

## Towards Virtual Reality GIS

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### ABSTRACT

Due to the rapid developments in the field of computer graphics tools allowing for the real time visualisation of complex 3D data are becoming available also for standard applications. One example is the visualisation of urban landscapes within GIS. This type of application additionally profits from the fact, that meanwhile the required urban models can be collected area covering and efficiently based on aerial data like stereo images or LIDAR. Nevertheless, the requirements for data collection are still increasing due to the current spread of visualisation applications. One example is the generation of realistic visualisations from pedestrian viewpoints. In such a scenario the viewpoint restrictions of airborne platforms do not allow for the collection of sufficient image texture and geometric detail for the facades of the buildings. Since this information is required to guarantee a good visual appearance of the urban model from pedestrian perspectives, additional data has to be provided. Thus, terrestrial sensors have to be applied. Frequently, virtual reality presentations of urban areas also require the integration of additional objects representing vegetation and street regions. Within the paper these data requirements for virtual GIS will be discussed. Additionally, the potential of integrating tools from computer graphics for this type of application will be demonstrated. As an example, programmable graphics hardware is used to provide a time efficient solution of complex geometric tasks to be solved during texture mapping of 3D building models.

### 1. INTRODUCTION

While the use of GIS was originally restricted to the processing, analysis and presentation of 2D geospatial data, the integration of 2.5D data like Digital Terrain Models soon became available as a standard feature. Meanwhile, there is a further trend towards 3D virtual reality GIS. These systems can represent and handle complex three-dimensional objects like buildings and allow for real-time visualisation applications. This trend has been triggered by the ongoing advancements in 3D data collection and presentation. As an example, real-time visualisation and exploitation of complex 3D data is already feasible by standard hard- and software components. For this reason, virtual reality techniques enabling the interaction with real or imagined environments are integrated in an increasing number of applications like electronic games, surgical training, or construction designs. The rapid developments in the field of computer graphics have also supported the use of virtual reality components within standard GIS. As an example, within the project GISMO at the Universität Stuttgart, the real-time large-scale visualisation of an urban area was realised exemplarily for the city of Stuttgart. Based on Open Source software and standard PC a 50\*50 km area with 36.000 building models could be rendered at interactive frame rates. In general, such virtual reality GIS are mainly used for the presentation of existing, imaginary, past or planned landscapes. Potential areas of application are in urban planning, tourism, real estate presentation, personal navigation, or cultural heritage documentation.

Virtual city models, which are required for these applications have become a standard product of photogrammetric data collection. However, different purposes like architectural planning or heritage documentation on the one side or landscape overviews on the other side require the availability of a different amount of detail. Thus, different sensor configurations have to be applied. Within the paper these requirements will be discussed in the following section. While section 3. will mainly focus on the collection and visualisation of 3D building objects, the integration of additional objects representing urban vegetation and streets is discussed in section 4. Additionally, throughout the paper, different examples will demonstrate how the use of virtual GIS will influence the way geo-data is collected and presented.

## 2. VIRTUAL LANDSCAPE MODELS

Virtual reality GIS are mainly applied for visualisations of urban landscapes. For this purpose 3D city models have to be available to represent the relief by a Digital Terrain Model and the sites by 3D building models. A number of applications additionally require the availability of transportation objects like streets or railways including tunnels and bridges. Other GIS objects of interest can represent water bodies, vegetation objects, and so-called city furniture like street lights, traffic lights, and benches.

