Photogrammetry 4.0 – Integrating Computer Vision, Computer Graphics, Photogrammetry and Serious Gaming for 3D and 4D App Developments

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Abstract

After analogue photogrammetry (Photogrammetry 1.0, 1840-1970), analytical photogrammetry (Photogrammetry 2.0, 1950-2000), digital photogrammetry (Photogrammetry 3.0, 1980-today) we are now heading towards embedded photogrammetry (Photogrammetry 4.0, 2010 onwards). With the advancements in geometric computer vision stemming from Structure-from-Motion (SfM), Dense Image Matching (DIM) and the efficient methods of photogrammetry using laser scanning and imagery from space, airborne, UAVs, and close-range, superb point clouds can be transformed to 3D models. These models are integrated into game platforms to provide Apps for smart cities using all conventional Operating Systems: Android, Apple's iOS and MacOS and Windows.

The European Project "Four Dimensional Cultural Heritage World (4D CH World)" offers 3D and 4D Apps for the Testbed Calw, a medieval town 35km southwest of Stuttgart, Germany. The reference surface is a 1m Airborne LiDAR DSM, which was filtered to get the bare earth surface. In addition, airborne imagery of GSD 20cm was used for DIM to generate more detail, in particular for the street surfaces and the Nagold river bed. Approximately 200 buildings have been modeled in 3D using terrestrial laser scanning, close range photogrammetry, and vanishing point geometry of computer graphics. The latter method reconstructed the 3D models of the past using old black & white imagery of the Calw city archive. All models have been homogenized in Autodesk 3ds Max and exported to the game engine Unity 3d, for virtual reality modeling and app output. Two apps will be demonstrated offering not only 3D and 4D models of the present and the past but also animations and walk-throughs. The workflows are discussed, pros and cons are given.

1. Introduction

The development of photogrammetry can be traced back to the Middle Ages (MA). Important painters like Albrecht Durer used the reconstruction of the vanishing point geometry (perspective) to produce paintings resembling real photographs (around 1500, see fig. 1). But it took another 350 years to use real photos for photogrammetric reconstructions. In between, the perspective geometry has been under research by mathematicians, such as by Girard Desargues (around 1600), who published the book "Projective Geometry" and the contribution of Johann Heinrich Lambert (1759), entitled as "Free Perspective". With the invention of photography by Louis Daguerre, 1839, who shot the first street photos of Paris, it was the French officer and scientist Aimé Laussedat who produced the first photogrammetric 3D reconstructions (1858). The German civil engineer Albrecht Meydenbauer (1834-1921) was interested in photogrammetric methods for the reconstruction of sacred buildings and introduced the term "Photogrammetry" on December 6, 1867, in a publication of the Berlin Architect Association.

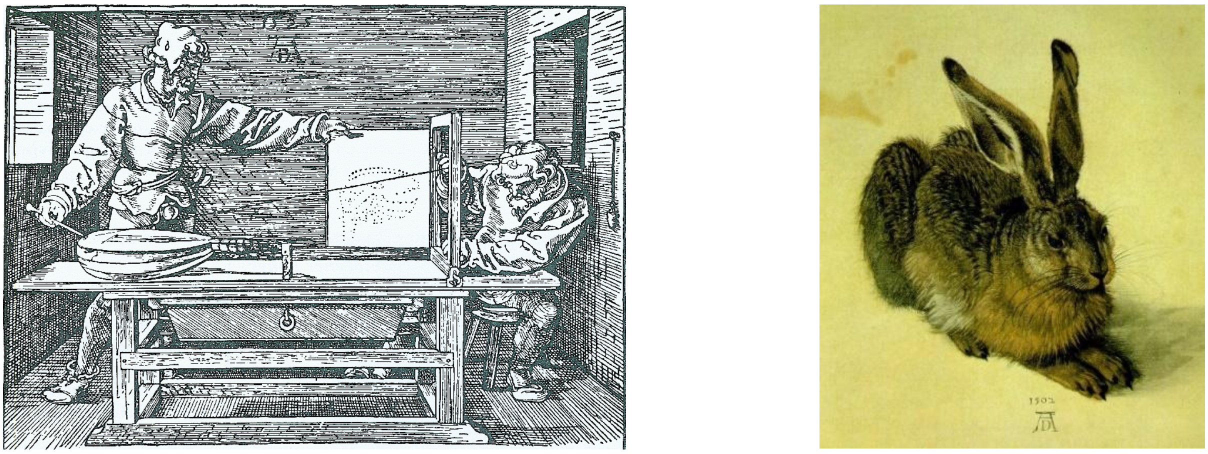


Fig. 1: (a) Reconstruction of the perspective in the MA (b) “The Rabbit” of A. Durer

