

2D AND 3D VISUAL PRODUCTS: FIRST STEPS TOWARDS VIRTUAL RECONSTRUCTION

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The main product of 3D digitisation is a 3D model. It can be presented in 2D space (when a 3D model is basically converted to a 2D raster using specific visualisation parameters of the 3D model) or in full 3D space. 3D space presentation of the model can be of virtual nature (3D animation, 3D SW viewer) or of tangible nature (3D print).

2D Visual products

2D visual products are a standard form, especially in the professional sphere, where printed or digitally distributed 2D information carrier still prevails as the main means of communication (printed or digitally distributed publications, articles, etc.). 3D digitisation, as already mentioned before, most often fulfils the role of a means to create 2D or 2.5D professional documentation (primarily the technical or graphical part). In the context of cultural heritage, this applies especially to the creation of graphical appendix of archaeological or historical architectural research documentation. In addition to such practical function, 2D reproduction of a 3D model can have special importance thanks to the software-conditioned highlighting of visual parameters of the respective 3D model which, in many cases, can add value from the perspective of dealing with specific professional issues.

Technical research documentation

3D digitisation is, in research documentation, especially useful for the creation of geo-referenced orthophoto plans of layouts of the structures, scaled orthophoto profiles and facades (of historical building), and scaled cross-sectional views, which are subject to vectorisation mainly in the CAD environment. In addition, the creation of DEM, which is then subject to specific visualisation algorithms, is frequently performed in the analysis of historical and archaeological potential of the landscape.

3D documentation is also very suitable for the creation of 2D graphic derivatives, which significantly reduces the time spent in the field. However, the experience from case studies shows that this work procedure also has limiting factors and issues that need to be taken into account. The most serious problem is represented by digitisation shadows, which can, in many cases, lead to the omission of documenting important parts of architecture or archaeological sites. This problem is often hard to solve. For instance, if a massive, floor-to-ceiling piece of furniture is in close contact with walls of the space scanned, then this can distort the width of wall partitions since the wall is covered and inaccessible for scanning. It is difficult to secure perfect accessibility to all spaces in building interiors. Small, confined spaces in which it is difficult to position the scanner for 3D scanning, or spaces with light conditions that do not allow a reasonable number and quality of images to be achieved, can often be documented only by using the classic method of taking measurements. The number of photographs that would have to be taken for IBM is huge in the case of small spaces with a complicated layout. 3D documentation would thus be ineffective relative to the data obtained (spaces with sanitary facilities, storage areas, anterooms, spaces under stairs and other internal areas). This inevitably leads to “white areas” in the models of elaborate buildings and complexes (Grůňová & Zachar 2015, 67-69).

Scanning of upper floors of architectural structures is also problematic. Digitisation shadows are formed not only in case of small architectonic details, but also along window sills and edges of window openings. In such cases, the terrestrial scanning needs to be complemented with the data collection performed by an UAV or done from a higher platform (e.g. scaffolding). This is, however, technically very demanding, particularly in the case of (dense) tree vegetation and terrain of a complex structure and elevation often surrounding architectural remains (castles). Therefore, in many cases, 3D digitisation needs to be completed with conventional geodetic methods (additional measurement of parts that can be accessed only with difficulty using Total Station or measuring tape). With regard to the total volume of data in the instances of complex historical architectonic structures, it is often the case that dense point clouds form the basis for vectorisation, instead of the textured 3D models (mesh), as point clouds are easier to manage from the perspective of hardware parameters. However, this can lead to visual overlap of several facade layers into a single surface, in case ortho-inputs for vectorisation of cross-sectional views are prepared, and this can be very confusing (Figure 58).

As the context implies, it is necessary for the documenter to experience the object/locality by doing their own research; this can prevent incorrect interpretations in vectorisation of the data. The person processing the data must be familiar with the building/locality and also, in vectorisation, it is required of the person to have knowledge of the structural aspects of architecture in general and historical architecture in particular, with

all its specifics. A lay person without experience and lacking adequate perception of space and knowledge of structures cannot distinguish important from unimportant and does not actually see the structure (Grůňová & Zachar 2015).

