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Survey, Modelling and Scientific Integrated Researches for Restoration and Enhancement of Cultural Heritage – A Study of the Bas-Relieves of the *Camerino dei Marmi di Alfonso I* for the *Estense* Castle

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Abstract

The research project described here concerns the high-definition 3D survey of the morphological and dimensional features of the collection of the marble bas-relieves carved at the beginning of the XVI century by the sculptor Antonio Lombardo to adorn the so-called "Camerino dei Marmi di Alfonso I" or "Camerino di Alabastro" in the Estense Castle of Ferrara. The sculptures remained in their former place until the end of the XVI century and at present they are one of the masterpieces of the Hermitage Museum in Saint Petersburg. The research project started in March 2004 in occasion of the exhibition entitled "Il Camerino di alabastro: Antonio Lombardo e la scultura all'antica" and held in the Estense Castle of Ferrara. At the end of the exhibition, in June 2004, the bas-relieves returned to Saint Petersburg; the great artistic and historical importance of these bas-relieves and the limited time in which these artefacts were in Ferrara made the advanced 3D survey a useful methodology to build up a data base where to collect metric, morphological, geometrical and surface data. The 3D digital scanning in fact was integrated with further researches and instrumental diagnostic analyses aimed at the comprehension of the significant features and surface specifications of the marbles in order to create an integrated system of dimensional data and surface morphological aspects as a data system organized in the form of a 3D hyper-textual data base.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation – Digitizing and scanning

1. Introduction

In March 2004, during the exhibition entitled *Il Camerino di alabastro: Antonio Lombardo e la scultura all'antica* and held in the *Estense* Castle of Ferrara, a research project started about the three-dimensional survey of marble bas-relieves carved at the beginning of the XVI century.

The bas-relieves were ordered by the Duke of Ferrara Alfonso I d'Este and they were made between the 1507 and the 1515 by the sculptor Antonio Lombardo; the sculptures remained in their former place until 1598, when the rule of Ferrara was transferred to the Papacy. After being moved to different locations the bas-relieves were taken to Saint Petersburg, at the beginning as a part of a private collection and later as one of the masterpieces of the Hermitage Museum. At present the bas-relieves are kept at the Hermitage Museum in Saint Petersburg. The research project involved the DIAPReM Centre (Development of Integrated Automatic Procedures for Restoration of Monuments) of the Department of Architecture of the University of Ferrara in collaboration with the Province of Ferrara, the Saint Petersburg Hermitage Museum and the *Opificio delle Pietre Dure* of Florence.

The research project set up by the DIAPReM Centre is related to the studies promoted by the Province of Ferrara and aimed at the restoration and re-establishment of the rooms in the ducal residence of the *Via Coperta*, which hosted the bas-relieves. For the whole of the artefacts, twenty-five bas-relieves, a high-definition survey of the morphological and dimensional features was carried out with a high metrical accuracy by means of the 3D scanning technology.

The instruments used for the 3D digital scanning

of the sculptures, the Konica Minolta Vivid VI-910, a triangulation-based laser scanner, and the Leica HDS 2500 and HDS 3000 laser scanners, based on the time of flight technology, were integrated with a high resolution photographic survey and further methodologies of analysis concerning historical researches aimed at the comprehension of the significant features and surface specifications of the marbles; both direct and instrumental diagnostic analyses were also carried out with the aim of identifying morphological aspects, macroscopic alterations linked to degradation, former interventions of restoration, ancient and modern stratigraphies, original marble manufacturing, etc. The instrumental analyses concerned stratigraphical and mineralogical studies, analyses by means of microscope, spectrophotometer and fluorescence UV. At the end of the data survey some 3D physical models of the bas-relieves were built by using a plaster powder prototyping technique. This methodology, when referred to stone materials, allows surface treatments like the definition of chromatic nuances by using the same techniques used for the restoration of the actual stone surfaces. For this specific branch of the research project a co-operation with the *Opificio delle Pietre Dure* of Florence was set up. The research is, therefore, oriented to the creation of integrated systems of dimensional data and surface morphological aspects shown in 3D form for the analysis and restoration of artistic assets, as a data system organized in the form of a 3D hyper-textual data-base network which may be consulted online. Such studies, still in progress, will allow to re-visit the historical events these bas-relieves went through; the knowledge of their past history is in fact the starting point for future enhancement projects and for tighter relationships between Ferrara and Saint Petersburg.