The following classification helps to define the paradigm shifts in photogrammetry:

- Analogue photogrammetry (1840-1970) – Photogrammetry 1.0
- Analytical photogrammetry (1950-2000) – Photogrammetry 2.0
- Digital photogrammetry (1980 till now) – Photogrammetry 3.0
- Embedded photogrammetry (2010 and in future) – Photogrammetry 4.0

This classification mirrors the transformations of industry; at present Industry 4.0 is used as synonym for intelligent and digitally nested systems providing autonomously and self-organized new industrial products. There are huge funding programs operating for Industry 4.0 projects in most industrial countries worldwide, which is missing for photogrammetry. Nevertheless, photogrammetry today is a highly acknowledged Applied Computer Sciences discipline, cooperating with neighboring disciplines as depicted in fig. 2. Other disciplines, such as remote sensing, satellite geodesy, engineering geodesy and cartography could be named here as well.

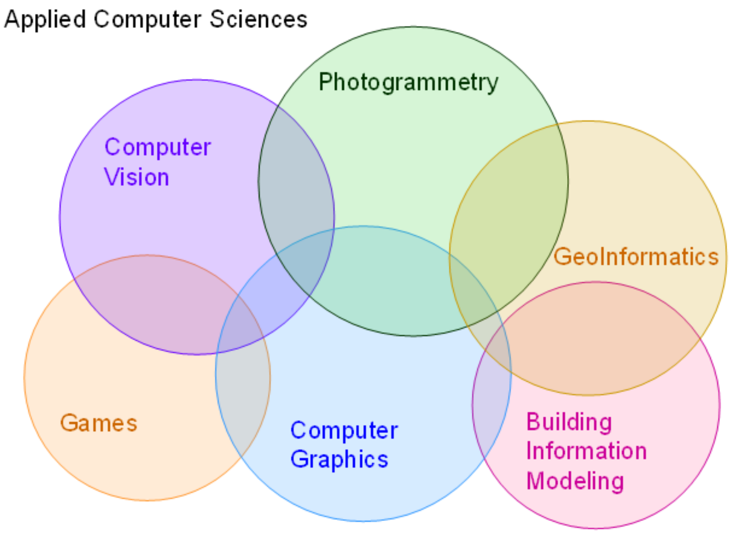


Fig. 2: Networking photogrammetry with other disciplines of Applied Computer Sciences

As demonstrated later on by the Apps Calw AR and Calw VR these products do not differentiate between disciplines – their methods are just used when required. Therefore it is proposed here to use the term “embedded” for the nested disciplines above, whenever applied to any 3D and 4D restoration. With the renaissance in digital photogrammetry in 2005, when first workflows using structure-from-motion and dense image matching algorithms were applied, it is today a very efficient discipline delivering not only colored point clouds of superb quality, but also interpretation methods for generating 3D models and providing semantic data (Hartley&Zissermann, 2000, Fritsch et al., 2013, Fritsch, 2017).

This paper is structured as follows: first we introduce the Testbed Calw, for which comprehensive geospatial basis data are made available. In-situ data collection and 3D modeling provides first 3D virtual reality building models (chapter 3), which are homogenized and complemented by interactive computer graphics. Chapter 4 deals with App developments and results to be discussed. The paper is concluded by a summary with outlook (Chapter 5), an acknowledgement and the references (Chapters 6&7).

2. The Testbed Calw

One of the main testbeds chosen for the European Union 4D-CH-World project is the historic City Center of Calw, a town located 40 km southwest of Stuttgart, Germany. Besides existing geospatial data, such as a LiDAR DSM/DEM, ALKIS footprints and georeferenced aerial photographs, more data have been collected using terrestrial laser scanning and close-range photographs to serve not only the interests of the researchers of the 4D-CH-World project and the EUROPEANA Library, but also the public, as this town has thousands of visitors every year.