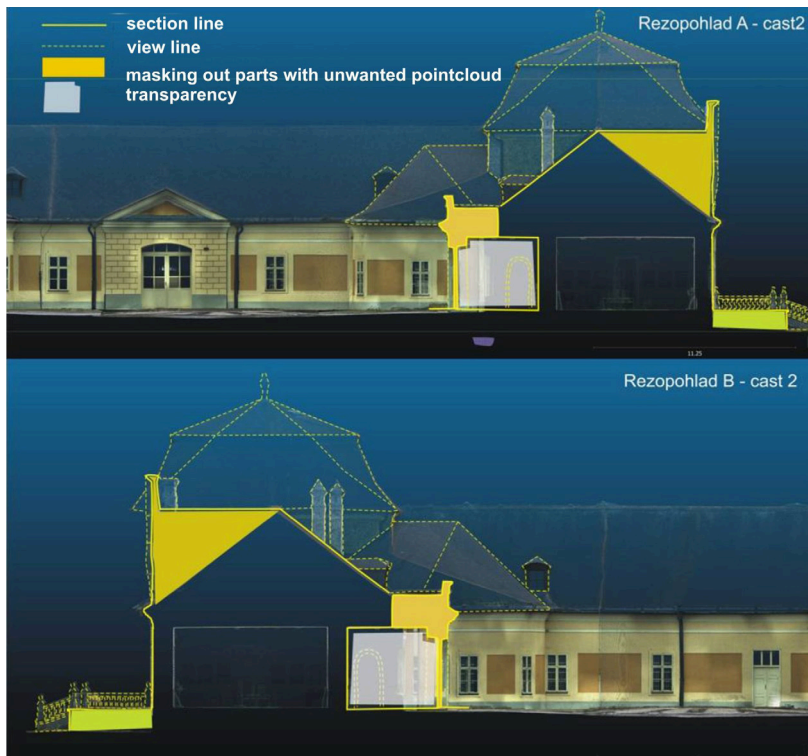


Figure 58. Example of unwanted transparency of the point cloud in the generation of a cross-sectional view.

Finally, yet importantly, it needs to be reiterated that the creation of 2D graphic documentation as a derivative of 3D digitisation significantly expedites work in the field, but subsequent processing of the data in office is very time-consuming. The focus of evaluation moves, in case of digital methods, 'from the field to the desk', which can be beneficial for the rescue investigation. Hardware demands (RAM, processor, graphic card) are implied by the nature of 3D documentation as such.

Shading filters

The application of shading filters is not a specific feature of 2D visualisation. In their basic form, shading filters form a standard equipment of the majority of 3D viewers and 3D modelling software. However, they acquire special meaning principally at the stage of conversion of a 3D model into a 2D raster, when they allow, according to the parameters of the filtration algorithm, to highlight certain elements of the model's surface. This helps mainly in the analysis of the documented object from a professional point of view, where it represents an added value with regard to visualisation. In addition to the standard native shading filters that are applied directly to a 3D model, such as basic

shading, ambient occlusion and volumetric obscuration, special shading algorithms used in GIS applications for 2.5D models can be also used: the sky view factor and topographic openness.

Basic shading

Any shading of the 3D mesh is determined by the existence of normal vectors which, in a mathematical sense, are the directions that are perpendicular to the surface of any given location (Nehab et al. 2005). Basically, the normals tell the software which side of the mesh is to be regarded as the inside, and which as the outside surface. This is of utmost importance for the distribution of lighting over a 3D model, as light bounces off surfaces in such a way that the angle of the incident light and the angle of the reflected light are equal to the angle of the surface normal. False normals' position can thus cause inadequate lighting and part of the internal side of the model can be wrongly visualised as the outer surface, or vice versa (Figure 59).