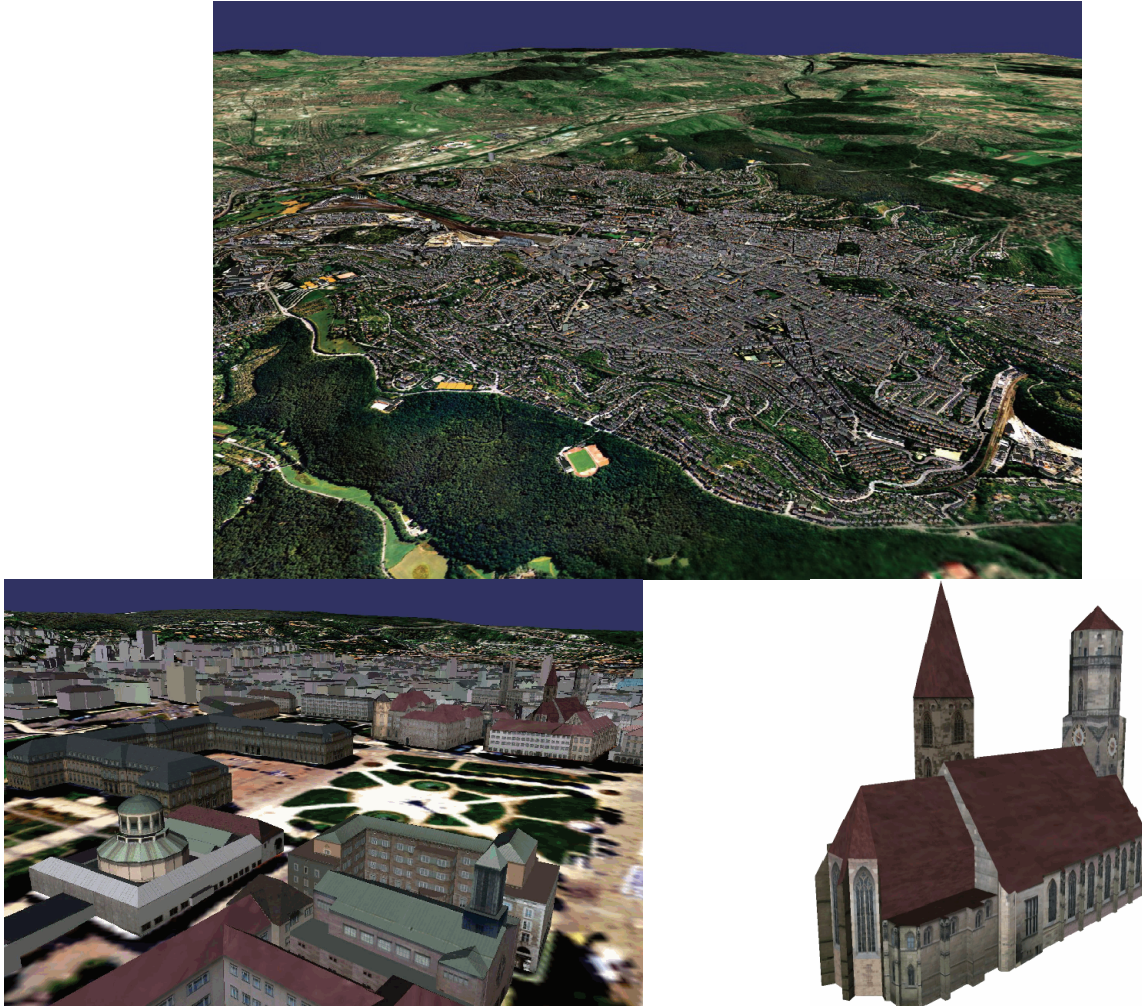


Figure 1: Different levels of detail for visualization of urban landscapes.

The development of tools for the efficient collection of 3D city models has been a topic of intense research for the past years. A good overview is for example given in (Baltsavias, Grün, van Gool 2001). Meanwhile, a number of algorithms are available, which are usually based on 3D measurements within airborne stereo imagery or LIDAR. In addition to the provision of such semi-automatic tools, the need for a standardization of 3D city models has been realized. Thus, a better interoperability and integration of different data is feasible. As an example, four categories can be defined in order to classify the different levels of details of city models (Kolbe & Gröger 2005). According to this categorization level of detail (LOD) 0 relates to a regional model, which is represented by a 2.5D Digital Terrain Model and LOD 1 refers to a city or site model defined by a block model for the buildings without roof structures. In LOD 2 buildings are already available with differentiated textured roof structures. Detailed architecture models have been generated in LOD 3, while the interior of the building is integrated to generate walkable models in LOD 4. This defini-

tion is similar to the different visualisation categories in urban planning. These categories are separated into visualisations of a complete city by a bird's view at a height of the virtual observer more than 200m, presentations of smaller districts at oblique views at distances from 200m to 5m, and pedestrian perspectives for the visualisation of places and single buildings (Danahy 1999).

