragmente mit noch ungesicherter Farbfassung. Weiterhin sind Einzelplatten, Steinbruchstücke und Einzeldrähte der Steinpanzer für weiterführende Versuche in München verblieben.
Von deutscher Seite fanden 2006 keine Arbeitsaufenthalte in China statt.

2.2. Lenkungsausschusstreffen

Das Lenkungsausschusstreffen fand am 20/21. Februar 2006 in Xi'an im Tanghua Hotel statt. Die Arbeiten in den einzelnen Teilprojekten wurden vorgetragen, diskutiert und das weitere Vorgehen geplant. Es wurde im Besonderen auf die Planung der Ausstellung in der Bundeskunsthalle in Bonn eingegangen. Für die Übersetzung wurde von der Münchner Seite Herr Chen beauftragt.

2.3. Aufenthalt in China zum Zweck der Besichtigung und Planung

Vom 23. – 30.7. hielten sich Herr Emmerling, Frau Blänsdorf und Herr Kocher in China auf. Die Reise diente der Besichtigung des Museum der Terrakottaarmeee in Lintong und der Steingrotten in Anyue sowie der Planung weiterer Arbeiten in den Teilprojekten. Besucht wurden das Museum der Terrakottaarmee, das Zentrum für die Konservierung und Restaurierung von Kulturgütern der Provinz Shaanxi und das Archäologische Institut der Provinz Shaanxi in Xi'an. Während des Besuchs in Anyue, Sichuan, konnten die für die Zusammenarbeit geplanten Grotten, Huayan-Grotte bei Shiyangshi und Yuanjue-grotte bei Anyue, eingehend besichtigt werden. Bei dem anschließenden Treffen im National Institute for Cultural Property (NICP) wurden neben den Arbeiten in Anyue auch weitere mögliche Projekte einer Zusammenarbeit vorgestellt und abgestimmt.

2.4. Besuch einer chinesischen Delegation

Die Delegationsmitglieder Prof. Dr. Zhao Rong, Fan Yanping, Wu Yongqi, Yin Shenping, Han Jinke und Han Wei waren vom 24. – 28. April in München. Die Herren Wang Dongfeng und Wang Liang kamen bereits am 18. April in München an und flogen ebenfalls am 28.4. zurück. Im Rahmen des Besuchs wurden Besichtigungen des Schlosses Neuschwanstein, der Wieskirche, der Porzellanmanufaktur und des Schlosses Nymphenburg, des Schlosses Herrenchiemsee, der Fraueninsel sowie der Münchner Innenstadt unternommen. Da die Herren Zhao Rong und Wu Yongqi auf Einladung der KAH Bonn den 24. und 25.4. in Salzburg verbrachten, nahmen sie an den ersten drei Ausflügen (Neuschwanstein, Wieskirche, Nymphenburg) nicht teil. Als Übersetzer wurden Herr Chen Ganglin bzw. Frau Ma Yimin beauftragt.

3. Kongresse, Tagungen

3.1. Symposium „Unter der Gelben Erde“ in Bonn

Zum Auftakt der Ausstellung „Xi’an – Kaiserliche Macht im Jenseits“ in Bonn fand vom 21. bis 23. 4. 2006 ein Fachkongress mit internationalen Teilnehmern statt. Unter dem Titel ‚Unter der gelben Erde’ wurden die wissenschaftlichen Ergebnisse vorgestellt wurden, auf denen die Ausstellung beruht. Die Beiträge werden in einem Kongressband veröffentlicht, im Januar 2007 erschienen ist.

3.2. IIC – Kongress in München

Vom 28.8 bis 1.9. 2006 fand der Kongress „Objects in context: Crossing concervation boundaries’, organisiert vom International Institute for Conservation (IIC) in London und dem Doerner-Institut, in München statt. Frau Bucher und Frau Blänsdorf präsentierten in Vorträgen ihre Arbeiten innerhalb des Projektes: „Stone armor 2200 years ago: early mass production methods in China“ bzw. „A colourful world for the Emperor’s soul: the polychromy of the terracotta sculptures at Qin Shihuang´s burial complex”. Herr Horn stellte anhand eines Posters mit dem Thema “3D Models of Terracotta Warriors – Virtual colour reconstruction of the polychromy” seine Arbeiten zu virtuellen Farbrekonstruktionen an Figuren der Tonkriegerarmee vor.

