TOOLS AND WORKFLOW FOR THE RAPID ACQUISITION OF 3-D CITY MODELS

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ABSTRACT

In this paper, we describe how a virtual 3-D city model can be build from a number of data sources. After an introduction into data acquisition, we describe in detail a selection of tools which can be used to model a wide range of objects from aerial as well as terrestrial sources. Having employed a number of those tools in a project where we modelled parts of Hannover, we comment on their strengths and weaknesses. We also show the overall workflow used to finally produce a video animation of the virtual city model.

INTRODUCTION

Many applications are based on city models, which contain in particular a three-dimensional representation of the buildings and other objects, sometimes complemented by a virtual reality representation of the surfaces. Since the acquisition and continuous update of 3-D data is much more pretentious than in the 2-D case, a high degree of automation is necessary in order to make 3-D models economically feasible. Consequently, automatic methods for the acquisition and update have been and still are a topic of research. However, there are nowadays tools commercially available which allow to acquire city models from aerial and terrestrial sources. In this paper, we show how existing tools can be combined for the acquisition of a city model.

DATA ACQUISITION

Aerial images

Aerial photogrammetry has been and still is one of the preferred ways to obtain three-dimensional information of the earth's surface. Being very well understood and delivering accurate results, the major drawback is that automation of the measurement process is closely related to image understanding – being a problem hard to solve. Progress has been made since the late 1980's especially in the field of digital image matching for digital terrain model generation. However, these methods are often not well suited to derive the surface in cities where usually many sharp jump edges are present. They also strongly depend on image quality and sufficiently strong contrast between adjacent image regions.

Aerial laser scanning

During the 1990's, a new method for obtaining surface models became available: airborne laser scanning *(Baltsavias, 1999)*. Laser scanning is able to provide dense clouds of directly measured three-dimensional points. The point density and degree of preservation of jump edges makes the integration of automated processes – such as range data segmentation – relatively easy. The main drawback of airborne laser scanning is that the laser beam just samples the earth's surface in some fixed pattern; it is not capable of pointing to particular objects directly. Thus, its lateral measurement accuracy is not very high, unless very high density scanning data is used.

Close range photogrammetry

Close range photogrammetry is a very established procedure, its first roots dating back as early as 1860, where Albrecht Meydenbauer made his first investigations into architectural photogrammetry. Nowadays, there are highly automated close range measuring systems, especially in industrial environments where artificial targets can be used *(Atkinson, 2000)*. In architectural applications, the selection and measurement of points is still mostly carried out manually, however, matching and bundle adjustment procedures in the background speed up the acquisition process considerably. Powerful software packages are available nowadays, such as PhotoModeler, ShapeCapture, or Pictran.

Terrestrial laser scanning

Large progress has been made in the area of terrestrial laser scanners during the last decade. A number of scanners is nowadays available which allow to measure millions of 3-D points in a matter of minutes *(Luhmann, 2004)*. Although it is usually the case that dense terrestrial 3-D data is acquired for selected objects only, using a fixed number of viewpoints, it is worth to note that there are commercial systems under development which allow to acquire dense, large scale 3-D point clouds from terrestrial laser scanning using moving platforms *(Wack et al., 2003; Kress-Lorenz et al., 2004)*.

THE HANNOVER CITY MODELLING PROJECT

In the following, we report on a project at the University of Hannover, Germany, in which a 3-D city model was obtained using both aerial as well as close range acquisition systems. The four methods and acquisition systems were:

1) semiautomatic modelling from aerial images using inJECT,
2) automatic and semiautomatic modelling from aerial laser scanning using ATOP,
3) modelling from terrestrial images using PhotoModeler,
4) semiautomatic modelling from terrestrial laser scans using Geomagic and Cyclone.

The idea of the project was not only to obtain a model, but also to compare the different acquisition techniques, the degree of automation, the total effort required, etc.. It was also a test for the new release of our own semiautomatic city modelling tool “ATOP”. All other applications in this list are commercially available tools.

Besides acquisition, a major concern was the integration of all data sets into a single model. As our purpose was mainly the visualization of the results, we have not put any effort into the storage in databases (see *Anders, 2004*). The subsequent sections first present the overall workflow we used for building a 3-D city model, then each of the acquisition techniques as well as on the integration stage is described in more detail.