### 3. COLLECTION AND VISUALISATION OF BUILDING OBJECTS

As already discussed, complete sets of 3D building models can be provided efficiently using airborne data collection. The collected 3D models usually represent the footprints and the roof shapes of the buildings. While this level of detail is sufficient for a number of applications, the viewpoint restrictions of airborne platforms frequently limit the amount of detail, which can be made available for the facades of the buildings. For this reason visualizations of building models collected from airborne data are mainly useful for overviews from elevated viewpoints. This is for example demonstrated in the top image of Figure 1. In contrast, a number of applications in the context of urban planning or 3D navigation require visualizations with a very high degree of realism for pedestrian or only moderately elevated viewpoints. This type of visualization, which is depicted exemplarily in the bottom row of Figure 1, is only feasible, if data from terrestrial platforms are additionally available. This can be realized by approaches like close-range photogrammetry or terrestrial LIDAR measurement. These methods allow for an autonomous collection of virtual city models. However, the existing models from airborne data collection should be integrated during evaluation in order to increase the efficiency of such terrestrial data processing.

#### 3.1. Texture mapping from terrestrial imagery

As an example, texture mapping for building facades can be realised easily if a 3D building model is already available. In that case correspondences between the model and the respective terrestrial images have to be defined. For this purpose a GUI can be used, which enables a human operator to provide such corresponding primitives. However, this manual process is too time-consuming, if a large number of buildings have to be processed. Alternatively, the co-registration of image and model data can be determined directly. In order to directly link the image and object space the exterior orientation of the camera at the time of exposure can be measured by an appropriate sensor system. This type of information is for example available from vehicle based mobile mapping systems, which integrate CCD cameras and laser scanners with GPS/IMU devices for direct georeferencing (Talaya et al 2004). Nevertheless, the large expenses of inertial measurement units will usually prevent the use of such high-end systems for standard applications. However, direct georeferencing can alternatively be realized by low-cost components like a navigation grade GPS and a digital compass, if the resulting approximate exterior orientation is further refined. For this purpose an automatic matching of the image against a 3D CAD model of a visible building as it is provided from the 3D virtual city model can be realized. This has for example been demonstrated by localizing the visible silhouettes of the depicted buildings based on a shape-based-matching approach (Haala & Böhm 2003). After the matching, checkpoints can be generated automatically from the 3D coordinates of the visible building model in order to improve the exterior orientation by a spatial resection. Further refinement of the exterior orientation is feasible by a modified spatial resection using corresponding linear features, which can be extracted very accurately by standard image processing algorithms (Klinec, 2004).

Once the camera parameters and the exterior orientation are available, the 3D object coordinates of the geo-referenced building model can be linked to the corresponding coordinates of the texture image. Based on this information, the presentation of the textured model by a standard VRML viewer is feasible. Nevertheless, the quality of visual realism is limited since these viewers only



allow for simple transformation during texture mapping. As an example, complex geometric image transformations to model a perspective rectification or lens distortion are not available. For this reason, these effects are usually eliminated before texture mapping by generating ‘ideal’ images, which are then used as an input for the standard viewer.