4. Ausstellungen

4.1. Ausstellung in Bonn

Vom 21.4 – 23.7. fand in der Kunst- und Ausstellungshalle in Bonn die Ausstellung „Xian – Kaiserliche Macht im Jenseits“ statt. Die Ausstellung zeigte chronologisch geordnet, Stücke der Qin- bis Tang-Dynastie. Die Auswahl der Einzelstücke basierte auf dem chinesisch-deutschen Forschungsprojekt. Insbesondere konnten Stücke gezeigt werden, die normalerweise China nicht verlassen dürfen, jedoch ausnahmsweise gezeigt werden konnten, weil sie im Rahmen des Projektes konserviert worden sind. Die Forschungen zur Technik und die Konservierungsmethoden und –erfolge wurden in gesonderten Vitrinen, Wandtafeln und Computeranimationen vorgestellt. Zwei Animationsfilme der TU Darmstadt gaben einen profunden Einblick in das historische und geographische Umfeld der beiden großen Grabanlagen Qin Shihuangling und Zhaoling. In drei Monaten besuchten 110 000 Besucher die Ausstellung.
Während der Ausstellung fanden Themenführungen zu bestimmten Aspekten statt, die auch von Mitarbeitern des Forschungsprojektes gehalten wurden. Frau Blänsdorf stellte die Farbfassung der Terrakottafiguren vor (21. 6.), Frau Zorn aus dem Römisch-Germanischen Zentralmuseum die daoistische und buddhistische Symbolik ausgewählter Ausstellungsstücke (14. 6.).

4.2. Ausstellung im Rahmen des Wissensspeichers

Als Rahmenprogramm des IIC-Kongresses in München fand eine Reihe von Studio-Ausstellungen stand, bei denen die einzelnen Institutionen besondere Projekte der Forschung und Konservierung vorstellten. Das Bayerische Landesamt erstellte zwei Ausstellungen, von denen eine das Forschungsprojekt mit China präsentierte. Dieses war mit zwei Vorträgen auch auf dem Kongress vertreten. Die Ausstellung zeigte die verschiedenen Aspekte des Projektes mit Postertafeln, welche die Konservierung der Erdarchitektur, die Forschung zu Technologie und Konservierung der Farbfassung, Untersuchungen zur Terrakotta und deren Klebung sowie die Bergung und Erhaltung der Steinpanzer vorstellte. Fünf Vitrinen enthielten originale Bruchstücke sowie die Materialien und Werkszeuge, die zur Herstellung der Steinpanzer und zur Bemalung der Terrakottafiguren dienten. Die zwei in Bonn gezeigten großen Kopien von Kriegern mit rekonstruierter Bemalung bildeten den Mittelpunkt der Ausstellung.
Auf zwei Monitoren wurden Arbeiten zum Einsatz der Virtuellen Realität am Beispiel des Grabkomplexes des Ersten Kaisers vorgestellt: Am Computer bearbeiteten 3D-Modellen gezeigten werden, welche farbenprächtige Erscheinung die Tonkrieger ursprünglich besessen haben. Ein Video visualisierte die Farbrekonstruktion eines Generals der Terrakottaarmee. Durch eine

virtuelle „Szene“, die aus mehreren Panorama-Filmen zusammengesetzt war, konnte man sich durch die Gruben der Tonkrieger bewegen.

Weiterhin wurde ein Modell eines Ganges aus Grube 2 ausgestellt, das zu diesem Anlass gebaut worden war. Einführende Texttafeln und der erste Teil des Animationsfilmes aus Darmstadt konnten aus der Bonner Ausstellung nach München übernommen werden.
Ausstellungseröffnung war 31. 8. Wegen großen Interesses wurde die zunächst für 10 Tage konzipierte Ausstellung verlängert. Sie war auch am Tag des offenen Denkmals (9. 9.) und bis zur ‚Langen Nacht der Museen' (21. 10.) zu sehen. In dieser letzten Nacht benutzten 200 Besucher die Möglichkeit, die Ausstellung zu besuchen.