2. Historical notes

The bas-relieves were ordered by the third Duke of Ferrara, Alfonso I d'Este, to adorn the so-called *Camerino di Alabastro*, an evocative and "mythical" place of the Reinaissance of Ferrara wanted by the Duke in the *Via Coperta* of the Castle. The building of the Castle of Ferrara, known as Castle of "San Michele", started in 1385 as a defensive measure by order of Niccolò II. It was the seat of the Estense family, that ruled the city from 1264 to 1598, when the rule of Ferrara was transferred to the Papacy.

Under the Duke Ercole I, who ruled from 1471 to 1505, an expansionistic politics started and in this period the Castle changed its defensive rule into a magnificent residence. In 1471 a series of restoration works started also at the so-called *Via Coperta*, an evocative and charming building that connected the Castle with the Ducal Palace. At the beginning the *Via Coperta* was a simple connection between the two buildings to allow a safe passage from the Ducal Palace to the courtyard of the Castle. In 1471 the arches that supported a raised passage were built. The structure was designed to replace the previous and unsafe wooden bridge

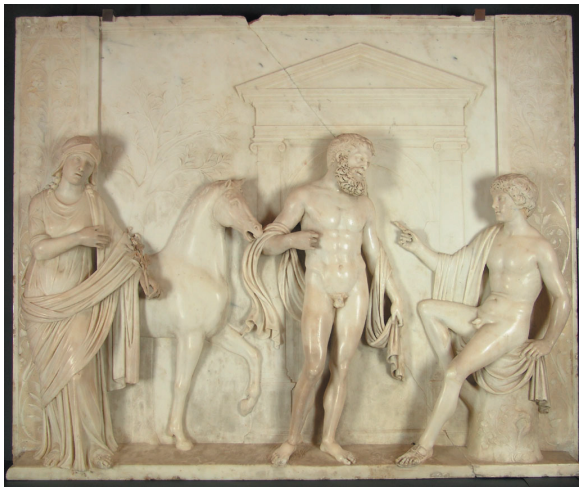

Figure 1: *Image of one of the marble figurative bas-relieves named "La contesa tra Minerva e Nettuno per il possesso dell'Attica".*

and it was modified, enlarged and changed in its destination until it was turned into the direct connection between the Duke and the Duchess rooms when the *Via Coperta* became an embattled open passage in 1473. In 1499 painted and adorned walls were built and also the upper level of the *Via Coperta* was covered. On this cover a close passage was built. In 1501 started the arrangement of the rooms of the *Via Coperta* as places to collect artistic masterpieces. The duke Alfonso planned to build a private room and a private studio, a room covered by precious marbles and bas-relieves. So the structure of the *Via Coperta* was further enlarged and a room with a pavilion roof was built. The rooms that formed Alfonso's private place collected artistic masterpieces and in this collection the bas-relieves of Antonio Lombardo were included. There were few witnesses of these magnificent rooms because of the dismantlement and the dispersion of the art collection that followed the transfer of the rule of Ferrara from the Estense family to the Papacy, the fire that destroyed the rooms in 1643 and the inappropriate use of this building in the following centuries [Cer04] .

2.1 The engraving of the bas-relieves of the *Camerino* and the history of the collection

Antonio Lombardo was probably born in 1458 and, as is known, he was a famous sculptor, working with his brother Tullio, since 1475. After working in Venice, Padua and Mantua, he arrived at Ferrara in 1506 and started to work on the *Camerino* in 1507. Probably the works on the *Camerino* stopped because of the war of the Cambrai alliance and they started again in 1511 and kept working until 1515 when the sculptor died.

The artistic training of Antonio Lombardo was influenced by the classical Roman sculpture concerning the proportions of the parts and the anatomy of the engraved figures, the classical draping and the details as armours and footwear.