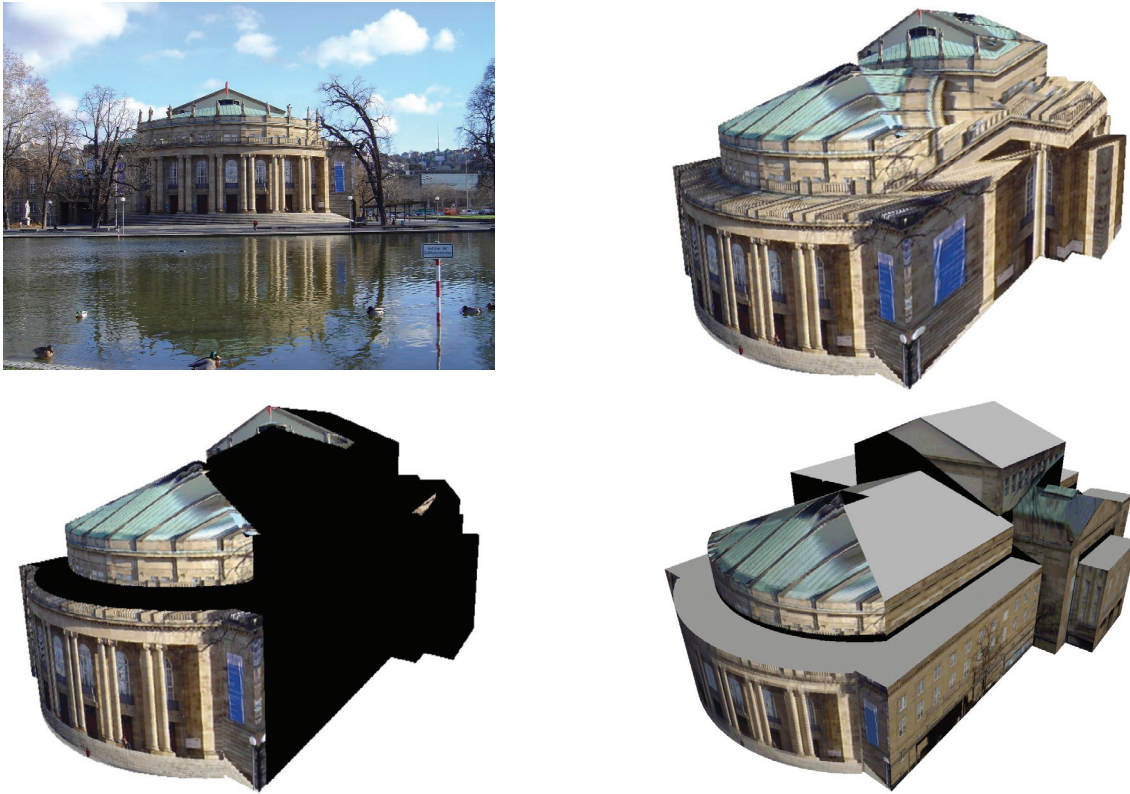


Figure 2. Results of texture mapping using programmable graphics hardware.

Alternatively, as it is depicted in Figure 2, these distortions can be eliminated on-the-fly using programmable graphics hardware (Kada et al 2005). Since this approach is based on technologies that can be found in today’s commodity 3D graphics hardware, time efficient solutions are feasible even using standard systems. The applied graphics processing units (GPU) are optimized for the transformation of vertices and the processing of pixel data. However, as they have evolved from a fixed function to a programmable pipeline design, they can now be utilized for various fields of applications using high level programming languages. Thus, in addition to their great computational power, programmable graphics hardware also allows the direct implementation of complex algorithms. In our application, this was used to additionally solve problems resulting from self-occlusions and to integrate multiple images during texture mapping. Additionally, the façade texture is directly extracted from the original images. Thus, a generation and storage of intermediate images is not required. Finally, façade textures of higher quality are available since image pixels only have to be interpolated once within the whole mapping process. For the application shaders were used to realize specialized projective texture lookups, depth buffer algorithms and an on-the-fly removal of lens distortions for calibrated cameras.

In Figure 2 the original input image is depicted top left, the automatically textured building model with the occlusion culling disabled and enabled is visible in the top right and bottom left image, respectively. In the bottom left image invalid texture pixels are marked by black pixels. Finally, the texture mapping from multiple images with selected occlusion free pixels is depicted exemplarily in the bottom right image of Figure 2.



Figure 3: Image collected from high resolution panoramic camera with textured building models.

In addition to the use of standard cameras, panoramic images can be applied to further increase the efficiency of the texture mapping process (Haala & Kada 2005). Frequently, panoramic images are generated by the combination of several overlapping images from simple digital cameras and for example provided for tourist purposes in internet applications. In contrast, as it is demonstrated in Figure 3, high quality panoramic images can be captured by dedicated camera systems, which allow a precise photogrammetric evaluation. As it is depicted exemplarily in the top left image of Figure 3, texture for a considerable number of buildings is available from a single scene, especially if the panorama is collected from an elevated point. In addition to the reduced amount of images to be processed, the application of panoramic scenes allows to minimize changes in illumination, since the images can be collected within short time intervals.

### 3.2. Geometric refinement using terrestrial laser scanning

Façade texture can substitute geometric detail at least for a number of building objects. Nevertheless, some applications still require a considerable geometric refinement, especially if large scale visualization is aspired. For this purpose, dense 3D point clouds can additionally be used, which are captured by terrestrial laser scanning. As a first processing step these point clouds, which are usually provided from multiple viewpoints, have to be transformed to a suitable reference coordinate system. For this purposes, usually coordinates of signalized targets are provided in the selected reference frame. However, similar to standard image georeferencing, considerable manual effort is required for such a control point measurement. In order to speed up this process, direct georeferencing can again be used. As already discussed in section 3.1. low-cost components like navigation grade GPS and a digital compass provide an approximate position and orientation. In our approach, the resulting coarse georeferencing of the laser point clouds is then improved using a 3D city model, which is available from airborne data collection (Böhm & Haala 2005).