5. Arbeiten zu kunsthistorischen und kunsttechnologischen Fragestellungen

5.1. Farbfassungen der Terrakottafiguren: Kleidung, Muster und Materialillusionen

Die Rekonstruktion der Farbfassung ganzer Figuren muss sich mit der Farbverteilung und der Schließung fehlender Bereiche beschäftigen, da keine Figur und kein Muster ohne Fehlstellen erhalten sind. Um korrekte Rekonstruktionen anfertigen zu können, ist es erforderlich zu verstehen, was diese Farbfassungen darstellen sollten, besonders den Schnitt der Kleidung und die Art ihrer Verzierungen. In derselben Weise können auch Skulpturen von Tieren wie Wasservögel oder Pferde und Gegenstände wie die Bronzekutschen untersucht werden.
Beispiele erhaltener Textilien aus der Zeit der Streitenden Reiche (*zhanguo*) bis Han Dynastie sowie gemalte oder modellierte Darstellungen von Bekleidungen und Mustern wurden mit den Terrakottafiguren verglichen. Diese Arbeit wird dadurch erschwert, dass es fast keine Publikationen in westlichen Sprachen gibt und auch in Chinesisch wenig grundlegende Arbeiten. Die Untersuchungen sind deshalb erst begonnen, konnten jedoch bereits einige Fragen klären. Die Terrakottakrieger tragen Jacken und haben dicke bauschige Ärmelaufschläge und Kragen. Die Untersuchungen der Farbigkeit und die Vergleiche konnten zeigen, dass die Jacken selbst mit glatten Kanten enden, Ärmelaufschläge und Kragen also zu einem Untergewand gehören. Die Generäle tragen doppelte Jacken, wobei die Kanten der Außenjacke mit schmalen Borten eingefasst sind. Zumindest in zwei Fällen ließ sich darauf eine feine Musterung nachweisen. An der Außenjacke enden die Borten in der Taille, während sie an der Innenjacke, wenn vorhanden, um alle Kanten herumlaufen. Dieselbe Art der Jacken konnte auch an den knienden Tierpflegern nachgewiesen werden. Dort sind allerdings nur die Halsausschnitte, nicht die Ärmelkanten mit Borten besetzt. Ärmelaufschläge und Kragen zeigen dieselbe Farbabfolge und sind ein- bis zweifarbig. Als dritte Farbe ist manchmal noch das Futter zu sehen, das meist hell gestaltet ist. Das Vorkommen von rosa Futterstoffen ist insofern erstaunlich, als an historischen Textilien der Zeit nur ungefärbte Futterstoffe nachgewiesen wurden.

Die an Gipskopien im Maßstab 1:1 realisierten Rekonstruktionen von Fassungen zeigten nicht nur, wie erstaunlich kräftig die Farbtöne sind, wenn sie ohne Fehlstellen und Verschmutzungen zur Wirkung kommen, und wie viele Farben zum Einsatz kamen. Die extrem farbenfrohe, aber harmonische Farbwirkung war ein überraschender Effekt dieser Rekonstruktionen, da trotz Beschreibungen dieser „Farbigkeit“ in grafischen Rekonstruktionen immer sehr viel gedecktere Farben dargestellt wurden. Die Farbigkeit der Kopien ist jedoch durch zahlreiche Pigmentanalysen zuverlässig nachgewiesen. Die Bemalung der Inkarnate klärte nicht nur technische Fragen, sondern zeigte auch, dass die Maler bis in die Details der Augenbrauen realistische Darstellungen schufen.

Die Muster auf den Panzerborten herausgehobener Offiziere wurden bereits 2004 und 2005 untersucht. 2006 wurden die Muster auf den Röcken der Akrobaten untersucht, die sich technisch insofern von den Soldaten unterscheiden, als sie einfarbig und plastisch gestaltet sind. Die verwendeten geometrischen Formen sind teilweise ähnlich, z.B. die gebrochenen Rauten, gewinkelte Ornamente und achtzackige Himmelskörper (meist als „Sonne“ interpretiert), teilweise aber auch ganz anders, mit geschwungenen Formen oder rosettenartigen Applikationen. Ähnlichkeiten lassen sich vor allem zu Textilien aus Mawangdui bei Changsha nachweisen. Dort wurden Stoffe gefunden, die fast identische Muster aus gebrochenen Rauten in versetzt angeordneten Reihen zeigen. Es handelt sich um Seidengazen und einen Damast. Stoffe mit rosettenartigen Dekorationen könnten Stickereien, Damaste oder auch samtartige Textilien darstellen. Die Interpretation der Muster ist auch in diesem Fall nicht einfach. Vor allem die rosettenartigen Dekorationen, die an Streublüten erinnern, sind ungeklärt, da es noch keine floralen Ornamente in dieser Zeit in China gibt. Die Erklärung als „Kreuz“- oder „Punkt“- und „Kreis“- Ornamente erscheint jedoch auch unbefriedigend. Die Herkunft dieser Formen ist auch noch unklar.