The overall workflow

We started from an aerial laser scan and 2-D ground plans, processed by the ATOP offline software. This delivered a base model of the project area of the city of Hannover. This model was derived using the automatic capabilities of ATOP and offered already correctly positioned 3-D building models with roof structures and textures. Using the integrated semi-automatic modeller the data set was then evaluated by a human operator, and roof structures which have not been acquired correctly by the automatic approach have been corrected. This model was exported in VRML (geometry) and JPEG (roof textures).

For the buildings where the exact roof structure could not be modelled using the roof types of the ATOP approach the commercial software inJECT was used. This software uses semi-automatic measurements in several mono images in order to derive roof structures. As with the ATOP approach, the buildings are modelled in terms of primitives. The result was also exported as textured VRML models.

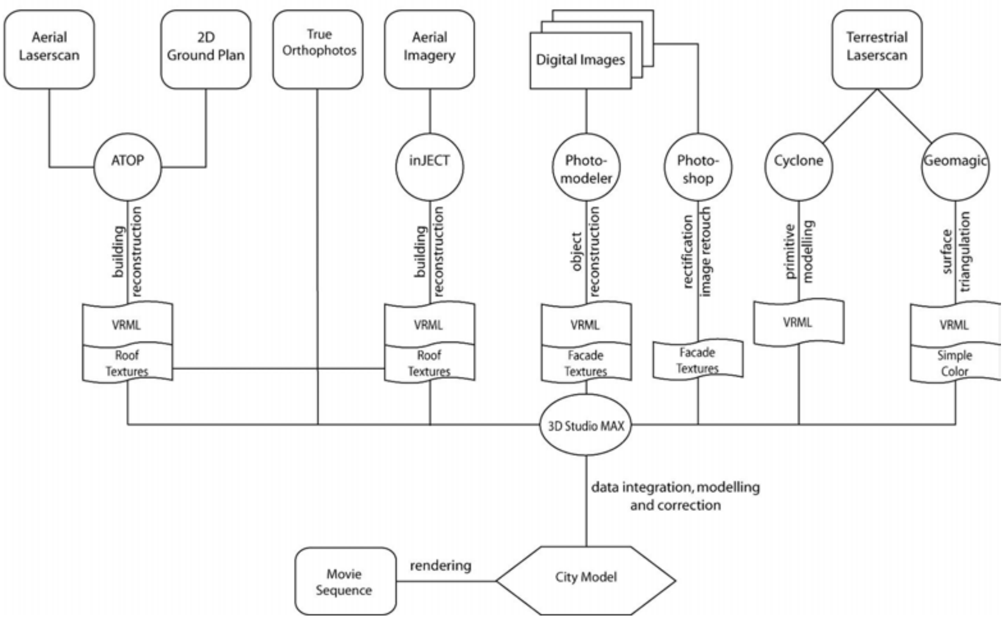

Figure 1: Overview of the workflow in the "Hannover City Model Project"

At this point, using the ATOP approach and the commercial software inJECT, an already very convincing model could be provided covering the whole project area. A ground was added with an aerial image as texture, and roof structures with texture, but the facades of the buildings – at this time of the project – were nothing more than extruded polygon edges from the ground plans which have only been provided to avoid the roof structures from floating in the air.

For the creation of more realistic realizations of the building facades, three different work-flows were figured out and have been used in this project. The acquisition of high resolution photos, the reconstruction of geometries and the rectification of the facade textures using the well known program PhotoModeler, and the processing of terrestrial laser scanning data to derive different types of elements from highly detailed facade parts to even complete building geometries. Two applications have been used for the modelling based on laser scan data sets. Free-form objects such as statues have been represented by their triangulated surface, which was obtained using the software Geomagic. For selected buildings, a detailed CAD model was derived using the software Cyclone, which is based on fitting primitives to the original terrestrial laser scan data set. Textures for these geometries have been acquired separately using a Nikon D100 still image camera. The rectification was done using the imaging application Adobe Photoshop. There are also specialized tools like rectifyIt, however Photoshop has been used to reduce the amount of training and because this software offers all functions for image management, cropping, rectification, image editing, composition and simple radiometric corrections.

After all buildings and elements were reconstructed to the desired extend, the goal was to visualize the results. Different ways are conceivable, as there are still images, animations and video-sequences or navigable 3D environments. The decision for the user-sufficient way of visualization is application-dependent. The creation of still-images or animations can be performed with any 3-D modelling software which is capable of handling the amount of data which is needed for the visualization (e.g. 3D Studio MAX, Maya, Cinema 4D, etc.), but for the creation of a free or even limited navigable 3D environment, one has to enter the first league of visualization soft- and hardware. In recent computer games like Star Wars Rogue Leader the user can navigate in large 3D environments, but the path of navigation is limited, so every possible position has been pre-rendered. Nowadays, the usage of game engines for the visualization of general environments becomes feasible *(Fritsch and Kada, 2004)*.