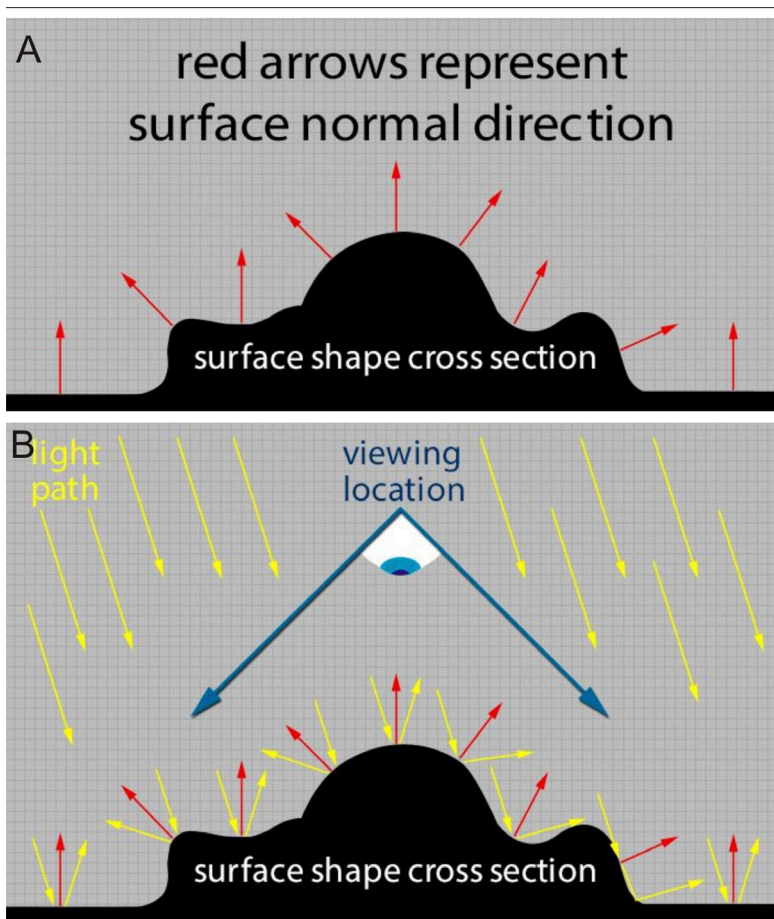


Figure 59. Demonstration of how normals function by shading a 3D model. A: position of normals' vectors in reference to the model's surface, B: visualisation of the light reflectance according to the position of normals. Available online at <http://culturalheritageimaging.org/Technologies/RTI/>.

Most IBM software generate normals when exporting a 3D model. On the other hand, TLS data (point clouds) contain information on normals only when saved in PTX file format. In other cases, normals have to be computed separately, either directly upon the point cloud or after the mesh generation.¹ Most modelling software, as well as 3D viewers, nowadays enable multi-directional lighting systems, which include several partly or fully manually adjustable lighting sources that create illumination of a 3D scene according to particular needs.

Radiance scaling

In the open-source MeshLab SW there are a lot of shading filters for improving or altering standard visualisation of a 3D model. The most useful amongst them is definitely *Radiance scaling*. This rendering technique is aimed at visualising shape by shading through the modification of light intensities around specific features. The main goal is to correlate shading with the variation of the surface features in order to enhance the shape's plasticity by visually augmenting concavities and convexities. The *Radiance scaling* rendering technique works in real-time in modern graphics hardware. As a consequence, surface features can be inspected interactively (Granier et al. 2015). In general, this shader augments the surface by changing reflected light intensities of the model based on the surface curvature and characteristics of the material. It is focused on emphasising surface concavities and convexities, which make plasticity of the surface geometry more obvious. In this sense, parts of the surface can be made more visible than they are under standard illumination.

The shader offers several display modes (Lambertian scaling, Colour descriptor, Grey descriptor and Lit sphere scaling), each containing an enhancement slider. Lambertian radiance scaling produces light grey visualization of the mesh, whereas carved areas are shown in a darker shade of grey. The grey descriptor also changes the visualization to grey, but uses darker colour tones. Colour display mode operates on the same principle as grey descriptor, but generates multicolour output scheme. Lit sphere scaling enables the transition of scaling dominance either for concavities or for convexities, thus changing the default balance between them. Unlike other display modes, the Lambertian can be joined with the basic shading lighting. This allows the user to highlight the model from different perspectives. Other modes use static light, so when the model is turned around, the edges of the surface remain visible. This makes it easier to get an overall perspective of the surface.

