Multi-scale 3D Digitization at Nidaros Cathedral:

from archiving to large-scale visualization

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Abstract: 3D scanning in cultural heritage (CH) is used in most cases either for the faithful generation of digital models of CH objects or for visualization purposes. In this paper, we move a step further and concentrate on documenting the requirements and our experience in 3D scanning for alternative CH application scenarios, where digitization is not the end product, but rather the means to augment the existing information and acquired data. In our work, which is part of the PRESIOUS EU-funded project, we aim at utilizing and inventing new methodologies and technologies for the prediction of geometric information on CH data, ranging from the digitization process itself to geometric reassembly, shape prediction and simulation/prediction of monument degradation. To this end, the scanning requirements of the different processing tasks are given, including specialized high-definition scans for erosion measurement, meso-scale digitization for reassembly as well as for the visualization of the results. Important practical lessons are drawn and the actual digitisation pipelines of state-of-art 3D digitisation technologies are given. A practical discussion summarizes our multi-scale digitisation experience (giving the accuracy, required time and resulting data size that we observed), mainly drawn from the digitization activities at the Nidaros Cathedral, Trondheim, Norway.

Keywords: 3D digitisation, multi-scale, cultural heritage.

Introduction and Motivation

Modern archaeology can leverage a large contingent of Visual Computing tools in order to dramatically increase efficiency and make yesterday's dreams a reality. First, in archaeological *documentation*, textual descriptions and images can now be augmented with textured 3D scans of objects. Such scans allow the realistic virtual handling of objects from any corner of the world, the closest-to-reality archiving method and even the 3D printing of copies of these objects. Second, several aspects of *processing* a collection of fragments can be performed by computer, relieving the archaeologist from some tedious tasks; for example, a digitized collection of 3D fragments can be automatically checked for potential matches (PAPAIOANNOU et al. 2002). For large collections, this process soon goes beyond the capacity of the human memory.

However, the first step required in order to use such tools is the 3D digitisation of the objects of interest. Much research effort has been directed to this problem in computer science and related fields and several 3D digitisation attempts have been made. Although huge steps have been taken, the general feeling still remains that 3D digitisation is a difficult and costly process.

In this paper we outline a pipeline for the digitisation of cultural heritage artifacts in order to address the highly diverse requirements of procedures related to the preservation of Cultural Heritage (CH) content, ranging from digital archiving to geometric processing and real-time visualization. It is worth noting that up to now, most digitisation processes strived for maximum fidelity at any cost, since the digitisation process aimed strictly at faithful reproduction of the CH artifacts. The factors that affect the choice of technology are numerous and include the size of the object, the required accuracy, the portability of the scanner, its cost and the amount of training required (PAVLIDIS et al. 2007).

We identify the surface reconstruction requirements of the digitisation procedure, in the context of computer-assisted restoration, and describe our experience with the 3D digitisation of fragments related to the Nidaros Cathedral in Trondheim, Norway. Best practices are identified and the actual manpower involved is estimated. We also describe the PRESIOUS EU project within which the 3D scans took place. The digitized collection is available online at http://presious.eu.

The PRESIOUS Project

The scanning experience described in this paper was gained within the PRESIOUS Project, so a few words about PRESIOUS are in order. PRESIOUS is an FP7 EU-funded STREP running from 2013 to 2016. It aims to exploit Europe's strategic advantages in Cultural Heritage (CH) in order to develop products that will make it a leading player. Breakthrough ICT solutions to the following challenges are sought: a) the difficulty and inefficiency of the 3D digitisation process, b) the quantification of Stone monument degradation, and c) the reconstruction of objects from large numbers of constituent fragments that may be worn, immovable, dispersed or incomplete. Using a common core of geometric processing, analysis and retrieval methods, PRESIOUS aims at predictive geometric augmentation technology with the following scientific objectives (Fig. 1):

a) **On-the-fly auto-completion for 3D digitisation** that exploits similar template models to allow gradual shape prediction from partially digitized objects. Such a system will potentially open a whole new range of possibilities for decreased acquisition times and simplified procedures.

b) **Estimation and prediction of monument degradation**. The project will investigate models for forward and inverse erosion prediction based on targeted high-accuracy surface scans, allowing one to essentially move the artefact's surface condition "back and forth in time" and visualize and measure the dynamic state of the deteriorating object.