Neben Textilien sind auch andere Materialien fasstechnisch nachgeahmt worden: Am Wagenlenker der Bronzekutsche Nr. 1 stellt eine weiße, mit Pünktchen besetzte Scheibe eine *bi* Scheibe aus Jade mit dem typischen Kornmuster dar. Der Wagenlenker zeigt somit auch, dass die rituellen *bi* Scheiben als Gürtelanhänger getragen wurden. Ähnlich strukturierte weiße Flächen am Schild dieses Wagenlenkers erinnern an Einlegearbeiten, z.B. die Silber- und Goldtauschierungen an

qinzeitlichen Bronzeobjekten. Dass Silber- und Beinobjekte mit weißer Farbe dargestellt wurden, zeigen die Gürtelschnallen (im Original Bronze oder Silber) und die Haarspangen und Knebelknöpfe (im Original aus Knochen) an den Terrakottakriegern.
Technisch faszinierend und einzigartig sind die Gestaltungen der Bronzevögel mit einem lebensechten Gefieder. Verschieden gestaltete Federarten, wie Flaum, Dauen und Schwungfedern und ihre Anordnung auf dem Körper können als Nachweis gelten, dass die Handwerker-Künstler der Zeit lebende Vögel genau studierten.

5.2. Aufnahme und Auswertung der Inschriften in der Jinchuanwan-Grotte

Unter der finanziellen Unterstützung der BLFD habe ich in der zweiten Hälfte des Jahres 2006 die folgenden wissenschaftlichen Arbeiten erfolgreich durchgeführt:
1. Englische Übersetzung der Texte. Die vier Texte von dem Mönch Xinxing (540-593), dem Begründer der Drei Stufen Lehre, wurde zusammen mit anderen orthodoxen buddhistischen Texten in einer Grotte in Jinchuanwan in der Provinz Shaanxi, eingemeißelt und dadurch überliefert. Drei von den Texte Xinxings sind besonders wertvoll, weil sie anderwärtig nicht überliefert sind und neue historische Materialen für die Forschung der einst populären buddhistischen Lehre bringen. Die übersetzten Texte sind:

1) Clarifying the Methods in the Scriptures about Arousing the Mind to Enlightenment in Accord with One's Depth of Capacity 明諸經中對根淺深發菩提心法
2) Clarifying the Methods in the Scriptures of the Great Vehicle about the Difference of the Mundane and Transmundane two Stages Persons Arousing the Mind to Enlightenment 明诸大乘修多罗中世间出世间两阶人发菩提心同异法
3) The Abridged Excerpts from the "Chapter of Moon Store" of the *Great Collection Sutra* 《大集月藏分经》略抄出
4) Sutra of Buddha Names of Seven Rosters 七階佛名經

2. Fotodokumentation der Grotte. Die eingemeißelten Texte und die Grotte mit ihrer Umgebung sind systematischen digital mit der Auflösung 3456x2304 Pixels dokumentiert. Von den zahlreichen Dokumentationsfotos sind 83 Bilder exemplarisch wie vereinbart mit dem A4 (210x297mm) Format entwickelt. Diese sollen der Restaurierung sowie der weiteren Forschung der Grotte dienen.