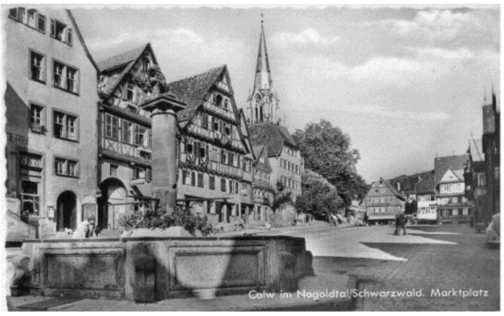
Calw is also famous for being the birth town of the 1946 Nobel Prize winner in literature, Hermann Hesse, who was born 2. July 1877 and lived here until 1895. In some of his work he described locations of Calw in great detail, linking it with his childhood memories.

The reason for Calw having been chosen as the testbed for the EU 4D-CH-World project is simple: there is a huge amount of data for any 3D and 4D modeling approach available. First of all, an existing 3D virtual reality model of about 200 buildings can be rendered with an image data archive dating back to the 1850s and 1860s, when the first glass-plate photographs were collected. Those photo collections are made available by the Calw city archive and have been partly digitized. As Calw is a tourist attraction, thousands of photos can also be downloaded “from the wild” using Flickr, Picasa, Panoramio and many other sources.

(a) Calw 2015

(b) Calw VR 2015

(c) Calw 1957



(d) Calw 1890

Fig. 3: The Calw Market Square

Fig. 3a and 3b represent contemporary Calw (2015) by photo and 3D VR model, while fig. 3c and 3d represent Calw from the years 1957 and 1890.

Besides the photo collections, the following geospatial databases of Calw are available and used for the App developments: a LiDAR Digital Surface Model with Ground Sampling Distance (GSD) of 1m, for which the bare Digital Elevation Model (DEM) was derived by filtering vegetation and urban environments (see fig. 4). Furthermore, cadaster data such as ALKIS building footprints could be used for quality control and georeferencing. Airborne photography with a GSD of 20cm was processed by Dense Image Matching (DIM) (Hirschmueller, 2008, Rothermel et al., 2012) obtaining a high resolution DSM (see fig. 5) to be filtered and merged with the LiDAR DEM. The outcome of this fused 2.5D reference data is the final reference surface for creating the 3D and 4D Apps. It is important to note, that the street levels have to be aligned with the 3D building models and the 2.5D reference surface. This alignment is manually approved, otherwise too much alignment errors would occur.