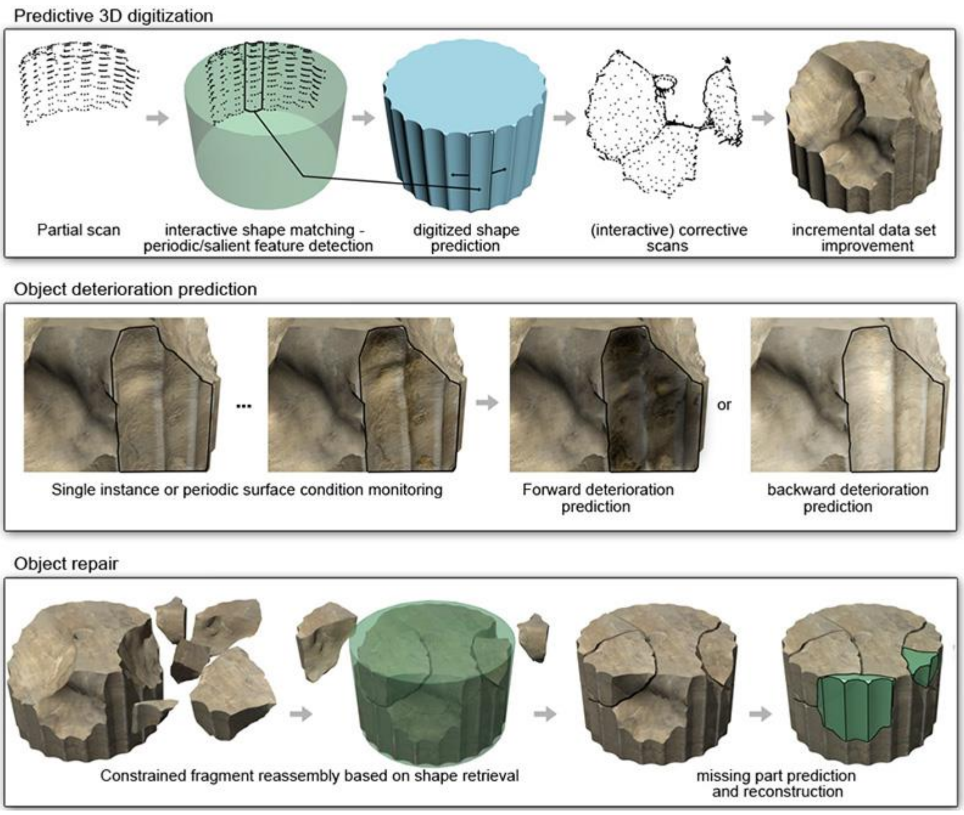

Fig. 1 - Overview of the PRESIOUS project objectives.

c) **3D CH object repair**. Automated, predictive reconstruction from fragmented CH objects that goes beyond reassembly by proposing the synthesis of missing parts using geometry auto-completion. This will aid the physical and virtual restoration process.

The Nidaros Fragment Collection

Most of the larger cathedrals have a collection of old building blocks, sculptures and gravestones – a Lapidarium - that has been collected over the centuries. The Restoration Workshop of Nidaros Cathedral has one of the largest such collections of medieval building stone in Europe, with over 5000 fragments.

In 1531 the cathedral was damaged by a large fire. Some of the damaged parts of the church were repaired and rebuilt, while others were in ruins until the restoration of the church began in 1869. During the restoration it was discovered that large amounts of stone and sculpture that had fallen down were later used as rock fill in masonry built in the years after the fire. These stones were documented and preserved, and in recent restoration work used as a basis for reconstruction of the damaged parts of the cathedral. Although some stones were partially destroyed, they could nevertheless be an important historical source. The stones were collected, systematized and stored in the basement of one of the large wooden buildings in the Archbishop's Palace, next to the cathedral.

In 1983 there was a disastrous fire in the Archbishop's Palace, and the building that housed the stone collection was totally destroyed. The fire also led to significant damage to the stone collection itself. The storing racks collapsed and the stones fell down; in addition heavy items that were stored in the floors above fell on the top and broke many of the stones. Finally, the heated stones cracked when cold water was poured on to stop the fire. In the years after the fire, extensive efforts were made to organize and catalogue the material again.

Some of the stones were also tried to be manually puzzled together. There is still however a lot of work to be done if one wishes to reconstruct the collection. The entire collection was moved to Dora in 1996 (see Fig. 2), an old submarine bunker from World War II, in Trondheim, Norway, and stored under fireproof conditions. This is the place where the scanning of the fragments in our repository took place. The only exception is the tombstone (5 pieces) which was scanned at the Crypt of the Cathedral.

We selected a total of 60 pieces from 7 distinct collections that represent typical items from Dora. We ensured that some of the selected fragments match with some others, in order to later test our automatic reconstruction methods. The digitized fragments are publicly available at:

http://www.presious.eu/resources/3d-data-sets

Fig. 2 - View from inside the storage facility of the Nidaros Cathedral fragment collection at Dora, Trondheim, Norway.

Digitisation Requirements for Archiving, Geometry Processing and Large Collection Visualization

In the PRESIOUS project, the digitized three-dimensional content is not by itself the end product of our processing systems, since we aim at producing new information by analysing the CH objects. Therefore, representation fidelity is not the single most important factor for choosing a digitization method or technology. In fact, as will be explained below, for certain geometry processing stages (e.g. fragment matching), high-resolution scans can severely hinder the process in terms of speed and computational resources, without providing additional, exploitable information in the geometric processing and analysis stages that follow the digitization (see example in Fig. 6).

The digital models are used for a) erosion evaluation and surface degradation prediction, b) fragment reassembly via geometric matching, c) virtual measurements and experimentation in a fully interactive 3D workspace, d) virtual collection showcases and of course e) digital archiving. We discuss below the different requirements of each target application and how this affects the digitization and post-processing procedures.

Erosion Evaluation

In order to be able to computationally evaluate the erosion of monuments and simulate the progress of surface degradation, first of all, an accurate digitization of the damaged surface areas is required. PRESIOUS will investigate computational methods for predicting the damage of the exposed surfaces by taking into account both the chemical modelling of the material and the changes in the meso-scopic structure of the surface. In order to achieve the latter, we employ *differential scanning*, i.e. periodic capture of the surface at a very fine resolution in 18-month intervals.