These characteristics made this artistic work unique in the framework of the Italian sculpture of the end of the XV century. The bas-relieves are characterized by typical details of the ancient classical sculpture like acanthus leaves, naturalistic elements, heraldic and allegorical figures. However close examinations and deep studies about iconographical meanings of the bas-relieves and about the main topics of the *Camerino di alabastro* were carried out by scholars and at present many different interpretations coexist, but it is a shared opinion that this collection represents a very important document of the Italian humanistic culture. In addition to the artistic exceptionality of the bas-relieves, the history of the collection and the discussion about the former place and the number of pieces increase the importance of the collection. In fact, after being moved to different locations (*Palazzo dei Diamanti* in Ferrara, a Castle in the dukedom of Modena and Paris in private collections) the bas-relieves collection was bought by a Russian noble man in 1893 and placed in a museum of Saint Petersburg. In 1917 all the private collections and all the art works exhibited in museums were collected at the Hermitage Museum of Saint Petersburg; the bas-relieves of the Camerino di alabastro were transferred in 1931 [Cer04]. The bas-relieves returned to Ferrara in 2004, after being moved from their former place four centuries ago, in occasion of the exhibition entitled *Il Camerino di alabastro: Antonio Lombardo e la scultura all'antica* and held in the *Estense* Castle.

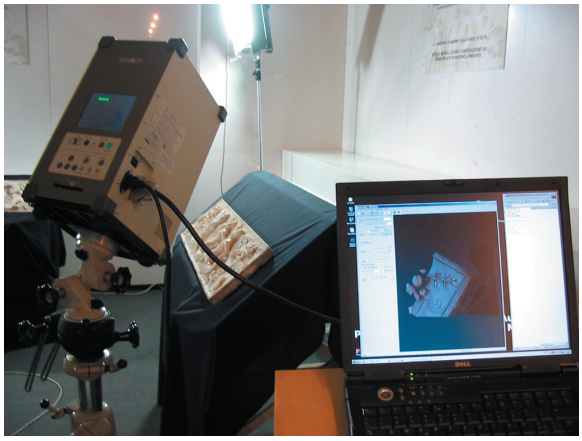

Figure 2: *A survey equipment was set up to carry out the research during the opening time of the exhibition in the Estense Castle.*

3. From the historical knowledge to the scientific researches for the comprehension of the conditions of the marble surfaces

The research project started with the historical studies concerning the bas-relieves and it developed through the analyses of the surfaces and of the patina, the study of the original marble manufacturing and of the colorimetric data. These researches were aimed at the evaluation of the conditions of the marbles and at the hypotheses about the former place of the bas-relieves.

Before and during the three-dimensional survey, historical researches and direct surveys were carried out.

By means of the laser scanner technology an experimentation about the reflectance data started. The reflectance data are acquired by the laser scanner as well as the metric data. Reflectance is the intensity of the laser beam at the moment of the "impact" with the object to be surveyed and it allows the visual recognition of the different materials, of the surface specifications and of the marble state of conservation.

This kind of investigation was performed by processing the reflection data and was followed by a more detailed analysis of the colorimetric data based on spectrophotometer techniques.

Moreover analyses by means of the ultraviolet fluorescence were carried out. In particular the ultraviolet fluorescence analysis shows the emission of visible light in consequence of the selective (partial) absorption of an ultraviolet incident radiation; the wave-length of the emission and the consequent colour of the emitted light depend on the chemical and physical specifications of the material; therefore different materials could have different colours and intensity of fluorescence.

Figure 3: *Image of the analysis carried out by means of the ultraviolet fluorescence. Different materials or other marble specifications can have different colours and intensity of fluorescence.*

This technique was integrated with microscopic direct observations by using both indirect and side light in order to identify and to understand the significant features and surface specifications of the marbles, the morphological aspects, the macroscopic alterations linked to degradation, the former interventions of restoration, ancient and modern stratigraphies, original marble manufacturing, etc.

By means of the ultraviolet fluorescence analysis it is possible for example to identify pigments, colouring-matters and patina.

In addition to the researches mentioned above some further not-destructive analyses were carried out both on the marble surfaces and on the collected samples. In particular, statigraphical analyses with optical microscope and SEM and mineralogical and spectrophotometric analyses were carried out.

Figure 4: *The model obtained by the Leica HDS 2500 laser scanner in the visualization of cloud of points in "false colours".*

Figure 5: *Four bas-relieves were too big to be removed from the position in which they had been put for the exposition, so they were scanned in the exhibition area by moving the instruments on purpose.*

On the basis of the results obtained by the direct survey and the ultraviolet fluorescence analysis, some homogeneous areas (for materials and conservative conditions) of the surfaces were chosen to compare the previous results with a more detailed analysis of the colorimetric data based on spectrophotometer techniques. The spectrophotometers used for this research were the Konica Minolta CM 508i and the Konica Minolta CM-2600d; this one in particular acquires the closest band spectrum to the ultraviolet and the infrared. The spectrophotometer acquired data from 360 nm up to 740 nm, so that it was possible to identify the fluorescence UV in the reflectance spectrum. The data acquired by means of the spectrophotometer will be stored in a digital and paper database aimed at the:

- periodical monitoring of the sample areas to check, first of all, possible colorimetric alterations;
- not-destructive identification of ancient patina;
- progressive checking of the interventions of restoration.