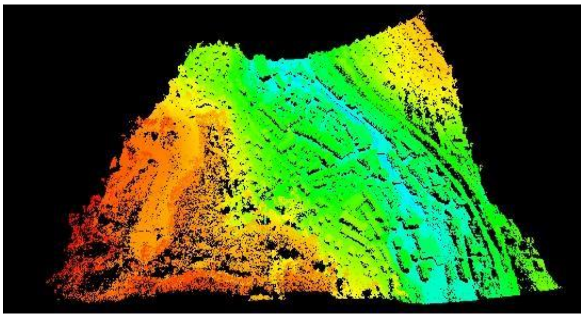


Fig. 4: (a) LiDAR DSM@1m GSD

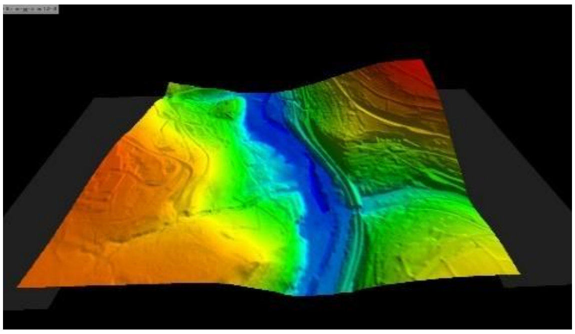


Fig. 4: (b) LiDAR DEM@1m GSD

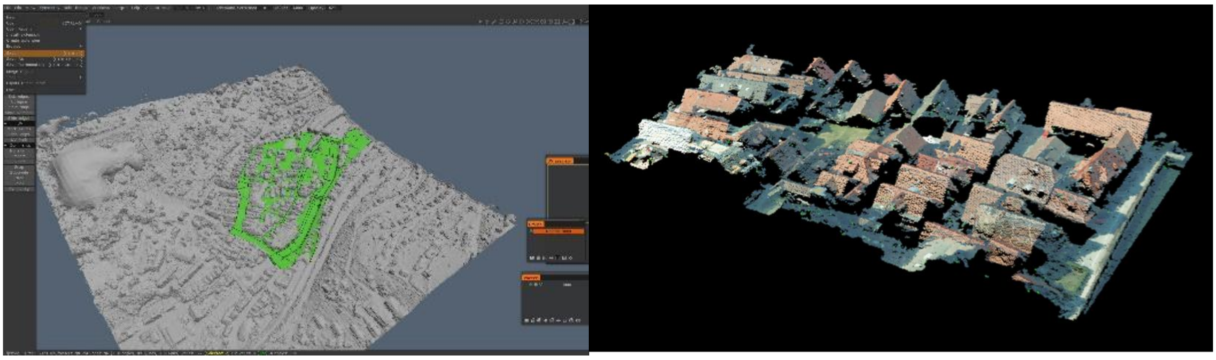


Fig. 5: (a) DIM DSM and street level alignment@20cm GSD (b) DIM roof landscape@20cm GSD

Although huge efforts in photogrammetric research have been made during the last two decades to derive 3D virtual reality building models from point clouds, the results are not yet of a sufficiently high standard of quality for direct use. Thus quite often, in-situ data collections (laser scans, photos) are used as inputs for advanced 3D and 4D modeling.

3. In-situ Data Collection and 3D Modeling

Based upon the 2.5D DEM as reference surface, about 150 fully textured 3D building models of the Calw Market Square and surrounding streets have been created, by a combination of terrestrial laser scanning, and aerial and close range photogrammetry. These Virtual Reality building models were delivered by 10 Master's Theses of the international Master's Course GEOENGINE of the University of Stuttgart, Germany. Moreover, further 3D building silhouettes were created graphically (Debevec, 1996) to complete the town's building infrastructure for the app developments.

After collecting the point clouds, mainly by terrestrial laser scanning and close range photogrammetry, every model is made up of different model elements such as points, lines, surfaces, bodies, cylinders, cones and cuboids – also a cube is introduced. The main body of the model is made from extruding a patch. To be more specific, only the objects which are larger than 20cm, are included in this modeling approach. Therefore, the level of detail of the models is only restricted to the overall shape of the facades, without considering any windows or wall trimmings on it. In order to start reconstructing the model for a building the first step is fitting planes to the point cloud. Automatic methods, as presented in Fritsch (2003) and Fritsch et al., (2013), cannot be applied here, as we require high quality 3D virtual reality models. Leica's Cyclone software delivered the 3D CAD models as first outcomes of the Master's Theses (see fig. 6a). It was demonstrated that the accuracy of the façade reconstruction is very high - almost all root mean squares are close to 0.01m. It proves that Leica's Cyclone software is reliable and effective when using point clouds to reconstruct the object surfaces. However, the reconstruction of the roof landscapes using DIM is not as precise as the façade reconstruction. Specifically, the RMS in the Master's Theses was about 0.3m, because of the coarse aerial GSD, which was 20cm. Therefore, the accuracy of the point clouds from aerial photogrammetry is weak compared with terrestrial laser scanning (TLS).

Thus, the final point cloud merger considered different accuracies in a 7-parameter transformation, implemented in the Gauss-Helmert adjustment model (Fritsch&Klein, 2017). Here, an arbitrary coordinate system (xyz) is transformed into the world coordinate system (XYZ) using control points defined in both systems.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \lambda \mathbf{R} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \qquad (1)$$

The unknown parameters are the scale factor $\boldsymbol{\lambda}$, the rotation matrix $\mathbf{R}$ hiding 3 rotations and the translation vector $\boldsymbol{t}$. A linear parameter estimation of this nonlinear equation defines the 7 transformation parameters.

All 3D CAD models delivered by the students have been textured using Trimble's Sketch-Up software (see fig. 6b). As the students are not computer graphics experts their VR models carry the texture in huge file sizes, up to 10MB for one building. In order to keep an App content minimum, all VR models of the students have been post-processed using Autodesk 3ds Max to homogenize textures and downsize the files. The final 3ds Max VR models are exported to the game engine Unity to render the VR models and to create the 3D and 4D Apps. The 4th dimension is representing the time, as the contemporary VR building models can be re-textured using photos of the past. Also this step is carried out in Autodesk 3ds Max.