6. Untersuchung zur Maltechnik und Rekonstruktionen von Farbfassungen

Der Schwerpunkt der Arbeiten im Jahr 2006 war die Umsetzung der gewonnenen Erkenntnisse über die Farbfassung in Form von Rekonstruktionen, die auf Abgüssen, kleinen Kopien oder Musterplatten ausgeführt wurden. Zwei Abgüsse im Maßstab 1:1, eine General und ein kniender Bogenschütze, waren Ende 2005 in China vorbereitet und lackiert worden. Die Bemalung erfolgte in München und wurde Anfang April fertig gestellt. Die beiden Figuren waren in der Ausstellung in Bonn zu sehen. Die Bemalung der Kopien erbrachte über die bereits erfolgte Dokumentation der Farbfassungen weitere wichtige Erkenntnisse, welche die Wirkung der Figuren und die technische Realisierung solcher Farbfassungen betreffen.
Die Pigmente wurden den nachgewiesenen Farbmitteln entsprechend ausgewählt und zum größeren Teil in einer Beijinger Fabrik für mineralische Pigmente gekauft. Das heute nicht mehr erhältliche Chinesisch Violett wurde extra zu dem Zweck der Bemalung von Prof. H. Berke an der Universität Zürich hergestellt (insgesamt 1 kg), so dass auch hier mit dem nachgewiesenen Material gearbeitet werden konnte. Als Bindemittel wurde experimentell eine Mischung aus Hühnerei und Hasenhautleim als das Material ermittelt, das den Originalen am ähnlichste Schichten ermöglichte. Durch die Analysen an der Universität Pisa durch Prof. Maria Perla Colombini und Ilaria Bonaduce wurde Ei als Bindemittel in der Fassung der Terrakottaarmee und den Bronzevögeln zur gleichen Zeit nachgewiesen. Die Bemalung wurde durch die Dipl. Restauratorin Carolin Roth ausgeführt. Für Fragestellungen, die sich während der Arbeit ergaben, wurden von Frau Blänsdorf weitere Untersuchungen durchgeführt, wie z.B. zur Partikelgröße von Zinnober in rosafarbenen Farbschichten, sowie Farbmuster erarbeitet. Alle Flächen wurden farbig geschlossen, auch wenn für einzelne Flächen das Wissen über die Farbigkeit fehlte. Für die Schließung dieser Flächen wurden andere Figuren als Vergleich herangezogen und auch Muster der Generäle der Bronzekutschen einbezogen. Somit ergab sich ein Gesamteindruck, der zwar in Details diskutiert und korrigiert werden kann, aber eine realistische Möglichkeit für die Bemalung darstellt. Anhand der Bemalung konnten auch Fragen nach dem Pigmentverbrauch, der Art der zu verwendenden Pinsel und Werkzeuge, Auftragsstärken und Empfindlichkeit der Farbschichten geklärt werden.

Anschließend an die zeitlich auf den Ausstellungsbeginn in Bonn ausgerichteten Arbeiten wurden weitere Rekonstruktionsversuche unternommen. Elf farbig gefasste kleine Kopien von knienden Bogenschützen wurden in einer Kiste aufgestellt, die im Inneren als Modell des Ganges G18 aus Grube 2 gestaltet ist, aus dem zumindest neun der Bogenschützen stammen. Die Farbfassung zweier Tierpfleger in halber Lebensgröße wurden an kleinen Kopien ausgeführt, welche die sehr

unterschiedlichen Farbigkeiten und die Art der Kleidung mit aufgesetzten Borten deutlich zeigen.

Die plastisch gestalteten Muster auf den Röcken der Akrobaten, einem Gürtelanhänger des Generals der Bronzekutsche Nr. 1 und der Bronzevögel wurde auf Musterplatten nachgestellt. Es zeigte sich, dass die gewählte Bindemittelmischung auch hier zu sehr guten Resultaten führte. Für die aufwendige Gestaltung des Federkleides der Bronzevögel konnte ein Arbeitsablauf und eine Auftragstechnik gefunden werden, die möglicherweise der ursprünglichen Technik entspricht.

Die Analysen an der Universität Pisa waren die erste erfolgreiche Bindemittelbestimmung an Proben der Terrakottaarmee. Dies wurde durch ein spezielles Verfahren erzielt, bei dem das Probenmaterial gereinigt, durch mikrowellenunterstützte saure Hydrolyse aufbereitet und mit GC-MS analysiert wurde. Die Kombination von molekularbiologischen Verfahren und analytischer Chemie ermöglichte, auch aus den sehr geringen Probenmengen trotz Verunreinigungen und Abbau des Bindemittels noch eindeutige Ergebnisse zu erzielen. Da ein solches Verfahren bislang nicht zur Verfügung stand, waren alle bisherigen Versuche ohne positives Ergebnis geblieben.