Nidaros Cathedral was built out of several stone types over the ages that involved various restorations; the main stone types used in the exterior of the Cathedral were soapstone and sandstone/metasandstone (STOREMYR 1997). Material recession rate for soapstone is about 5mm/100y (STOREMYR 1997) while for sandstone it is between 0.3-16mm/100y (ANDRE & Phalip 2010, GEIKIE 1880) Assuming an overall recession rate of 5mm/100y, we expect an annual recession rate of 0.05mm. This is a very hard requirement to meet with most scanning equipment. One of the few scanners that could deliver that kind of accuracy, the SmartSCAN line, is manufactured by our partner Breuckmann GmbH, a part of AICON 3D Systems GmbH. We have directly chosen this particular equipment because it has been used in the past by Prof. Theoharis group to perform a pilot scan on one of the columns at the archaeological site of Elefsis, Greece, in 2010. The high-precision acquisition has been repeated in April 2013 and is shown in Fig. 3.

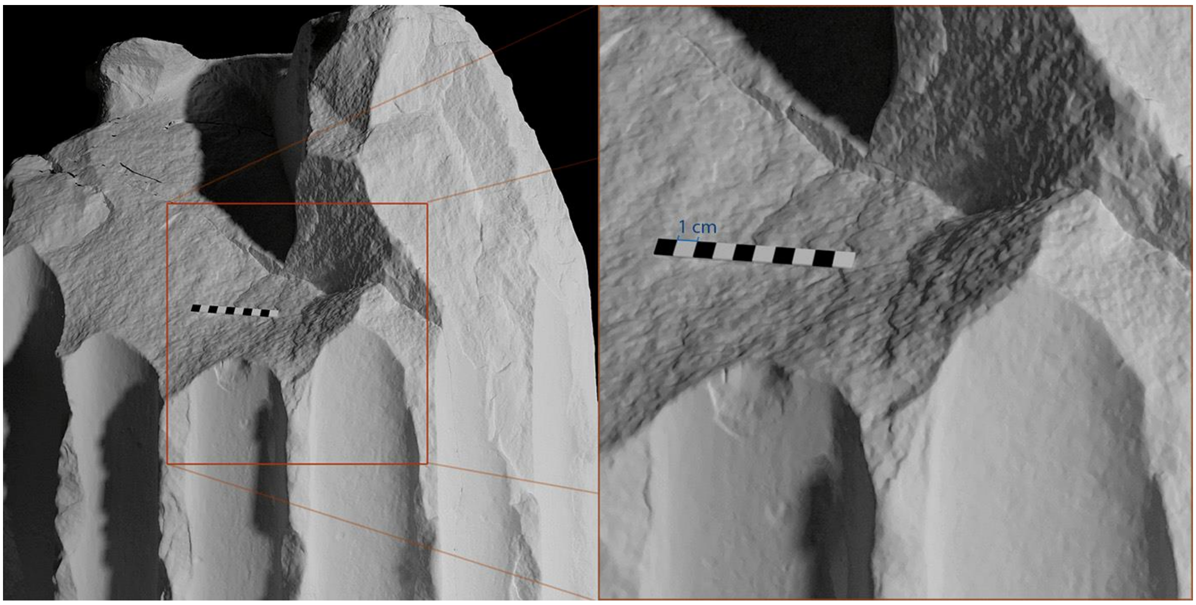

Fig. 3 - Very high resolution scanning for differential erosion measurement. This is a 20-milion-triangle partial model of a digitized column at the Elefsis archaeological site (total 75 million triangles).

One of the most difficult tasks in determining the differential deformation of the geometry is the registration of the successive scanned results. Since the interval between scans is long, it is very hard to use external landmarks to align the captured data. Even worse, employing identifiable features on the monument or placing markers on it is questionable, since the surface is expected to degrade as a whole, although in a smaller, but not predictable rate compared to the regions of intense degradation we aim for. To this end, alternative registration methods are investigated based on the entire captured surface.

Fragment Reassembly via Geometric Matching

In the pioneering work of our team (PAPAIOANNOU et al. 2001, PAPAIOANNOU et al. 2002, PAPAIOANNOU & Karabassi 2003), it was shown that *computer-assisted reassembly* of generic three-dimensional fragments is possible, even as a fully automated procedure. In the years that followed researchers have proposed improved methods to address this problem (HUANG et al. 2006, WINKELBACH & Wahl 2008) and have also succeeded in producing high-accuracy techniques for constrained matching of specialized forms of artifacts, such as potsherds (KAMPEL & Sablatnig 2003, WILLIS & Cooper 2004).

In geometric matching, separate fragments are puzzled together by determining a matching score among pairs and at a global registration level, an optimal clustering is sought that forms aggregations of correctly aligned pieces. To this end, several algorithms have been proposed, but all share a common prerequisite; the noise, or conversely the smoothing, introduced by the scanning procedure and the intrinsic high-detail structure of the fractured faces should not interfere with the matching process. Particularly for the latter factor, irregular yet systematic degradation of the fragments, after the original object has been split, renders fine relief fluctuations inconsistent between the complementary broken faces. This means that surface comparisons need to take place at a larger scale than the typical resolution of scanning for archiving purposes (1-2mm). Through a careful examination of both the original pieces and the resulting scans, for typical slate, marble, sandstone or other movable objects with $12cm^2$ of contact surface or greater, the minimum confidence margin should be around 3-4mm. This does not account for digitization errors and weathering, which have to be considered in the matching process. Therefore, after we scan our fragments for digital archiving, we post-process them to reduce their resolution, as much of the finer detail will not be taken into account but will have a severe performance impact on the geometric matching (see Fig. 4).

