

# DOCUMENTATION OF COMPLEX FACADES AND CITY MODELLING THROUGH THE COMBINATION OF LASERSCANNING AND PHOTOGRAMMETRY

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## ABSTRACT:

One of the consequences of the introduction of digital image processing into photogrammetry consists of the possibility to generate digital orthophotos of facades. Solutions offered by orthophoto modules customary in trade are usually based on a flat undistorting procedure.

Hitherto, such orthophotos were mostly used for quick documentation of “simple” facades or indoor walls. Considering the costs, one had to accept the shifting reproduction of elements situated outside the undistorted area.

Now, thanks to the rapid progress of the 3D laserscanning technology, the fast registering of complex three-dimensional objects through a dense net of 3D - measuring points has finally become possible. The laserscanner measures several thousand points per second, thus, data acquisition for a single position is finished after only a few minutes. Through a number of scans performed on locations (“scan position”) chosen around an object of interest, even niches, windows a.s.o. can be registered.

The respectively different methods of laserscanning and photogrammetry complement each other ideally: laserscanning allows gaining extremely precise and detailed 3d models in a relatively short time. Photogrammetry provides the matching realistic texture. Therefore, the calculation of totally undistorted “true orthophotos” even for complex facades is no longer impossible. However, as the scanned geometry is primarily three - dimensional and produces “overhangs”, procedures known from airborne photogrammetry have to be adapted. In practical conditions, one should furthermore consider occurring relevant changes of light-exposure in the pictures of facades used for further processing.

The method to be presented in this paper consists of transforming the scanned geometry through orthophoto projection – parameters into a “depth-picture”, followed by the calculation of the true orthophoto. The depth picture and the appropriate accompanying true orthophoto are of the same dimensions, thus allowing a combination resulting in a 3D Orthophoto.

The 3D Orthophoto represents a precise „spatial image” of the original, and may therefore be used for three - dimensional mapping out of areas of interest. While carrying out the mapping in CAD, the depth information stays at the operator’s constant disposal. Hence, the 3D Orthophoto enables:

- Digitalisation of depth-relations vertical perpendicular to perspective view,
- Automatic calculation of profiles,
- Three - dimensional mapping of lines and surfaces, and
- Automatic transformation of mapped out elements of the view into the system of the object

Two software modules appropriate to the method to be presented in the following sections, CityGRID Ortho for calculation of the 3D Orthophoto and “Scandig 3D” for analysis in AutoCAD, are at general disposal.

## 1 INTRODUCTION



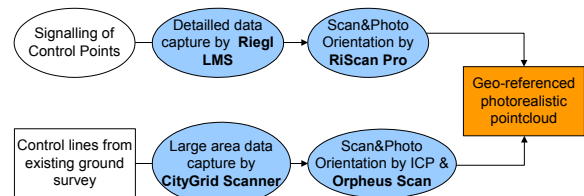
With ongoing research, many ways of creating city models can be found in literature. Following the traditional approach roof modelling is done from aerial photogrammetry and later extrusion of facades. Due to standards of modern multimedia, a significant drawback of such models gets more and more evident: The poor representation of the facades. In consequence of an increasing demand for photorealistic reality, these models can hardly be presented to the public.

These obstacles can be overcome at a reasonable price by 3D laserscanning and digital photogrammetry. As one of the first of all manufacturers, RIEGL Laser Measurement Systems provides hybrid systems for rapid data acquisition based on 3D laserscanners and high resolution digital cameras.

From that data, efficient 3D modelling can be performed by GeoDATA’s CityGRID software. For sustainable creation of value, the management of such citymodels is done by a database system, providing data for applications such as cultural heritage documentation, architectural restitution, city planning or virtual reality walk throughs.

In the following sections we would like to introduce a practical workflow for data acquisition, 3D modelling and maintenance of city models.

## 2 DATA CAPTURE



Depending on the area of interest we developed two scenarios for data acquisition. The first method is based on control points. Using surveyed control points it is possible to gather the required data in a fast way and tremendously simplifies the afterwards geo-referencing task. The whole process can be done in the RIEGL companion software RiSCAN PRO.