7. Untersuchungsschwerpunkt Farbfassungskonservierung

Die Versuche im Jahr 2006 konzentrierten sich auf die Optimierung der Festigerzusammensetzung für die Elektronenstrahlmethode (EB-Methode). Die bisher verwendete Formulierung erfordert eine hohe Energiedosis zum Aushärten und der resultierende Film ist nicht flexibel genug. Polymerisationsversuche mit einem neuen, in hohem Maße hydrophilen Monomer (Glycerolmethacrylat, GMA) ergaben viel versprechende Ergebnisse. Die Zugabe dieses neuartigen Monomers zur Festigermischung hat drei große Vorteile gegenüber dem herkömmlichen HEMA (Hydroxyethylmethacrylat): Zum einen ist die zur Aushärtung erforderliche Energie deutlich herabgesetzt, der resultierende Film weist eine stärkere Haftung zur Terrakotta auf und ist zudem hydrophiler, kann also besser Wasser speichern. Im Laufe des Jahres wurde zunächst die Eignung von GMA für Elektronenstrahlhärtung untersucht, danach der optimale Anteil der Substanz in der Festigerformulierung ermittelt. Alle Tests wurden auf Objektträgern sowie auf standardisierten Terrakottaproben mit aufgelegten originalen Lackschollen durchgeführt.
Parallel wurde eine effektive Synthesemethode für das Monomer GMA im Labormaßstab entwickelt. Da GMA relativ neu auf dem Markt ist und zur Zeit noch teuer, ist eine günstige Synthesemöglichkeit von Vorteil.
Ein weiterer Punkt 2006 war die Suche nach einer geeigneten Analysemethode zur Charakterisierung der Polymere, aus denen die gefestigten Filme in der EB-Methode bestehen (v. a. PolyHEMA, PolyGMA,). Ein großes Problem ist, dass es sich um unlösliche Polymere handelt, was die meisten gängigen Analysemethoden zur Bestimmung von Molmasse und Vernetzungsgrad ausschließt. Eine spezielle Anwendung der Feststoff-NMR-Spektroskopie könnte hilfreich sein, dies muss jedoch noch weiter erprobt werden.

8. Virtuellen Farbrekonstruktionen von Figuren der Terrakottaarmee. Entwicklung und Ausführung von virtuellen Objekt- und Panoramavideos.

Farbrekonstruktion an 3D-Modellen von Kriegern der Terrakottaarmee

Der Schwerpunkt der Arbeiten für das Jahr 2006 lag auf der Vorbereitung und Ausführung der Präsentation der 3D-Modelle für die Ausstellung „Xian – Kaiserliche Macht im Jenseits“ in der Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (KAH) in Bonn. Ziel der virtuellen Bearbeitung war es zu zeigen, welche Farbigkeit die Figuren der Tonkriegerarmee ursprünglich besessen haben. Mit Hilfe von am Computer bearbeiteten 3D-Modellen sollte das ungefähre ursprüngliche Erscheinungsbild der Tonkrieger visualisiert werden. Das heutige Erscheinungsbild diente dabei als Ausgangspunkt für die Ergänzung der gealterten Farbigkeit sowie für die Rekonstruktion der ursprünglichen Farbigkeit.
Für die Bearbeitung am Computer wurde die Oberfläche mehrerer Tonkrieger mit 3D-Scannern digitalisiert. Die dabei entstandenen Gitter-Modelle bilden die Grundlage für die Gestaltung der Oberfläche mit Texturen. Als Texturen wurden Digitalfotos verwendet, die den heute sichtbaren Zustand der Krieger zeigen. Auf diesen Texturen aufbauend, erfolgte die virtuelle Bearbeitung der 3D-Modelle mit einer 3D-Paintsoftware.
Anhand von zwei unterschiedlichen Ansätzen sollten die Möglichkeiten der virtuellen Realität aufgezeigt werden. Beim der ersten Variante wurde am Beispiel des knienden Armbrustschützen T21G18-01 mit dem „grünem Gesicht“ eine virtuelle Ergänzung der Farbigkeit durch Retuschen anhand gealterter Farbwerte ausgeführt. Die zweite Variante erfolgte am Beispiel des hochrangigern Generals T9:1 mit einer virtuellen Rekonstruktion der annähernd ursprünglichen Farbigkeit.
Zur Veranschaulichung der Vorgehensweise für beide Varianten wurden 3D-Animation erstellt, welche in chronologischer Abfolge die einzelnen Arbeitsschritte zeigen. Abgespeichert auf zwei DVD’s konnten beide Animationen in Form einer Endlosschleife mit DVD-Abspielgeräten kontinuierlich auf Monitoren in der Ausstellung vorgeführt werden.