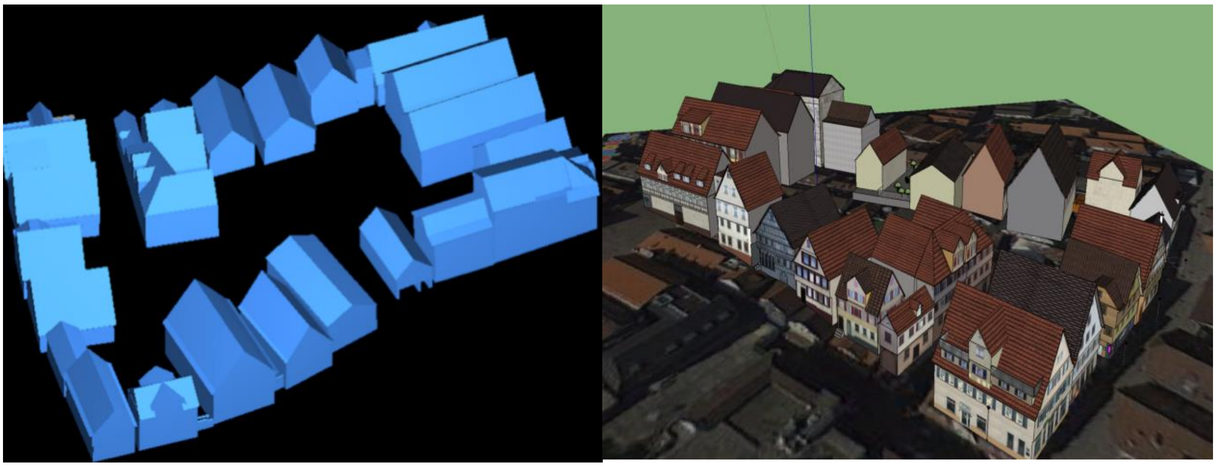


Fig. 6: (a) 3D CAD from TLS (Cyclone) (b) 3D VR model (Trimble's Sketch-Up)

4. App Developments

Computer games have been used for real-time visualizations for the past three decades (Harrison, 2003). In the meantime efficient Game Engines have been made available for App development, such as Blender and Unity.

For the development of our Apps the software package Unity is used. It is a cross-platform engine that allows for the development of video games for PCs, mobile devices and web browsers. With an emphasis on portability, the engine targets the following APIs: Direct 3D on Windows and Xbox 360; OpenGL on Mac, Linux and Windows, Open GL ES on Android and iOS, and proprietary APIs on other video game consoles.

The overall aims for the App development are given as follows: (1) Use Operating Systems Android, iOS, MacOS and Windows, (2) provide real-time 3D environments using OpenGL ES 3.0, (3) the GUI should offer auto-scaling and orientation, (4) allow for additional steering using embedded accelerometers and gyroscopes, (5) all text, audio and video narration must be available for at least two languages (English, German), (6) allow for augmentation through target tracking, (7) triggering scenes by using GPS sensors, (8) provide an interactive map display with turn-by-turn directions, and (9) overlay original site artefacts with reconstructions.

Before designing and implementing an App, a storyboard has to be defined. Storyboards are graphic organizers in the form of illustrations or images displayed in sequence for the purpose of pre-visualizing a motion picture, animation, motion graphic or interactive media sequence. The storyboarding process, in the form it is known today, was developed at the Walt Disney Studio during the early 1930s, after several years of similar processes being in use at Walt Disney and other animation studios. Designing a storyboard for an App is a very time-consuming process, but very important, as it creates for the programmer an outline of which features and functions must be fulfilled.

4.1 Calw AR Apps

The Calw AR Apps demonstrate individual buildings in 3D when using 2D ground plans as orientation for the camera of the mobile device. The link between the 2D orientation plan and the 3D model is created in Unity. Thus, every 2D plan or sketch can be extruded to 3D and 4D showing not only geometry but also semantic information, if desired.