Ambient occlusion, Volumetric obscurance

Ambient occlusion is a method for computing lighting on the surface of an object that takes into account the light brightness due to occlusion of the surface in relation to the light source. In fact, it is a type of light in computer graphics that is used to simulate general illumination. In its essence, it is a way of simulating shadowing caused by objects blocking the ambient light. In general, visualisation is most often calculated by casting

¹ For this purpose, MeshLab or CloudCompare (both open-source) can be used.

virtual rays in all directions from the surface. The rays that reach the background or 'sky' increase the brightness of the surface, whereas a ray that hits another object does not contribute to illumination. As a result, the points (mesh triangles) surrounded by a large amount of geometry are rendered dark, whereas points (mesh triangles) with little geometry on the visible hemisphere appear light (Coombe 2015). In other words, parts of the model's surface that are 'open' are visualised in a bright way and parts of the surface that are 'occluded' are depicted in dark tones.

Besides the professional graphic and 3D modeling SWs, the easiest way to compute ambient occlusion rendering is to use open-source SW CloudCompare or MeshLab. In both cases, the illumination of a point cloud or vertices of a mesh is calculated as if the light is coming from a hypothetical hemisphere or sphere around the object. Several parameters are to be set in order to run the calculation. The most important parameter is the cone amplitude which determines the extent of the (hemi)sphere that sends the light towards the object. The next component of the algorithm is the number of light rays sampled on the (hemi)sphere and directed towards the model's surface, which influences the level of detail. The more rays used, the finer the results. The final resolution is based on the size definition of the depth texture (the rendering context resolution). From the point of view of the final output, *ambient occlusion* is very similar to *radiance scaling* as both shaders bring enhanced visual distinction of concavities and convexities of the model's surface, thus augmenting the plasticity of the model. Furthermore, *ambient occlusion* can produce slightly different visualisation forms when being deprived of the surface vector normals. In this case, the model acquires a kind of an 'X-ray appearance'.

A specific form of *ambient occlusion* is *volumetric obscurance*. The shader operates on the same principle, but avoids darkening of occluded parts of the model, which is very often the case in *ambient occlusion*.

Radiance scaling, *ambient occlusion* and *volumetric obscurance* are all suitable for pointing out particular features on the surface with few variations. They are especially useful for the detection of attributes and various visual patterns on flat geometry, where shapes and patterns are carved into the surface of built-in bas-reliefs (e.g. ancient tombstones, votive stones with inscriptions etc.) (Figures 61, 62). The detection of such features can also be achieved by the application of a special lighting system, or the so-called Reflectance Transformation Imagery,² but both of the procedures have quite a few special requirements that have to be met on the spot, which is not always manageable or requires special equipment. On the other hand, 3D modeling with the above-mentioned shading deliverables is easily done on the spot, with minimal endeavour, and mostly requiring only a camera.

Another possible field of application of shading algorithms is the recording of historical sculptures. Especially, draperies and facial expressions can be substantially underlined, thus enhancing the overall dynamic movement and plasticity (Figure 61). In this sense, IBM, in combination with shading algorithms such as *ambient occlusion* and *volumetric obscurance*, can be used for a better visual understanding of tangible art.