The macroscopic direct researches carried out by Dr Gian Carlo Grillini allowed the identification of the marble of the bas-relieves as *marmo lunense*, probably the so-called *marmo di Carrara*. In one of the main figurative bas-relieves, named *La fucina di Vulcano*, there are also some other kinds of precious marble, probably alabaster and *pavonazzetto*.

4. The 3D survey – The previous works and the survey procedure setting up

The survey went on during all the time the bas-relieves were exhibited in the *Estense* Castle; therefore a survey apparatus was set up to carry out the research during the opening time of the museum and that allowed the visitors to take part in the survey procedures and in the research activities promoted by the Province of Ferrara. Thanks to the museum staff the bas-relieves, two at a time, were moved from their position in the exhibition area and put on 45° inclined easels in order to be surveyed. This procedure was carried out for all the bas-relieves with the exception of four pieces that were too big to be removed from the position in which they had been put for the exhibition. So these bas-relieves, two decorative and two figurative, were scanned in the exhibition area by moving the instruments on purpose.

Scan of any 3D object requires the acquisition of many shots of the artefact from different viewpoints; in this way it is possible to gather geometric information on the whole surface. This procedure is needed especially for the scanning of the bas-relieves, very rich in decoration. According to the purpose of the research project the 3D survey of the sculptures was carried out by means of the Konica Minolta VI-910 laser scanner. This instrument in fact allows to scan the details with the highest possible precision; in order to scan the bas-relieves it was put at a fixed distance of 60 cm from the object to be surveyed. Each detail of the sculptures was scanned five times: once frontally and twice from the right and from the left side with an angle of 45°. Than the bas-relief was turned upside-down to repeat the same scanning procedure.

4.1. The acquisition procedure

The device used for the digital scan of the bas-relieves is a Konica Minolta VI-910, a triangulation-based laser scanner. A light emitter produces a thin red laser sheet directed to the surface to be surveyed in order to acquire all the points allowed by a selected range. This instrument works in a range of scan from 7x7 cm up to 1.1x1.1 m. The scans were carried out by using a telephoto lens with a 0.5-1 mm accuracy for each scan. Up to 250 high definition shots were scanned for each bas-relief so that even the smallest details could be surveyed. In the meantime the scan registration started; while an operator went on scanning, another member of the team registered groups of 10-15 shots in order to build up the digital model without working on too heavy files.

This scanning procedure was integrated by using the Leica

HDS 2500 laser scanner, an instrument usually applied in architectural field and used in this research project in order to check the metric data acquired by means of the Konica Minolta VI-910 and to examine the marble surfaces. In fact, a branch of the analysis concerning surface specifications was performed by processing the reflection data acquired by means of the 3D laser scanner. The Leica HDS 2500 is based on the "time of flight" technology: the measure of the position of each surveyed point is based on the time of flight, which is the time elapsed between the emission of the laser beam and its reflection by the object to be surveyed. The reflectance data are acquired as well as the metric data; reflection values allow the visual recognition of the different materials.

The reflectance data are also related to the angle between the laser and the object to be surveyed; therefore the scanner was placed at 150 cm height from the ground level and at a fixed distance of 300 cm from the bas-relieves to be surveyed; the instrument was able to be slid on a trolley with wheels in order to keep the distance unchanged during the scanning of the bas-relieves.

General shots of the whole surface of each bas-relief with 1x1 cm grid were integrated with denser scans of a 0.5x0.5 cm grid to acquire the more relevant details.

A Kodak color map and two targets of reflectance material were put in each scan view in order to check the colorimetric data and to calibrate the maximum range of reflectance.