Visualization

Visualization requirements are linked to the scale of observation and the target users. For example, an inspection of a single piece by a non-expert requires far less detail and degrees of freedom compared to a CH expert, although this does not necessarily imply that the final visual fidelity should be inferior in the first case.

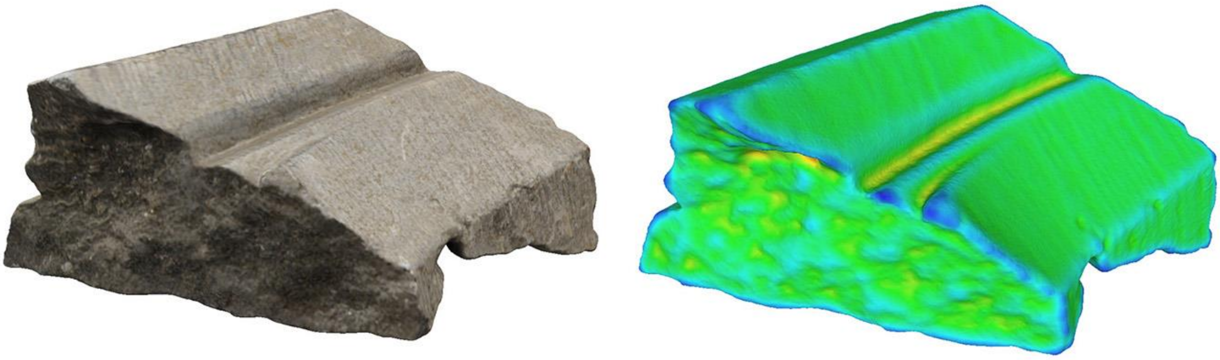

Fig. 4 - Geometry processing (curvature extraction using fast, custom descriptors) on a scanned fragment. Medium resolution models (shown here) result in comparable feature detection accuracy compared to the high resolution ones, at approx. 1/60 the computational cost.

Scale imposes resource constraints on the ability to render and manage the 3D data in a graphical user interface. Although this is of a marginal consequence in pre-rendered graphics (e.g. videos and documentaries), it has a serious impact on real-time visualization, such as in interactive environments or on-line services.

Despite the constant increase in parallelism and processing power of modern graphics processors (GPUs), visualizing massive scanned data and large collections of objects can be very challenging. The sheer amount of geometry and high resolution textures that need to be transferred to and processed by a GPU in such an application can quickly reduce the responsiveness of the interaction and drain the system's resources, especially the graphics memory. In order to bypass these constraints and maintain a consistent, high-quality visualization experience (e.g. Fig. 5), we need to either resolve to alternative, less demanding but also less attractive forms of visualization (e.g. untextured point rendering), or rely on multiple detail levels that can be used interchangeably.

Fig. 5 – Real-time rendering of a subset of the scanned fragments using our custom engine, with realistic materials, real-time global illumination and camera effects.

In PRESIOUS, we have identified three generic categories of resolution with respect to observed scale for fragments and CH monuments in general (Fig. 6):

- **High resolution**: single-piece inspection for study purposes. This is usually done in stand-alone tools like Meshlab (MESHLAB 2013). The models are the direct product of the scanning process, after de-noising and hole-filling. Typically they consist of 1 million to 2 million triangles for moderate scales up to 60cm wide.
- **Medium resolution**: these are used for rendering close-up views of pieces in a collection, in the presence of the other pieces in the view. Therefore, medium-resolution models constitute the high level-of-detail (LOD) models for collection visualization and virtual workspace interactive applications. Additionally, they are the primary models used for the geometric processing (see previous sub-section). The medium resolution models are either the product of medium resolution scanning or are derived from the high resolution ones via re-meshing. Textures are also usually reduced to save texture transfer bandwidth in the graphics card. Medium resolution models are also good for high definition stills and videos. Typical polygon count: ~150 thousand triangles.
- **Low resolution**: these are created for real-time visualization purposes only after drastically reducing both the geometry and the textures or are the product of low resolution scanning. They constitute the low LOD for collection visualization and are used for distant objects in the field of view and when many parts are simultaneously visible in the window of the interactive application. Typical polygon count: 30 thousand triangles.