Entwicklung und Ausführung von virtuellen Objekt- und Panoramavideos

Da dem Besucher der Terrakottaarmee in China der Zutritt zu den Gruben der Krieger und Pferde verwehrt ist, verbleibt ihm nur der Blick vom Grubenrand. Durch eine in der Grube angefertigte virtuelle Rundumsicht können die Tonkrieger aus unmittelbarer Nähe studiert werden. Mit Hilfe der Panorama-Videos ist es möglich, sich virtuell in die Gruben zu begeben.
Für die Ausstellung in Bonn im Jahr 2006 wurde ein Entwurf für die Präsentation von Panoramavideos erstellt; im Anschluss daran erfolgte die Ausführung und Umsetzung dieses Konzepts. Für die Präsentation auf einem Monitor in der Ausstellung wurden mehrere Panorama-Movies aus dem Grabkomplex des Ersten Kaisers zu einer „virtuellen „Szene“ zusammengefasst. Ausgehend von einer Startseite konnte hier zu drei unterschiedlichen Panoramen navigiert werden, welche den „Blick in die Grube“ von besonders eindrucksvollen Plätzen aus den Gruben 1 und 3 ermöglichte.

9. Konservierung der Steinpanzer

Die Arbeit im Jahr 2006 konzentrierte sich auf die praktische Umsetzung des Restaurierungskonzepts. Dafür wurden verschienen Partien von Steinpanzern für die museale Präsentation fertig gestellt. Mit Hilfe der Lasertechnologie konnte die bisherige Präparation des Objekts optimiert werden: Man entschloss man sich, das Objekt auf einer durchsichten Plexiglasplatte zu präsentieren. Sie sollte es für den Betrachter ermöglichen, auch die Objektunterseite und somit das komplizierte Verknüpfungssystem der Drähte, sichtbar zu machen. Um eine sichere Auflage zu ermöglichen, musste eine passgenaue Auflage hergestellt werden. Dafür wurde die Auflagefläche mit einem Laserscanner vermessen. Mit Hilfe dieser Daten konnte eine Vakuumtiefziehform gefräst werden. Diese ermöglichte das Tiefziehen einer Acrylglasplatte mit einer Stärke von nur 2 mm. Die Platte mit eingebettetem Fragment wurde auf 4 Tragesäulen über einem Spiegel positioniert und konnte so beidseitig betrachtet werden.
Die Restaurierung erfolgte in München in Zusammenarbeit mit chinesischen Kollegen. Zunächst wurde eine exemplarische Dokumentation des Fragments erstellt. Erfasst wurden Bestand, Zustand und Restaurierungsmaßnahmen. Steinplättchen und Bronzedrähte wurden mechanisch mit Blaseballen und Pinseln gereinigt. Die Reinigung der Erdkrusten erfolgte mittels Ultraschallmeißel und Mikroschleifgerät, wobei sich besonders das Schleifgerät bewährte. Aufgrund der kleinen Schleifscheiben war ein sehr detailliertes Abarbeiten der Auflagen möglich. Da bei dem Schleifvorgang kaum oberflächlicher Druck ausgeübt wurde, bleiben auch extrem fragile Steinpartien unbeschadet. Die Festigung der stark pulverisierten Steinpartien erfolgte mit einem elastifizierten Steinfestiger auf der Basis von Kieselsäureester (Remmers 300E) behandelt. Das Festigungsmittel wurde mit einer Pipette so lange aufgetröpfelt, bis das mürbe Material keine Flüssigkeit mehr aufnahm Zum Kleben formschlüssiger Bruchkanten wurde Mowital H15-B30 in Ethanol (30%) benutzt. Bei abgeriebenen Bruchkanten wurde der Lösung 60% Glasplättchen (Größe 15 µm) als Füllstoff zugegeben und mit Pigmenten grau eingefärbt. Zur Vorisolierung wurde die Klebefläche drei Mal mit einer 1% Lösung, nass in nass bestrichen.
Ein weiterer Schwerpunkt lag auf der Literaturrecherche zum Thema Steinbearbeitung am Beispiel von Jade. Nachdem die Herstellungstechnologie der Steinpanzer weitgehend untersucht wurde, blieben Fragen offen. Die Oberfläche der einzelnen Plättchen zeigen keinerlei Bearbeitungsspuren von Sägeblättern oder Rotationsscheiben, die dazu dienten, den Stein aufzuspalten. Auch die Entdeckung der antiken Werkstätten für Steinpanzer, in welchen verschiedenste Werkzeuge und unfertigen Plättchen gefunden wurden, konnte diesbezüglich keinen Aufschluss geben. Zudem blieb die Literaturrecherche zur Bearbeitung von Kalkstein im Alten China erfolglos. Aus diesem Grund wurden Literaturangaben zur Bearbeitung von Jade konsultiert und ausgewertet. Jadebearbeitung hat in China eine jahrtausendlange Tradition. Es konnte davon ausgegangen werden, dass die Bearbeitungstechnik des äußert zähen Gesteins durchaus auch auf den um ein vielfaches weicheren Kalkstein übertragen wurde.