5. Registration and modelling

During the development of the research project the registration procedure was continuously verified and improved. The scans were carried out in regular successions and all the acquired data were checked. Before the automatic registration procedure started, all the shots were re-named in order to get regular sequences of shots, but the complexity of the scanned objects and the large number of shots stopped the automatic registration frequently. Therefore, groups of shots were registered by means of the homologous point method in order to accelerate the procedure and to obtain easily managing files with the same orientation reference in the space. In this way, by opening the single range maps in the automatic registration software the complete registered model was obtained; the connections among shots avoided the breakdowns of the automatic registration procedure that, in this way, was principally aimed at optimizing the shots alignment before the merging procedure. As an example, we present the procedure performed by ISTI-CNR used to obtain the 3D digital model of the bas-relief named *Il trionfo di Ercole*. The scan of this sculpture was possible by means of 182 range maps and the sampled surface of the bas-relief was represented by 41 million (M) points. The steps to build up the geometry of the model were the following:

- range maps alignment to transform them into a common coordinate space; after being aligned, the sections of the range maps were geometrically overlapped;
- range map merging to build a single triangulated surface;
- mesh simplification to reduce the complexity of the

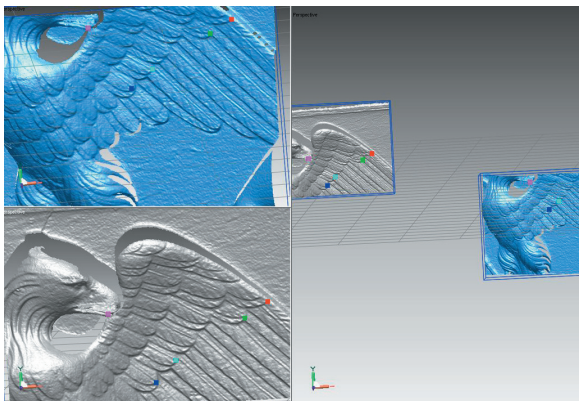

Figure 6: *The pre-registration procedure. Groups of shots were registered by means of the homologous point method with the same spatial orientation reference. The complete registered model was obtained by opening the single range maps in the automatic registration software.*

Figure 7: *The result after the group assembling of shots.*

Figure 8: *For each bas-relief all the single shots were placed in the reference space and saved again in order to be imported in the alignment software.*

obtained digital model.

The processing of the scan set was performed with the ISTI-CNR scanning tools. The range map mesh alignment was performed by means of the *MeshAlign v.2*, a semi-automatic scanning tool that allows a first approximate manual alignment followed by an automatic precise registration. The alignment was carried out with high accuracy even if the model included large areas geometrically not enough detailed, so that the processing required a long time.

The 3D survey was carried out with the highest possible density of sample (with a distance of about 0.3 mm between two sampled points); therefore each shot covered very small areas of the bas-relief and many shots hardly included the background marble areas, not engraved and almost flat, very hard to be aligned.

The range map merging was performed by *MeshMerge*, a software (scanning tool) that allows to merge a large number of range maps with a high metrical precision and to cover eventually remained small not sampled areas. Due to the high-density inter-sampling distance used in the scanning (0.3 mm), the final model produced - after merging - is very complex (25M triangle faces covering an area of about 1 square meter). Most applications require this representation to be reduced for easy managing. The *MeshSimplify* scanning tool (able to manage hundreds of millions of triangles) allows to simplify the complex triangles mesh; in fact, it allows to run simplification running on external memory and to proceed through easy simplification steps based on the "collapse" of the triangulated surface's edges. The initial 25M triangles mesh was simplified to produce a 6M faces model of the bas-relief; this procedure required about half an hour of work on a common Pentium4 reducing the mesh from 25M to 6M faces. The number of 6M of faces was chosen in order to prototype the model by means of a three-dimensional printer; this number of triangles is sufficient for printing the surface of the solid model with a proper reproduction accuracy. In the end, the visualization of the model was carried out by means of *Virtual Inspector*, a visualization system that allows to inspect a large complex 3D model at interactive frame rates. By using the *Virtual Inspector* system it is possible to change the viewpoints, the zoom tool, the position and the direction of the light source; in particular, the possibility to change the light position is very important because it is possible to simulate in real time the glazing light (*luce radente*) effect which is very often used in real inspection to enhance the visualization of the artifact.