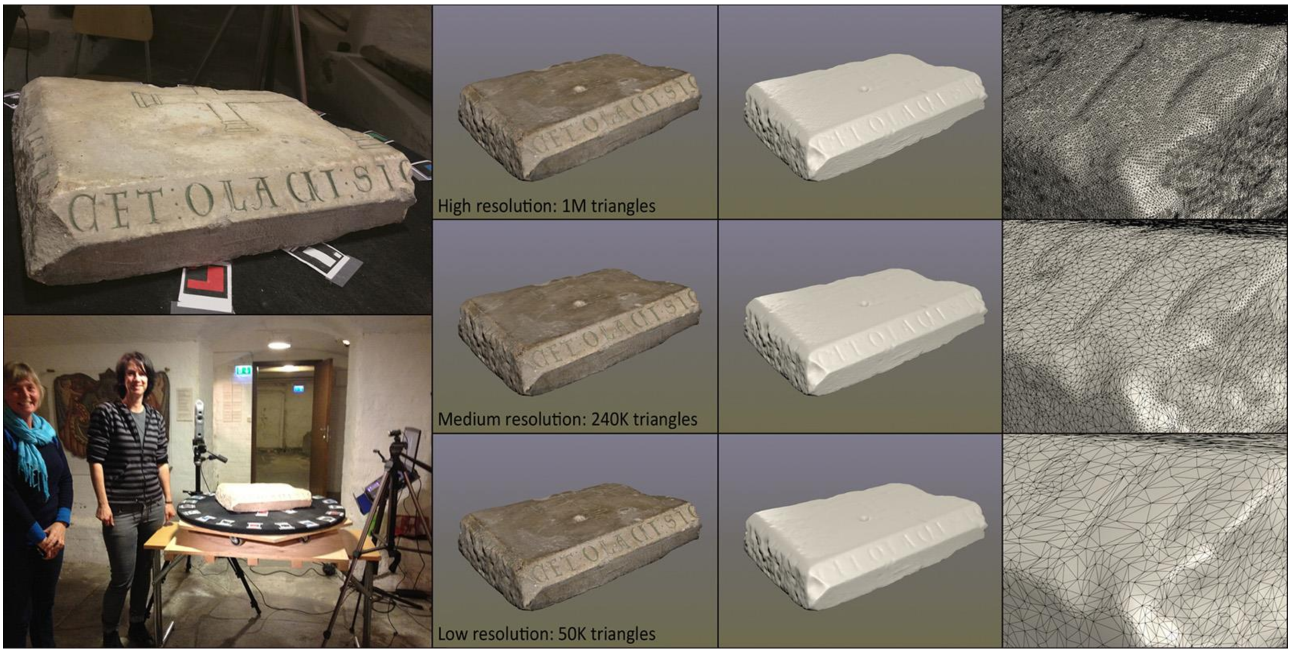

Fig. 6 - Scanning of a typical fragment. Left: Fragment of a tombstone from the Nidaros Cathedral Crypt and its setup for scanning. Middle: Comparison of the three resulting mesh resolutions with and without texture. Right: Closeup view of the mesh triangulation at the three resolution levels.

When capturing entire facades of a large monument, such as the Nidaros Cathedral, for visualization purposes, much ground has to be covered around the construction. Additionally, in order to avoid complex relighting calculations for the colour capture, which usually introduce subjective errors and colour shift, it is necessary to perform the digitization in a narrow time interval, so that the lighting conditions remain relatively fixed. In addition it is practically difficult to have access to CH sites for a long period of time. To this end, and since detail accuracy is not critical at such a large scale, one has to rely on photogrammetric tools, which use photographs taken from conventional cameras to produce a rough reconstruction of the geometry with texture.

The Digitisation Pipeline

Hardware and Setup

Erosion Scanning

For the erosion scanning we use a Breuckmann smart*SCAN* ^{3D} –HE R4 white light scanning system with different fields of view (Breuckmann 2013). The smart*SCAN* ^{3D} –HE marks the high-end (HE) edition of the Breuckmann smart*Scan* series of stereo-metric white light scanners. Two 4 megapixel monochrome cameras allow for fast data acquisitions with very low noise levels and large signal to noise ratio. We used the monochrome cameras for better accuracy. The colour version of this sensor or an additional set of colour images taken with an external camera would for colour reproduction of texture mapping wre the prime targets.

The scanner combines three triangulation angles (10°, 20°, 30°) in each scan for optimum coverage of an object, allowing reaching into narrow cavities thus reducing the amount of obstructed areas (Fig. 7).

The certified feature accuracy of the scanner the ranges between 0.008 and 0.079 mm for fields of view (FOV) with a 3D diagonal of the measurement volume ranging between 125 and 1250 mm. The working distance also depends on the (FOV) and varies between 370, 1000 and 1500 mm.