Wherever there is no possibility to signal control points (e.g. large area, no direct access to the objects) data acquisition can be done by CityGRID Scanner. The more complex geo-referencing process is based on an iterative

closest point (ICP) algorithm for relative orientation and control lines for absolute orientation. Both methods deliver a geo-referenced photorealistic pointcloud.

## 2.1. Detailed Data Capture

The hybrid sensors presented below are composed of a high-performance long-range laser scanner with a wide field-of-view and a calibrated high-resolution digital camera firmly mounted to the scanning head of the laserscanner. As for every image taken with the camera the position and orientation of the camera is measured with high accuracy within the scanner's own coordinate system, scan data and image data can be combined in a straightforward way without the need of user interaction.



Figure 2-1. RIEGL mobile scanning platform MSP-250

Figure 2-1 shows such a hybrid sensor based on an instrument series of RIEGL 3D imaging sensors. In order to cover the wide vertical field-of-view of the LMS-Z420i sensor of 80 deg, the focal length of the camera has to be 20 mm or less for a full-sized CCD or CMOS chip camera to capture images covering the whole vertical scan range.

The system is complemented by a data acquisition system based on a standard laptop. For convenience in numerous applications, both sensors, laser scanner and camera, are connected to a small portable USB server and subsequently to a wireless LAN hub so the data acquisition PC can be setup remotely. Data acquisition, sensor configuration, data processing and storage are done by the companion software RiSCAN PRO. The whole system is battery powered and highly portable, but yet robust and operable in a wide range of environmental conditions.

The Mobile Scanning Platform MSP-250 is especially designed to ideally complete the fast and efficient workflow with the RIEGL 3D Laser Scanner Systems. An extremely stable and easy to assemble system allows fast setup and single operator performance: transportation of the complete system for data acquisition from different positions and of single parts after dismantling. In combination with a Wireless LAN data transmission unit, the system can be operated independently and remotely controlled from any distant, safe position. Easy installation of the scanner unit by simply tilting of the well balanced

platform. Only while moving from one scan position to the next, the wheels touch the ground. In the upright scanning position, three ground contact points provide stable support.

## 2.2. Large Area Data Capture

CityGRID Scanner is a mobile mapping platform for cost efficient data acquisition of cultivated areas. Mounted on suitable vehicles (pick-up truck, Minivan,...) it is possible to collect data by means of a laser scanner and digital cameras. All sensors are mounted on a lifting/rotating unit. Therefore it is possible to run the sensors at approx. 4.2m over ground, which means a significant increase of visibility concerning ground obstacles (e.g. parked cars). The use of industry proven components for lifting/rotating unit, processors, independent power supply and sensors simplifies maintenance. The combination of the horizontal attached laser scanner and the rotating unit enables the user to capture a 360 degree scene up to the zenith. This opens field for a variety of applications - including closed environment applications.



Figure 2-2. CityGRID Scanner

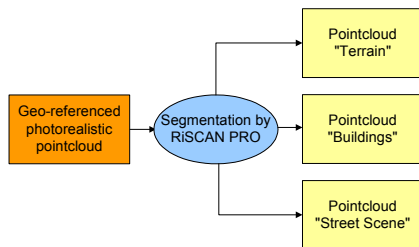
CityGRID Scanner is operational at two different modes:

1) Dynamic mode: The dynamic mode is meant for rapid data capture for texturing purposes of large areas in an economic way. CityGRID Scanner collects data mainly via the digital cameras with auxiliary scanner data. Driving through the streets at approximately 5 km/h the system triggers both cameras alternately, resulting in photo sequences of 5-7 fold overlap. Due to the vertical offset of the cameras, this leads to a zigzag base, which improves the semi-automatic photogrammetric post processing. Simultaneously the laser scanner measures the horizontal profiles of the passing facades for better geometric stability.