For the Hannover City Modelling Project, the creation of a video-sequence has been selected as the best way for a judicious visualization solution. The whole 3D-project has been integrated into the modelling application 3D Studio MAX and a six minute movie has been rendered.

Modelling from aerial images using inJECT

The commercial application inJECT is a semi-automatic application for the reconstruction and measurement of 3D building models using digital imagery. Instead of single point measurements, the tool allows to place complete primitive shapes – such as saddleback, ridge, flat roofs – in the scene, which are then adjusted by a few mouse clicks and automatic measurement routines. Measurement is done in mono images so that no special hardware or training is needed (Figure 2). The tool is able to export the measured shapes in VRML, ACIS, or DXF.

From our experience, it was possible to use the tool after a one day tutorial. Drawbacks were seen in the missing ability to link objects, for example to enforce adjacent buildings to having exactly the same height. Also, no curved surface objects are available such as cones or hemispheres. The VRML export is quite slow in the current version and it produces one texture image for each face which leads to a huge number of images hard to handle by subsequent visualization tools.

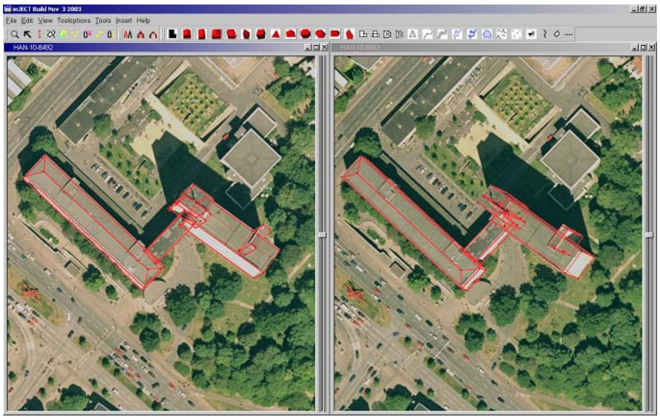

Figure 2: Snapshot of inJECT during digitization of a complex building.

Modelling from aerial laser scan data using ATOP

We use our ATOP approach for city modelling from aerial laser scan data. It starts from a laser scanning digital surface model (DSM) and 2-D ground plans of buildings, which provide strong information on building extents. The method uses two phases. In phase one, a fully automatic process generates an initial reconstruction for all buildings. For relatively simple buildings, this reconstruction already reflects the 3D structure properly. For more complex buildings, rework is required, which is done in phase two using a semiautomatic modeller (see Figure 3).

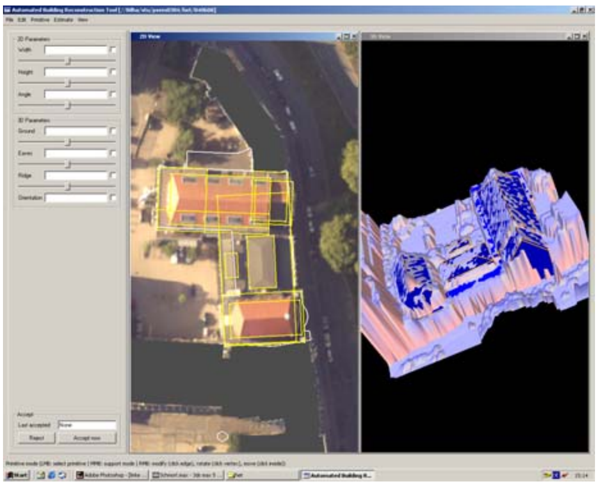

Figure 3: Reconstruction of a complex building using the semiautomatic ATOP modeller.

The system basically relies on the decomposition of ground plan polygons into two-dimensional primitives. Each two-dimensional primitive is the footprint of a corresponding three-dimensional primitive. The parameters of the roof, namely roof type (from a fixed library), height of the building and roof slope are determined using a segmentation and least squares adjustment. The advantage of this approach is that by using existing ground plans, high level (symbolic) information is "injected" into the reconstruction process, which makes it more reliable. Also, since the two-dimensional information is used as a starting point, links between the original database and the final three-dimensional database are established.