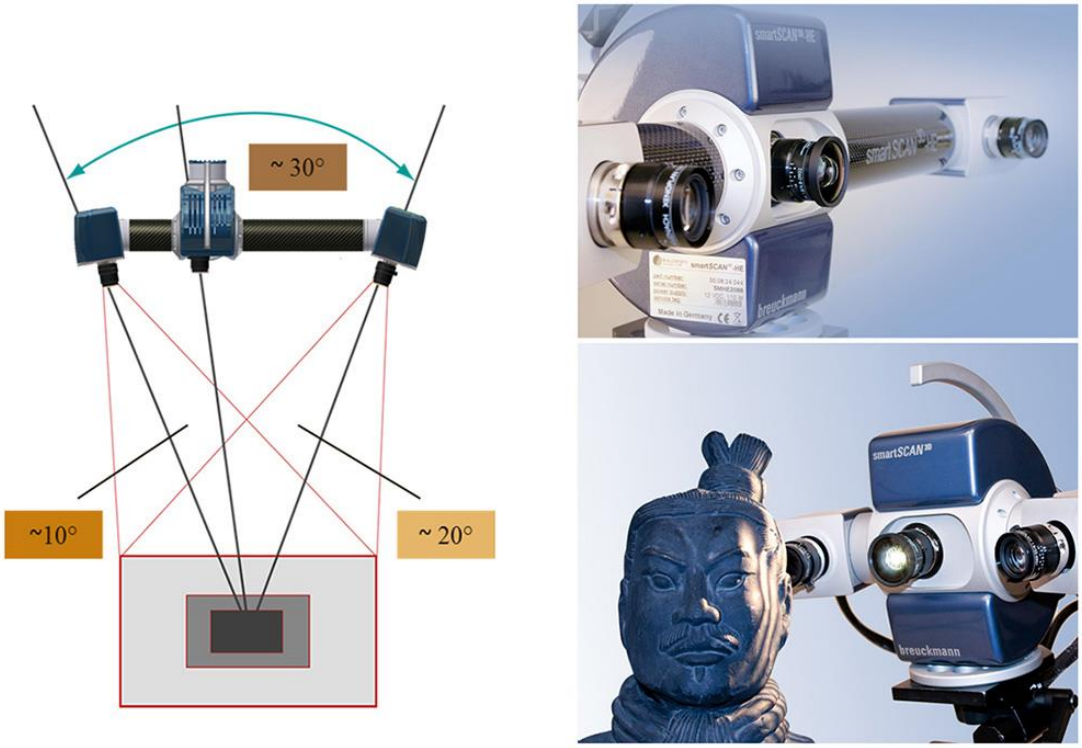

Fig. 7 - A smart*SCAN* 3D white light scanner with three triangulation angles. Left: the asymmetric placement of the cameras relative to the projector allows for triangulation angles of 10° and 20° for 3D data acquisition using white light scanning as well as 30° triangulation angle for stereo-metric measurements. The triangulation base length ranges between 240 and 470 mm depending on the field of view chosen for a scanning project (right).

The smart*SCAN* sensor weighs approximately 4 kg and is operated from a photo-tripod for quick and easy positioning. The shortest acquisition time for a single scan is 1s. The scanner is controlled by computer hardware and Breuckmann´s OPTOCAT software. The software controls all project steps including not only data acquisition, alignment, merging and hole filling of scans, but also measurements, inspection, texture mapping as well as data export. Raw image data are saved in a project allowing to revisit the original data, i.e. to apply an improved sensor calibration, add/exclude one of the three triangulation angles in a project, or utilize new processing algorithms available in future software versions.

OPTOCAT software includes a powerful 3D alignment procedure based on contour matching without markers as well as automatic scan alignment via index marks, turntable projects, control of external robots and navigation solutions.

Fragment Scanning

An Artec EVA 3D scanner (ARTEC 2013) was used for fragment scanning. This scanner works from a distance of between 0.4m and 1m and so is ideal for scanning movable objects between 10cm and 80cm in diameter, which was the approximate scale of the fragments in our case. A powerful Alienware laptop was used to host the Artec EVA and the associated alignment and reconstruction software, Artec Studio, during field scanning.

Although Artec EVA is advertised as usable in hand-held mode, we found that if the scanner was placed on a tripod at a fixed distance from the object being scanned, then the results were less noisy and registration across 3D frames was far more stable; the object itself was placed on a turntable (see Fig. 6). Also, although Artec EVA is advertised as requiring no markers, we found that having markers both on the turntable and on the object itself (see again bottom left inset of Fig. 6) improved the post-processing efficiency significantly.

Site Scanning

For site scanning we opted for a photogrammetry approach using Photomodeler (PHOTOMODELER 2013). In this case, an ordinary DSLR camera is used and this is actually the main advantage of the technology. Also, it takes the same amount of time to scan any size of object, since the method is neither limited by detection range nor has an absolute reference scale, which makes it suitable for large area scanning. A suitable fixed-focus lens has to be selected depending on the size of the object. The camera is then calibrated using Photomodeler targets of the appropriate size and then all its optical parameters are fixed (aperture, focal length, zoom).

The Data Capture Procedure

Erosion Scanning

A smart*SCAN* ^{3D} –HE R4 white light scanning system was used for both scanning campaigns in Elefsis and Trondheim that took place in March and April 2013, respectively.

In Elefsis a more than 2.2 m tall column drum with a diameter of approximately 1.2 m was scanned (Fig. 8). While only a small area is of interest for the successive erosion scans, the complete column was captured to provide a reference frame for future scans. Overview scans around the column were taken with a large FOV of 850 mm yielding an *x*, *y*-resolution of 0.3 mm and a z-resolution (along the viewing direction of the scanner) of 0.016 mm. In total 78 scans were taken and aligned to cover the whole column in this resolution. The part that was already scanned in 2010 and will be evaluated in detail to study erosion within the PRESIOUS project, was captured by 37 additional scans with a FOV of 400 mm yielding a z-resolution of 0.007 mm. All scans were aligned using edge alignment – index marks were placed in part of the model, but not used for alignment. The resulting model of the complete column represents a very large data set at highest resolution. The analysis takes place on subsets of the data in order to increase the speed of analysis, viewing and processing. Scans were taken after sunset to ensure optimum contrast of the projected pattern required for white light and stereo-metric scanning.

Fig. 8 - Visualisation of the 3D scanning results from Elefsis in OPTOCAT software (left). Data acquisition with a Beuckmann white light scanning system (right).