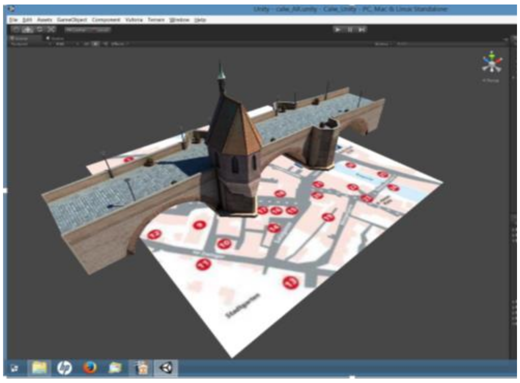


Fig. 7: (a) 3D VR model of Nikolaus Bridge (b) Unity correspondence 2D – 3D

4.2 Calw VR Apps

Fig. 8 presents the main screen of the App “Calw VR” and a street view of the Calw Market Square with the Town Hall. The 3D models of the past are generated by interactive modeling. Using vanishing line geometries the pose of a virtual camera supports the generation of 3D models, to be exported to Unity for providing App content. To view models from different eras in the App “Calw VR” a time-slide function is also offered.

Fig. 8: (a) Main screen of the Calw VR App (b) Street view of the Calw VR App

5. Conclusions and Outlook

The design and development of 3D geospatial Apps is a demanding task. Here, the cooperation between several fields is required: spatial data collection of photogrammetry plays an important role delivering raw data, that is, laser scan point clouds and photos to be processed for dense image matching and texture mapping. Computer Vision in parallel offers fast and efficient image processing pipelines to be used by non-photogrammetrists. Interactive 3D modeling is used quite often in Computer Graphics and the development of video games. Thus, collaboration is very important.

3D and time integration to allow for the fourth dimension requires effort, but is very valuable. The resulting Apps are creative tools, running on mobile devices of all kinds, and may be used in automotive Augmented Reality (AR) as well as environments for computer games.

3D and 4D Apps are also efficient tools for smart city developments. They allow for semantic data integration and story-telling at every geospatial position. Thus, the citizens may be informed about noise and insulations, energy consumptions, city climate visualisations and many more in an entertaining way using their mobile devices.

6. Acknowledgements

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7. References

Debevec, P. (1996): Modeling and Rendering Architecture from Photographs. PhD Thesis, University of California at Berkeley. Web-version available, 1996.

Fritsch, D. (2003): 3D Building Visualization – Outdoor and Indoor Applications. In: Photogrammetric Week ’03, Ed. D. Fritsch, Wichmann, Heidelberg, 2003, pp. 281-290.

Fritsch, D. (2017): Zur Integration von Photogrammetrie, Computergraphik und Serious Gaming – Photogrammetrie 4.0. Schriften der Sudetendeutschen Akademie der Wissenschaften und Kuenste, Munich, Vol. 37, pp. 143-167.

Fritsch, D., Becker, S. & Rothermel, M. (2013): Modeling Facade Structures Using Point Clouds from Dense Image Matching. Proceed. Int. Conf. Advances in Civil, Structural and Mechanical Engineering. Inst. Researach Engineers and Doctors, 2013, pp. 57-64, ISBN: 978981-07-7227-7.

Fritsch, D. & Klein, M. (2017): 3D Preservation of Buildings – Reconstructing the Past. Multimed. Tools Appl 2017, https://doi.org/10.1007/s11042-017-4654-5.

Hartley, R. & Zissermann, A. (2000): Multiple View Geometry in Computer Vision. Cambridge University Press, 655p.

Harrison, L.T. (2003). Introduction to 3D Game Engine Design Using DirectX and C#. Apress, Berkeley, CA, USA.

Hirschmueller, H. (2008): Stereo Processing by Semi-Global Matching and Mutual Information. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 30(2) 2008, pp. 328-341.

Rothermel, M., Wenzel, K., Fritsch, D. & Haala, N. (2012): SURE: Photogrammetrric Surfcae Reconstruction from Imagery. Proceed. LC3D Workshop, Berlin.

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Michael Klein, Founder and CTO of 7reasons GmbH, Vienna, is a professional in Computer Graphics and serving for more than 3 decades for computer graphics applications in archaeology and cultural heritage. He delivered astonishing deliverables for the Naturhistorisches Museum (NHM) Vienna, the outdoors preservations of the roman settlement Carnuntum, Austria, the Virgil chapel Vienna, and Haus der Geschichte Bonn, Germany, to name only view.
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