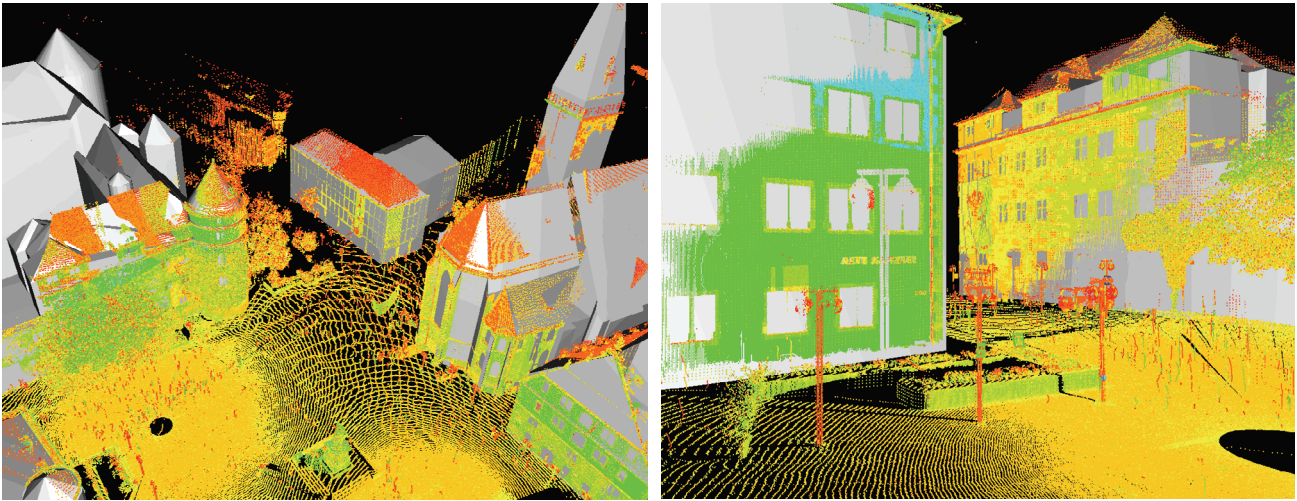


Figure 4: Overlay of existing building model and LIDAR data.

As it is depicted exemplarily in Figure 4, the point clouds can be aligned very well to building models, which are already given in the required reference frame. For this purpose, standard algorithms for surface registration like the iterative closest point approach are used (Besl & McKay 1992). Usually, these algorithms require manual interaction to provide a coarse alignment of the different scans. However, fully automatic processing is feasible in our approach since this information is provided from the GPS and digital compass measurements.