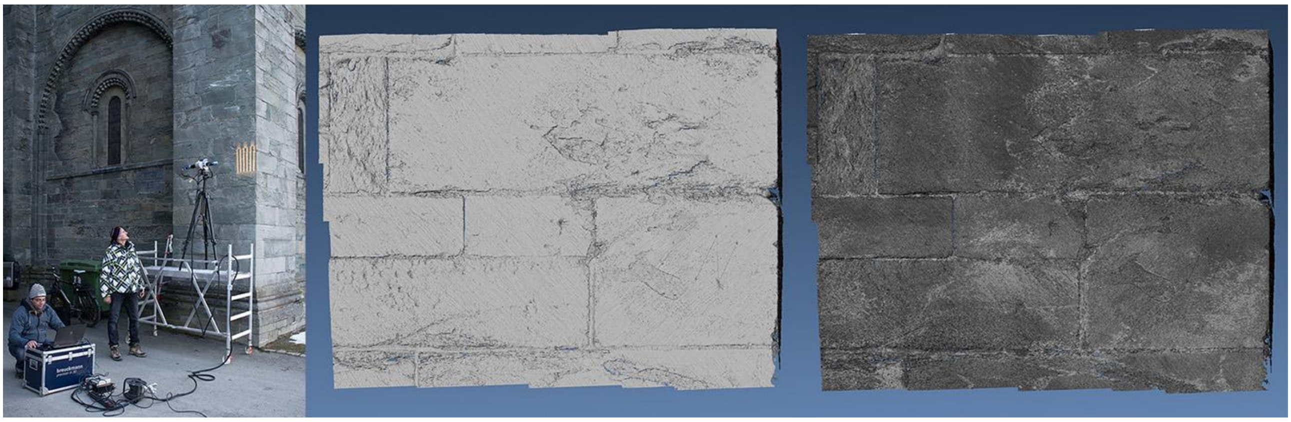

Fig. 9 - Scanning outside of the north entrance of Nidaros cathedral (left). The result from monochrome texture mapping (right) using sensor imagery provides an added value for documentation and visualisation. The scanned areas span approximately 1 by 0.9 m² and show stones affected by erosion. The average resolution in x, y is approximately 0.1 mm with a z-resolution around 0.007 mm. Please also note the two mason marks engraved in the rocks (middle). Such details are hardly visible in the textured image.

Several smaller areas were scanned at the Nidaros Dome in Trondheim (Fig. 9). The number of scans per area varied between 12 and 29 scans. Different FOV were installed to adjust working distance or amount of detail captured – FOV of 125, 250 and 400 mm were used with z-resolution of 0.002, 0.004, and 0.007 mm, respectively. Scanning was partly done outdoors at temperatures close to freezing.

For all areas scanned in Greece and Norway the scans were aligned using OPTOCAT software. The resulting STL files were saved with different compression rates keeping full resolution data as well as data that is easier to handle. The resulting model, merged in single STL, PLY or OBJ files, will be made available through the PRESIOUS website.

Fragment Scanning (using Artec EVA)

The following procedure was experimentally found to give good reconstruction results and minimise the human effort. First, for the data capture itself, we place the object on a turntable with small markers and add markers around the object's perimeter, as well. We take 4-6 3D scans around the object, each scan covering a 60^o-90^o sector around the object. We turn the object upside-down and repeat the process. Now both the top and the bottom side of the captured point cloud contain the markers of the turn table, but in a different reference frame, since we had to switch sides, i.e. move the object. However, due to the markers on the perimeter of the object (easy to remove stickers), we can register the top with the bottom side.

Using the Artec software, we align the partial scans of the top side using the captured markers on the turntable, thus building a *top-side* reconstruction. We repeat the process for the scans of the bottom side, using the same markers on the turntable, thus building a *bottom-side* reconstruction. Finally, we align the *top-side* with the *bottom-side* point clouds, using the markers placed on the perimeter of the object to create a single final 3D object (point cloud with texture). Before moving to the mesh generation stage, any point cloud noise spikes and background (e.g. the turntable) are manually removed. Optionally, one could extract the background by filtering out the respective points according to colour.

The point cloud is filtered for outlier rejection and a watertight mesh is generated by iterative relaxation and tessellation of a deformable surface on the point cloud. Then, having a complete surface model, we generate a texture atlas from the point cloud colours (see Fig. 6 middle). Up to this point, we could rely on the provided software for the scan alignment and the generation of the high-detail mesh, which is also exported in a convenient standard file format.

However, there are some steps that one must follow to ensure a reliable and manageable representation for the object as dictated by the requirements of our work: first, we create three versions of the polygonal mesh (high, medium, low) and discard the original version, since it has a very irregular and unnecessarily dense and view dependent sampling. For this re-meshing procedure, we use Meshlab (MESHLAB 2013). We do not use any fixed resolution settings but rather rely on visual inspection to determine the tolerable levels of surface decimation, as we must be extra careful not to smooth out any features of the geometry. The importance of the detected features depends on the level of detail. For example, it may not be necessary to retain the chisel marks of relatively large surface on the low-resolution version of the model, since the textural features will predominate in the visualization process.

The initial per-object texture atlas is typically stored at a 2048^2 pixel resolution. However, for medium- and low-resolution levels of detail, which are going to be visualized along with other fragments, we want to minimize texture transfers and optimize cache utilization in the GPU. Therefore, we build lower resolution textures (1024^2 and optionally 512^2) to accompany the medium- and low-resolution meshes. Furthermore, since for visualization we typically enable texture pre-filtering techniques in the graphics card, in order to avoid colour leaking across the texture atlas charts (separate regions), we perform an easy custom post filtering step (Fig. 10). Initially, the exported background is black and it is easily extracted and filled with the average border colour of the foreground. Then, for all foreground border pixels, a Gaussian filter is applied to diffuse their colour into the background. This ensures seamless texturing at all observation levels.