Stand der Arbeiten im Vergleich zum geltenden Arbeits-, Zeit- und Finanzierungsplan, Gründe für eventuelle Änderungen

Arbeits- und Zeitplan

Der Stand der Arbeiten entspricht den Vorgaben der Vorhabensbeschreibung.

Finanzierungsplan

Die Finanzierung der Forschungsarbeiten im Jahr 2006 erfolgte nach den Vorgaben des Finanzierungsplans. Einzelheiten sind der Jahresabrechnung aufgelistet.

Haben sich die Aussichten für das Erreichen der Vorhabensziele geändert? Wenn ja, welche Probleme sind entstanden?

Die Vorhabensziele konnten erreicht werden.

Haben sich die Vorhabensziele geändert? Wenn ja, warum?

Die Ziele des Vorhabens haben sich nicht geändert. Die Forschungen in den Bereichen Terrakottarestaurierung, Polychromie der Tonkrieger, Steinpanzer und virtuelle Rekonstruktion wurden planmäßig fortgesetzt. Die Vorhabensbeschreibung ist im Antrag für die Projektphase 2004 bis 2006 enthalten.

Sind inzwischen Ergebnisse anderer Arbeitsgruppen bekannt geworden, die für das Vorhaben von Bedeutung sind? Wenn ja, welche?

Trifft nicht zu

Sind für Vorhabensergebnisse
- Patente angemeldet worden?
- Erfindungen in Anspruch genommen worden?
- Neuerungen und / oder Verbesserungen bereits gemachter Erfindungen angefallen?

Wenn ja, bitte spezifizieren.

Trifft nicht zu

Liste eigener Publikationen von Vorhabensergebnissen
(bitte Sonderdruck gemäß Zuwendungsbescheid beifügen)

Publikationen

Die Publikationen befinden sich im Ausstellungskatalog und in der Publikation des BMBF „Der Vergangenheit eine Zukunft geben“. Die Publikation des IIC Kongresses kann auf Wunsch in Kopie angefordert werden.

‘Xi’an – Kaiserliche Macht im Jenseits. Grabfunde und Tempelschätze aus Chinas alter Hauptstadt’. Ausstellungskatalog der Kunst- und Ausstellungshalle der Bundesrepublik Deutschland in Bonn. Philipp von Zabern, Mainz 2006. 5 Essays:

Yuan Zhongyi, Rolf Snethlage, Die Herstellung und Zerstörung der Tonkrieger des Ersten Kaisers Qin Shihuangdi, p. 165-168

Catharina Blänsdorf, Xia Yin, Die Terrakottaarmee – Befunde und Analysen für eine originalgetreue Rekonstruktion der Farbigkeit, p. 169-173

Sandra Bucher, Duan Qingbo, Wang Dongfeng, Ein Puzzlespiel aus Stein – Herstellung, Bergung und Restaurierung der Steinpanzer aus der Grabanlage des Qin Shihuangdi, p. 174-176

Alexander Schmid, Daniela Bathelt, Ingo Rogner, Christoph Herm, Ulrike Ring, Zhou Tie, Zhang Zhijun, Die Erhaltung wassergesättigter Lack- und Farbschichten auf den Terrakottafiguren – Eine große Herausforderung für die Chemie, p. 177-179

Felix Horn, Die virtuelle Retusche – Rekonstruktion verlorener Farbschichten am 3D-Modell, p. 180-184

Objektbeschreibungen von C. Blänsdorf, Xia Yin und S. Bucher. Panoramafotos von F. Horn.

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Poster: Felix Horn, '3D Models of Terracotta Warriors – Virtual colour reconstruction of the polychromy'

21. 6. Themenführung „Restaurierung und farbliche Rekonstruktion der Terrakottafiguren" in der Ausstellung in Bonn durch Frau Blänsdorf, sowie drei weitere Führungen auf Anfrage am 21. und 22. 6.

1. 9. – 21. 10. Verschiedene Führungen durch Mitarbeiter des China-Projektes in der Ausstellung „Chinas Terrakottaarmee" im Bayerisches Landesamt für Denkmalpflege München