2 For Reflectance Transformation Imagery see: <http://culturalheritageimaging.org/Technologies/RTI/>.

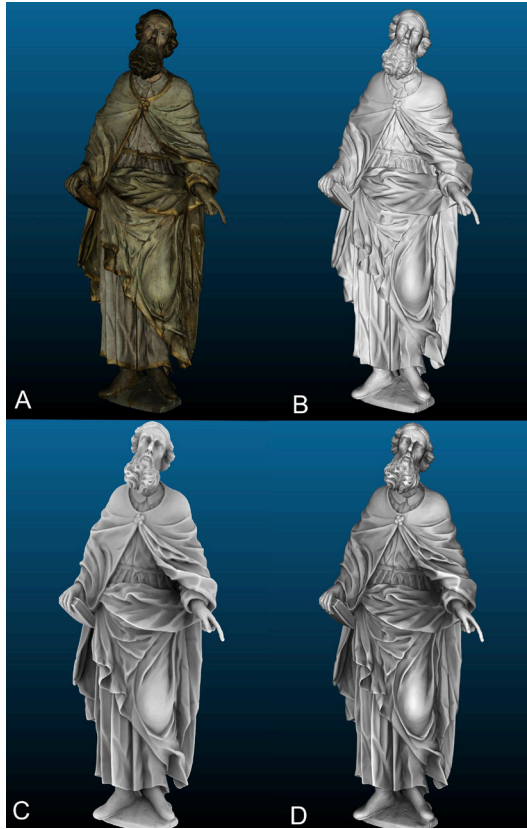


Figure 60. Various shading algorithms applied to a 3D model. A: textured 3D model, B: basic shading according to normals, C: ambient occlusion with normals off, D: ambient occlusion with normals on.

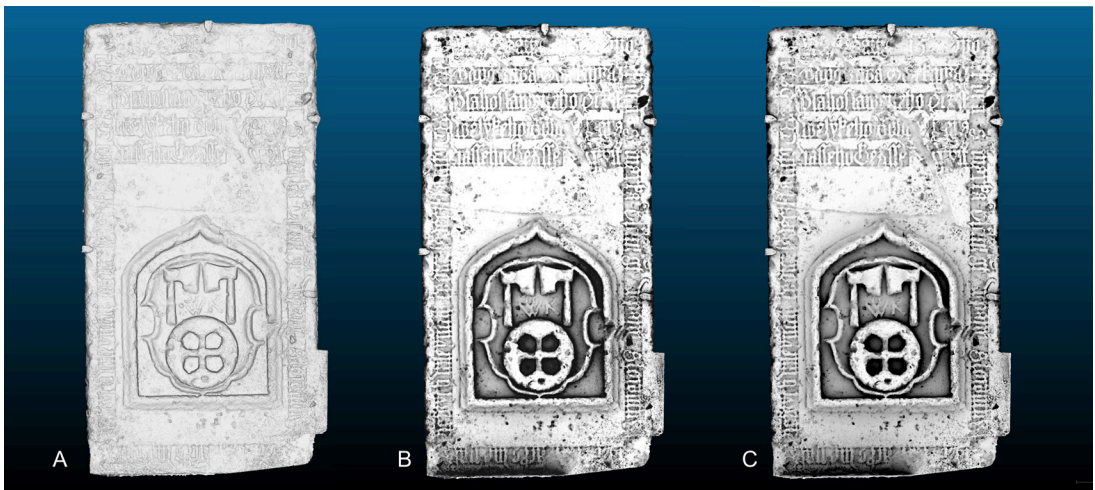


Figure 61. Ambient occlusion on the model of a 16th-century tombstone (bas-relief). Software Workspace CloudCompare. A: basic shading, B: ambient occlusion with normals on, C: ambient occlusion with normals off. Both ambient occlusion variants show very well the coat of arms and the writing on the tombstone.