The ability to automatically reconstruct a city model was found to be useful, since one gets a first impression quickly and further steps can be planned already, such as the definition of a virtual flight path for rendering a film. Nevertheless, in the densely built-up area used for this project, buildings were complex and had to be reconstructed mostly using the semiautomatic modeller. Due to the limited scan data density, the reconstruction of small structures such as dormers is difficult. The limited number of primitives in the current version was also identified as a drawback.

Modelling from close range images using PhotoModeler

PhotoModeler is a PC-based photogrammetric measurement tool. It offers the reconstruction of the third dimension using 2-D digital images. The operator can start with only a few images to keep the project concise and add additional images in later steps of the project. The main benefits of this application are the software guided workflow, and the very easy way of point-measurement and image orientation, even the calibration of the camera, which has been used for the acquisition is possible. Following the manual point-measurement, the image orientation and the creation of the 3-D point cloud is performed fully automatically. In the first step only the third dimension for every measured point will be derived. To create 3-D building models, the operator has to construct every relevant edge, as well as the definition of the faces, manually.

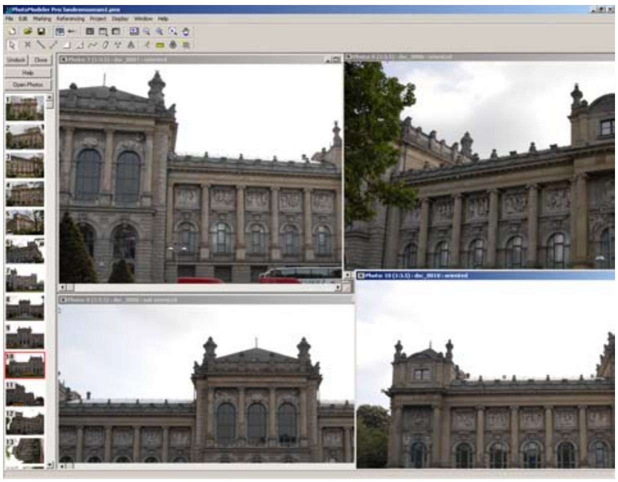

Figure 4: Close range photogrammetric measurement using PhotoModeler.

Facade textures are extracted and rectified automatically, so the final result is a full-textured 3-D building model. The complexity of the reconstructed 3-D building models is only limited by the amount of points, selected by the operator, and processed by the application.

Modelling from terrestrial laser scan data using Geomagic Studio

Geomagic Studio is a powerful tool for reverse engineering of surfaces. It has a rich functionality, including point cloud processing (noise reduction, outlier removal, thinning), alignment of different data sets, triangulated surfaces (triangulation from points, smoothing, hole filling, triangle reduction), and NURBS modelling. In the project, we used it to model free-form surfaces of statues, which were captured using our Riegl LMS Z360 terrestrial scanner.

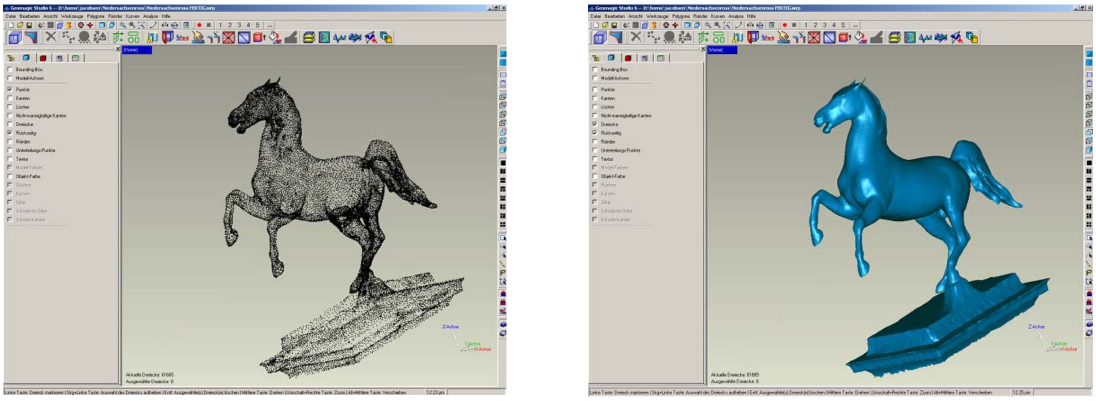

Figure 5: Using Geomagic Studio to model the "Horse of Lower Saxony". Left: Thinned point cloud from laser scanning. Right: Triangulated surface after editing.