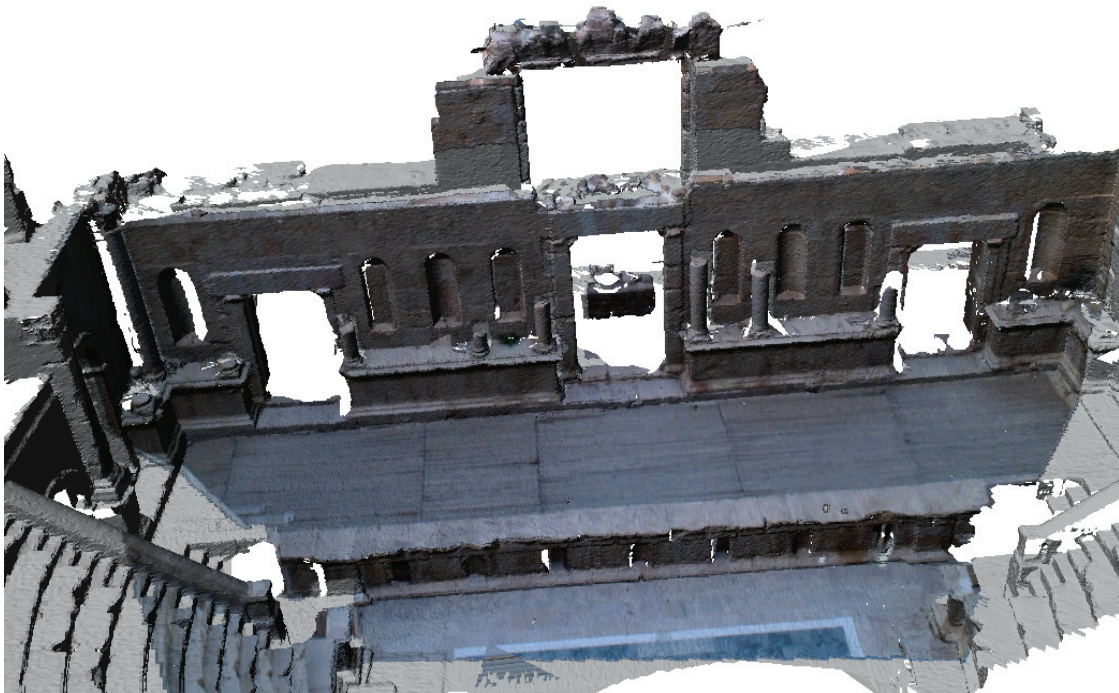


Figure 5: Textured reconstruction of a Roman theater based on terrestrial LIDAR.

While some visualizations in the context of urban planning can be realized based on a relatively simple building models, much more geometric complexity is required in the context of heritage documentation. In this context, frequently large-scale virtual reconstructions of buildings and monuments are provided by surface representations based on triangulated LIDAR points. As it is depicted in Figure 5, high quality texture is additionally integrated from terrestrial imagery (Alshwabkeh & Haala 2004). Thus, also this type of visualization application votes for an integrated processing of multiple data sources.

#### 4. INTEGRATION OF VEGETATION AND STREET OBJECTS

The visualisation of landscape models that only feature terrain and building data without any vegetation objects tend to look dull and lifeless. Especially trees are important visible elements within landscape planning applications (Ervin & Hasbrouck 2001), thus they have to be integrated, if a high degree of realism is aspired.

One option to realise the visualisation of trees is the application of a texture mapping. For this purpose a side-view photograph of a real plant is projected onto a 3D face, such as a rectangle. This so-called billboard technique allows a simple use of 2D images for the visualisation of 3D scenes. The applied photographs of the trees are most useful when made against a solid color background such as the sky. This background can then be isolated and set transparent in order to just visualize the plant during the rendering process. This approach usually provides a good degree of realism with comparatively low effort. However, during animations it is necessary to rotate the rectangles with the mapped tree images in order to keep its orientation perpendicularly to the viewing direction. For this reason, the faces seem to be lying flat on the terrain if observed from a bird's eye view. Hence, the billboard method is mainly used for low viewing azimuths like pedestrian scenes with a relatively low resolution.



Figure 6: Application of SpeedTreeRT to visualise realistic looking trees in real-time.

Alternatively, realistic visualizations of plants from close viewpoints can be generated based on automatic plant-modelling. These approaches make use of the fact, that the configuration of plants follows relatively simple rules. Thus, 3D models of trees and other plants can be generated despite of the complexity of plant forms. Modern software tools apply rather simple basic branching and recursion algorithms to generate remarkable botanically-correct plant forms within a wide range of parameters of shape, size, and complexity. The integration of such trees to a visualisation of Stuttgart, which was realised by integrating the commercial tool SpeedTreeRT within our GISMO application is depicted exemplarily in Figure 6.



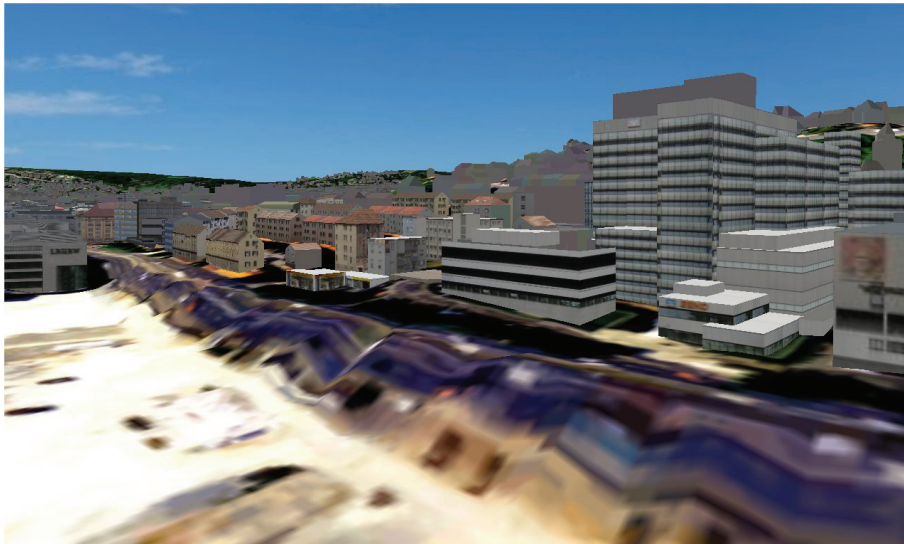


Figure 7: Visualisation of a street region based on using low-resolution DTM.