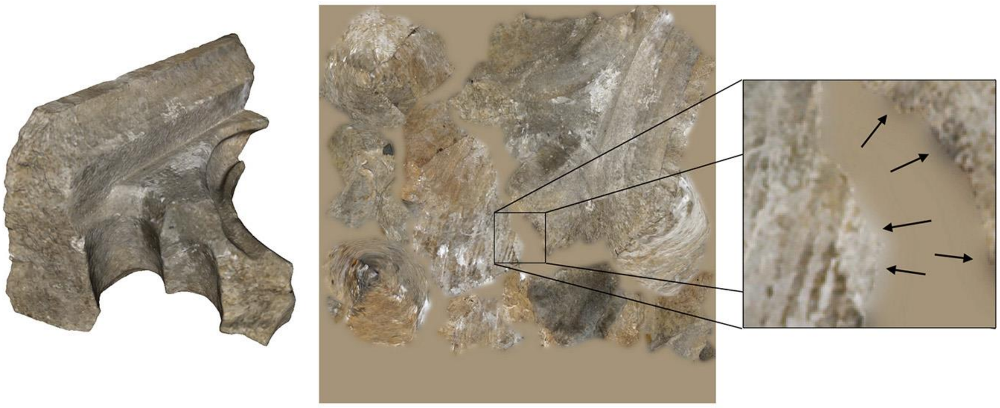

Fig. 10 – Texture atlas post-processing to reduce colour leaking at the seams during texture level-of-detail generation (mipmaping); a Gaussian filter is applied to diffuse the border pixels into the background.

Site Scanning (using Photomodeler)

We found the Photomodeler software rather difficult to handle; there are many things that one should know about taking the photographs and parameterising each step, if a good result is desired. As yet we are not content with the results. The following steps must be followed:

1. Acquire photographs from appropriate distance at approximately 20º between them.
2. Import photographs into Photomodeler and order them (manual or automatic).
3. Orient the camera for each photograph (manual or automatic).
4. Create surface mesh.

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Discussion

The acquisition of the high-resolution precision scans for erosion scanning using the Breuckmann scanner can take on the order of two hours for an area of approximately $1m^2$. This time estimate can vary significantly based on the detail that has to be covered, the number of scans that have to be taken, as well as the amount of obstructions that are present in the object. Post processing of the data requires very little user input and depends on the number of scans taken as well as the computer hardware. The scanning process may be automated almost entirely using a turntable for suitable objects. These high precision scans are essential if we aspire to measure recession rates of 0.05mm/year.

The acquisition of the scans of a typical 3D fragment using the Artec EVA scanner took about ½ hour, including placing the markers on the object and scanning it from both sides (top and bottom). The time taken to post process a fragment using the Artec software was about 2 hrs and included registration of the partial scans using the markers and noise removal. Thus a total of 2 ½ hours per fragment was necessary. With our parameter settings, the 3D reconstruction of a typical fragment occupied about 100Mb.

Scan type / Application	Accuracy	Time	Data Size
High Accuracy – Small scale applications, e.g. erosion measurement	~0.025 mm[1] (0.008-0.025 mm)	2 hours for $1m^2$	~2.5Gb for $1m^2$ at highest resolution Data compression for data reduction
Medium Accuracy – Geometry processing for fragment reassembly and collection inspection	~1mm	2 ½ hours for $30cm^3$ object	~100Mb for a $30cm^3$ object
Low Accuracy – Visualization of large scale monuments via photogrametric techniques (e.g Photomodeler).	~1-10cm	Days for the exterior of a small building	~60Mb for the façade of a small building

Photomodeler needs a lot of skill. In our experience, it takes long to acquaint oneself with the idiosyncrasies of the photogrammetric process and how to take the appropriate photographs. It is also weather dependent, cloudy days being the best due to the absence of shadows and direct lighting. For a rough reconstruction of the exterior of a building, a couple of photography days may be a reasonable estimate, although this can vary a lot based on the detail/distance used. A few hours of an experienced operator would then be necessary for post-processing plus several hours (or days) of computing time. The texturing we observed to be of rather low quality. Obviously, since Photomodeler is distance insensitive, accuracy can vary a lot; in our case which involved the reconstruction of a building façade, we observed an accuracy of 1 to 10 cm. The size of the reconstruction file can also vary a lot; the 60Mb figure resulted from a small number of high resolution DSLR photographs of a building façade with the settings that we used. We do not claim that we have mastered this technology as of yet; one of our PRESIOUS collaborators at NTNU is currently in the process of acquiring a large number of DSLR photographs from the interior of Nidaros Cathedral with the aim of reconstructing the interior in 3D using Photomodeler.

CH makes heavy demands on 3D scanning technologies ranging from the macro to the micro level. Opting for the maximum accuracy in all cases is neither necessary, nor practical. Thus different technologies need to be involved. Training and experience are a crucial issue, as the quality of the results and the productivity of technologies involved, depend on the skills of their operators. Another important issue is merging the results of the various technologies; for example, one may need to replace a statue that was scanned at low accuracy as part of a building with a medium accuracy scan of it, as this is an important point of interest for a virtual walkthrough of the site.

References

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