In our experience, there was quite an amount of manual work required to obtain models such as the one shown in Figure 5. At least with our laser scanner, due to noise and measurement from different viewpoints, we had a huge number of cases where the automatic surface merge produced double surfaces and incorrect topologies. Those areas had to be cut out and filled manually, which is very time consuming. Concerning textured surfaces, a shortcoming of Geomagic Studio (Release 6) is that it does not produce textured triangles as output, given coloured scan points. Thus, when the number of triangles is greatly reduced, the colour-per-point output produces much too coarse surface colours. (Polyworks has a module, IMTexture, which is able to produce reduced triangulated surfaces with texture maps.) A general point is that Geomagic hides many details on what the algorithms really do, obviously to make it usable for non-specialists. However, due to this, the user is often in doubt when being asked to set specific parameter values.

Modelling from terrestrial laser scan data using Cyclone

Cyclone is a multi module software system, one module being devoted to deriving CAD models from point clouds. It is usually bundled with Leica laser scanners, however it can also be purchased separately. Cyclone allows to fit simple primitives, namely planar patches, cylinders, and spheres, to scan data. This is done using a region growing where the seed regions are specified by the user interactively. Apart from this, there are other operations such as digitizing lines and curves, extrusion, etc.. We combined terrestrial façade scans with aerial scan data for the roof in order to be able to model entire buildings.

When using Cyclone to model façades, a major obstacle was to obtain closed surfaces. Since patches are extracted individually, they have to be connected manually in a second step. There is a point snapping functionality, however it does not work well when more than two patches meet in one point. As a result, there are usually small gaps between the patches. There is also no support for texturing the surfaces.

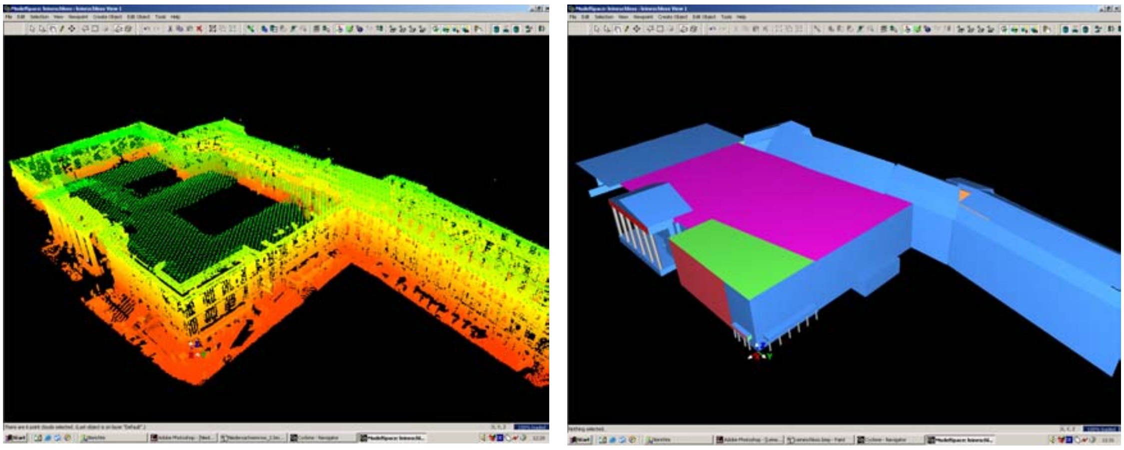

Figure 6: Modelling of the Leine palace in Hannover using Cyclone. Left: Terrestrial and aerial scan data. Right: Model made from planes and cylinders.

Integration of data sets using 3D Studio MAX

For the visualization and therefore the rendering of a video the software 3D Studio MAX (3DS) has been used. The data interchange in the whole project was done using the VRML standard, as it is supported by most applications and can be easily edited manually.

At the beginning the results from the ATOP approach have been imported to 3DS together with the aerial image of Hannover as ground texture, already providing a very realistic visualization. The path of the camera for the final animation has been created based on this scene. Selected buildings in the vicinity of the path have been reconstructed with the inJECT software to enhance the geometry and the visual impression.

Using a 6 mega-pixel digital SLR camera, texture facades have been acquired and mapped to the 3D-buildings. Buildings which are very well-known for the cityscape of Hannover or have an important meaning for tourism, politics and business, have been additional created by using primitive modelling in the 3D-point cloud acquired with a terrestrial laser scanner. Also very important elements like objects of art and statues have been scanned with a following triangulation of the point cloud to derive a closed surface. Alternatively some buildings received a more detailed façade which has been created using digital images and PhotoModeler.