In order to provide the required position of trees, a combined analysis of aerial images and LIDAR data can be applied (Straub 2003). Other objects like streets, which can also be used to improve the visual appearance of a virtual city model are frequently already available. Figure 7 exemplarily shows a visualisation based on a DTM with a relatively low resolution of 10m. The disturbing effects, which result from the tilted street surface are clearly visible. Even though DTM at higher resolutions are available, they will frequently be sub-sampled before rendering in order to speed up the visualization process. This simplification will again result in a visualization of street region, which is not satisfying.

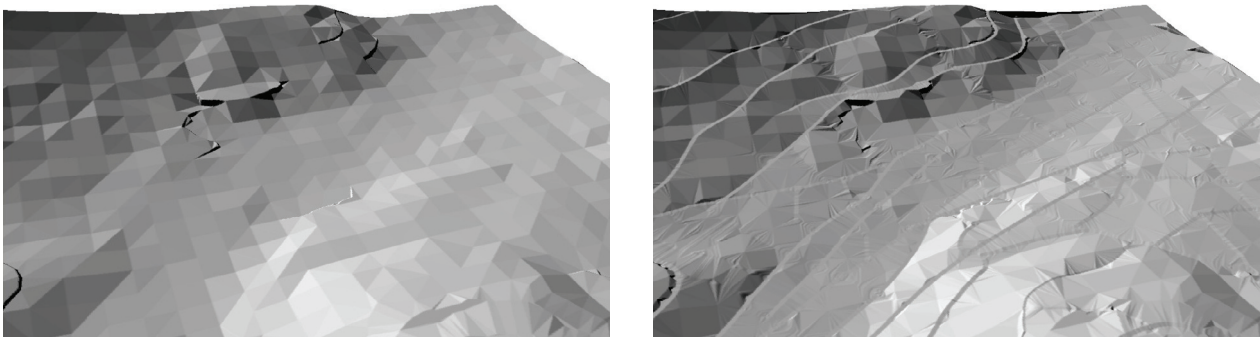


Figure 8: DTM of Stuttgart before (left) and after (right) integration of street data.

As it is depicted exemplarily in Figure 8 the visual appearance of such regions can be improved considerably, if street objects, which are for example available from the ATKIS-DLM are integrated in the DTM processing (Kada et al 2004). Similar information can also be provided from Geographic Data File (GDF), which is a European standard format used for car navigation purposes.



## 5. CONCLUSION

Photogrammetric applications can benefit considerably from current advancements in the field of computer graphics. Within the paper this was demonstrated by an automatic texture mapping of building objects, which was realized using programmable graphics hardware. This development additionally results in the integration of virtual reality components like the photorealistic representation of landscapes within GIS. However, impressive visualization requires a large amount of geometric and graphical detail. Thus, for visualisation applications, data collection from terrestrial sensors is required in addition to the use of standard airborne platforms. However, the efficiency of this terrestrial data collection can be increased considerably, if available information from airborne platforms is additionally integrated. Within the paper, this was demonstrated by a georeferencing process for terrestrial image and LIDAR data, which was supported by existing 3D building models from airborne data collection.

Despite the considerable progress of data collection, the required effort for virtual reality presentation of urban landscapes is still considerable. However, visual realism is not really necessary for all applications (Döllner & Walther 2003). This is for example demonstrated by the principles for drawings, which have been developed in cartography for the presentation of urban scenes. Frequently historic panoramic maps or bird's-eye views of cities prefer abstraction to realism. By these means despite the rich contents a high degree of visual clarity and a visually pleasing design is realised. These principles like the presentation and accentuation of orientation cues like landmark buildings should also be considered, if applications like pedestrian navigation are aspired. Hence, in addition to approaches for the collection of urban data, the spread of virtual reality GIS will also require a further improvement of computer based rendering techniques in order to select and present the information, which is really useful within the respective applications.

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