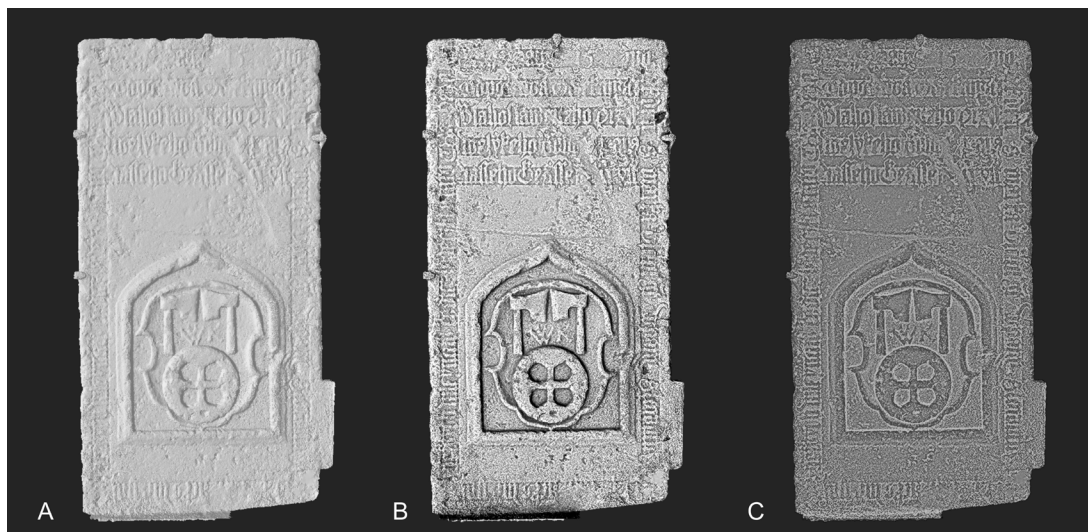


Figure 62. Examples of the usage of radiance scaling on the model of a 16th-century tombstone (bas-relief). SW Workspace MeshLab. A: basic shading, B: Lambertian radiance scaling, C: radiance scaling-grey descriptor. Both versions of radiance scaling enhance the appearance of the coat of arms and the writing on the tombstone.

3D Visual products

Until recently, 3D visualisation products have especially dominated the presentation sphere comprising mainly on-line 3D viewers (such as Sketchfab) and various types of 3D animations, saved in video files such as avi, mpg etc., most frequently allowing virtual flyovers over and around the 3D model. At present, 3D visual product offers a further benefit, connected specifically with the massive development of 3D print, which enables creating a more and more developed, tangible 3D copy of the digitised original. 3D print shows a huge potential, not only in view of the presentation and use in the popular sphere, but also in various professional sectors, such as the serial, standardised production of a prototype in the industrial sector, high-precision manufacture of medical prostheses and so on. In the field of cultural heritage, 3D print could, in the future, lead to a significantly cheaper production of copies of important art objects and the production of copies of different quality, according to the requirements of the client. The possibilities are numerous and the only limiting factor is the project budget.³

While 3D print as the tangible deliverable of 3D digitisation is on the increase, certain stagnation can be observed in the field of dissemination and general utilisation of 3D models in the virtual sphere. The possibilities for sharing and disseminating 3D files still face difficulties in the processing and management of large datasets and this constitutes a substantial problem for the majority of web applications. The original extent and size of

³ There are nowadays many projects aimed at the creation of full-fledged replicas at 1:1 scale by means of 3D print of the digitised originals, e.g.: http://www.arctron.de/de/galerie/galerie_archiv/2016/feuchtmayer_statue/

the files are unmanageable for the majority of web viewers (currently, the most widely used Sketchfab cannot work with mesh of the size exceeding 10 million triangles). Similar problems apply also to the generally distributable off-line file type for depositing 3D models – 3D PDF. Similarly, many graphic SWs are significantly limited as to the size and resolution of the mesh with which they are able to work.⁴ There is thus a considerable discrepancy between the potential of IBM SWs, which are currently able to generate 3D models of the size of up to several million of triangles, with extra high resolution showing very fine details on the one hand, and significantly limited capacity of their ‘reading’ by external modelling SWs on the other. To this end, the issue of general management and administration of the data, as well as the issue of effective retopologising of the original 3D data aimed at maximum possible reduction of the file size, whilst preserving all substantial details of the digitised object, remain important.

SW Platform	Web	License	Solution
Autodesk 360 Viewer	https://a360.autodesk.com/viewer/	open-source	on-line
Sketchfab	https://sketchfab.com/	open-source	on-line
3D Viewer online	https://www.3dvieweronline.com/	open-source	on-line
3D Viewer	http://3dviewer.net/	open-source	on-line
STL 3D Viewer (only STL files)	http://www.viewstl.com/fig	open-source	on-line
Open 3D Model Viewer	http://www.open3mod.com//	open-source	desktop
ShareMy3D	https://sharemy3d.com/	open-source	on-line
3DReshaper Free Viewer	http://www.3dreshaper.com/en/software-en/download-software/free-viewer	open-source	desktop
MarmosetViewer	https://www.marmoset.co/viewer/	commercial	on-line
Geomagic Verify Viewer	http://www.rapidform.com/products/xov/explorer-free-viewer/	open-source	desktop

Table 1. Overview of the most commonly used 3D viewers.

⁴ Usually, the upper limit of the resolution is around 30 million triangles.