After all buildings and elements have been integrated into 3DS, a sky map and automatically extracted trees from TreeFinder (Straub 2004) were inserted. In the last step, the animation was rendered following the prior created camera-path.

Project Size for the complete 3D City model of Hannover.

- Project size 4 GB
- 3DS Scene file 162 MB
- Video sequence 842 MB (6 min. AVI-File)
- Objects in Scene 439 (without trees)

- Total amount of polygons 820103
- Render time approx. 5:25 h
- Most complex single object: Ernst-August monument (Rider on horse), 374506 polygons.

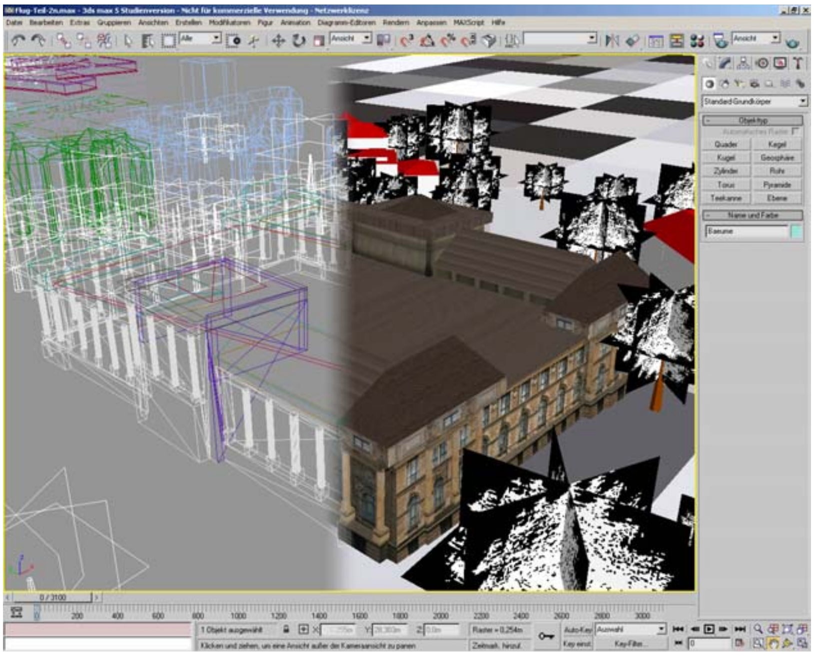

Figure 7: Final scene in 3D Studio Max.

The amount of polygons which were used for the Ernst-August monument seems to be excessive. Nevertheless, this was chosen because the visual impact of this object was very impressive and it demonstrated the high quality which can be obtained for free-form objects by using terrestrial laser scanners.

The whole project itself was handled using a dual-processor 3 GHz Pentium 4 Workstation with 2 GB of RAM, which should be considered as minimum system requirement in order to be able to handle the scene interactively.

Conclusions

In this paper, we have first discussed general aspects of the acquisition of 3-D city models. Then, we have detailed a workflow for modelling objects from close range as well as aerial sources. We have presented the software packages used in the “Hannover City Model Project” and commented on their main features and drawbacks.

To draw an overall conclusion, to build a city model using aerial and close range sources is still a major undertaking, as one runs easily into hardware and software limitations. Nevertheless, it is nowadays possible to realize such a project using standard off-the-shelf products. From an education viewpoint, we can recommend this very much as a student project, since the students get in touch with a number of sensors and tools as well as with integration, a “production chain” and the need for project management.

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LINKS

The links are for information only and do not imply any recommendation by the authors.

3D Studio MAX	http://www.discreet.com/3dsmax
ATOP	http://www.ikg.uni-hannover.de/forschung/vw_stiftung/index.en.html
Cinema 4D	http://maxon.net/jumps/cinema4d_portal_e.html
Cyclone	http://hds.leica-geosystems.com/products/cyclone5.html
Geomagic	http://www.geomagic.com/products/studio/
inJECT	http://www.inpho.de/
Maya	http://www.alias.com/eng/products-services/maya/
PhotoModeler	http://www.photomodeler.com/
Photoshop	http://www.adobe.com/products/photoshop/main.html
Pictran	http://www.technet-gmbh.com/index.htm
Polyworks	http://www.innovmetric.com/
RectifyIt	http://www.ifp.uni-stuttgart.de/private/Boehm/RectifyIt/intro.html
Riegl	http://www.riegl.co.at/
ShapeCapture	http://www.shapecapture.com/
Slim-3D	http://www.3d-shape.com/produkte/slim_d.php

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