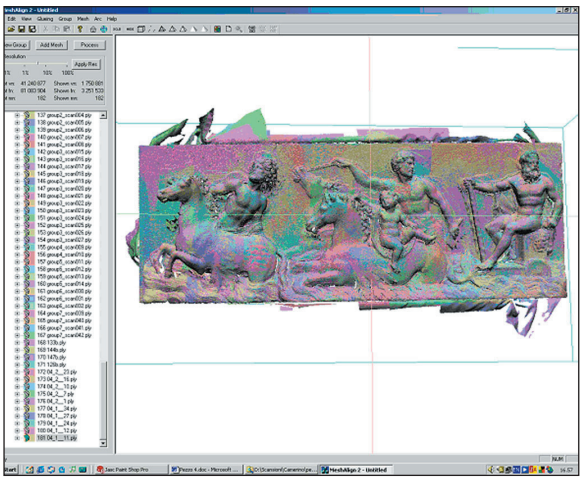

Figure 9: *The range map mesh alignment was performed by means of MeshAlign, a scanning tool performed by ISTI-CNR.*

6. The bas-relieves physical reproduction

The continuous development and updating of the most widespread instrumental techniques allow a wider use of them in activities related to the branch of the Cultural Heritage. Therefore the DIAPReM Centre developed research projects aimed at connecting the 3D laser scanner survey to the rapid prototyping technology (to turn the 3D digital data into physical data) and at experimenting a prototyping technology suitable in the artistic and architectural field. While the building up of a solid model by means of traditional techniques is based on the removal of material, the Rapid Prototyping technology works by means of a "layer by layer" procedure starting from a 3D mathematical digital

Figure 10: *Image of the model obtained by the merging procedure.*

model. In this way a lot of different materials (solid, liquid, laminar, etc.) can be used to produce the solid models. In artistic and architectural field the physical reproduction of original artifacts with detailed decoration, surface treatments or particular surface specifications is often required; so the research needed a 3D printer able to produce models very similar to the original ones. The Z406 ZCorporation is a 3D printer using plaster powder, a material commonly used in the past to manufacture models or mouldings. This prototype technique is based on the 3D printer technology patented by the M. I. T. The software linked with the 3D printer imports 3D digital models in VRML or STL file extension and convert them in layers with thickness from 0.075 mm up to 0.25 mm; this procedure, called slicing, determine the precision of the prototype. The layers are printed from the base to the top in order to obtain the complete solid model. By using this 3D printing methodology it is possible to build solid models with a standard of precision exactly similar to the acquired data one. After being completely dried up, the plaster solid model are injected with an acrylic resin. The material which the solid models are made of, allowed to start experimentations concerning the colouring of the surfaces according to restoration theories and techniques. In particular this 3D printing methodology, when referred to stone materials, allows surface treatments like the definition of chromatic nuances by using the same techniques used for the restoration of the actual stone surfaces. The high precision in the reproduction of the solid model and the accuracy of the surface treatment allow to obtain models which turned out to be very similar to the original ones. For this specific branch of the research project a co-operation with the *Opificio delle Pietre Dure* of Florence was set up.

Figure 11: *Before the 3D printing procedure, by means of Z406 ZCorporation technology, the model was divided into 15 parts. The model was 8 mm extruded to the interior side.*

7. Conclusions and future development

The described procedure can be extremely powerful in helping the historical analyses, checking and monitoring the sculptured items and setting up interactive metric data bases able to provide at any time information about the surveyed objects. In particular the precision, the acquisition speed of metric data and the opportunity to use these data to build 3D geometrical and physical models are very advantageous features which encourage the development of such integrated survey techniques. The results of this first experimentation have been already presented to the public with a thematic exposition organized by the DIAPReM Centre with the Province of Ferrara in the occasion of the latest *Fiera del Restauro* (an international restoration event) held in

Ferrara in April 2005; the exposition presented both virtual representations of the bas-relieves and of their details (realized by using the data base acquired during the 3D survey) and the details carried out by prototyping, so it has been possible to exhibit both solid and virtual representations of the artefacts at the same time and in the same place, suggesting new and interesting setting in museum dressing. The results obtained until now have shown that it is possible to organize data bases of a great variety and nevertheless complementary to one another, so as to allow a global view of the problem. The great artistic and historical importance of these bas-relieves

Figure 12: *One of the part of the solid model inside the Z406 ZCorporation 3D printer.*

and the limited time in which these artefacts were in Ferrara made the advanced 3D survey a useful methodology to build up a data base where to collect metric, morphological, geometrical and surface data; such a data base could be the main reference for studying the artefacts in the future and for implementing realistic simulations of restoration and maintenance interventions. Such studies, still in progress, will allow to re-visit the historical events these bas-relieves went through; the knowledge of their past history is in a fact the starting point for future enhancement projects and for tighter relationships between Ferrara and Saint Petersburg.

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