2) Stop-and-go mode: At special objects of interest or areas where no further geometry information (e.g. cadastral surveying) is accessible, it is possible to scan the entire scene. This is done by stop-and-go mode. Scanning special objects of interest is done by moving along the facades and scanning overlapping vertical strips with simultaneously triggered cameras. So each dataset consist of one scan and two photos. This strategy aims at a complete coverage of the object with photos and scandata for complete

modelling. A more area-based approach is to use 360-degree scans in a loose sequence. One 360-degree scan is realised by scanning six sectors of 60° field of view each. The resulting overlap – *RIEGL LMS Z420i* has a FOV of 80° - is used for control purposes. The precise rotating unit guarantees an automatic and accurate positioning of the scanner. Hence, such a 360-degree scene covers the whole semi-sphere of one scanposition. This scanning strategy recommends itself for open space areas, such as public places, courtyards, and urban corridor situations (e.g. streets,etc...).

### 3 MODELLING

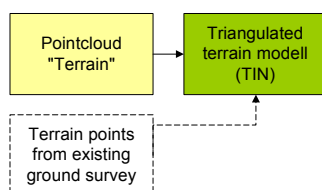


Data acquisition with *RIEGL* laserscanner such as the mobile scanning platform MSP-250 or CityGRID Scanner delivers high density point data. This data is the source for all further processing. Now, depending on the intended use of the citymodel, different approaches of modelling are requested for the various objects represented by the pointcloud. Generally a typical scan of a city scene can be described by three different classes:

- a) Pointcloud 'terrain'
- b) Pointcloud 'buildings'
- c) Pointcloud 'street scene'

Besides the thematic attributes, these groups also separate by their level of complexity. The strategy presented in this paper aims at a hybrid representation of the city model, where most geometric object (buildings) and the terrain are replaced by their wireframe description, whereas all non-shapeable objects are represented by the pointcloud itself. The side-effect of this strategy is the reduction of the huge amount of data as a matter of fact of lasers scanning. Along go the increase of usability and a decrease of the hardware requirements to handle such models. Therefore it is necessary to segment the pointcloud. This task can be done in *RiSCAN PRO*, providing an intuitive selection mode for fencing, masking and cut-away operations.

#### 3.1. Terrain Modelling



Actually, conventional survey, aerial photogrammetry and airborne laserscanning are regarded as possible data sources for terrain models.

We would like to stress out the possibility to use the terrestrial scandata to build up a high density local digital surface model. As practical experience shows collecting data from a slightly heightened position, significantly increases the usability of scandata for DTM computation.

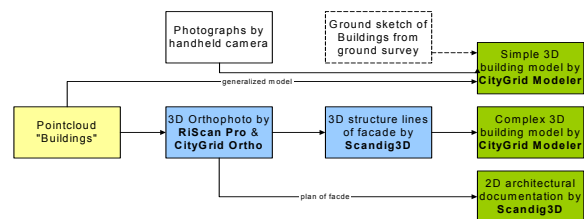
Of course, already existing DTM can be improved by this data!

The resulting terrain model should be stored as a triangulated network.

Computing the TIN out of scan data, results in a rather dense mesh representation of the surface holding a lot of small triangles. This leads to a blown-up representation of the terrain, which unnecessarily burdens the used hardware system. In order to keep the city model lean and usable, we strongly recommend the use of a terrain modelling software to optimize the TIN.

The created terrain model can then be imported to CityGRID Modeler.

#### 3.2. Building Modelling



As said before one has to take into account the later intend of use of the city model. According to this, three different products can be derived:

1. Simple model for rapid visualization
2. Complex model for detailed inspection
3. 2D plan for architectural documentation

#### 3.3. Simple Building Model

To keep down the expenditure of time to build up a wide area city model from the scratch, we assume the 'simple model' approach to fit best. The modelling itself is done in CityGRID Modeler using the combined photo-laser scanner data obtained by *RIEGL* laser scanner or CityGRID Scanner. The main principle is to derive significant lines out of the segmented pointcloud 'building'.

The first step is the construction of the ground sketch of the building. One way is to import ground information such as cadastral maps into CityGRID Modeler. In areas where no accurate cadastral information is available, the other way is to derive this information by means of horizontal sections of the laser data.





Figure 3-1. Building modelling from hybrid scandata.

Furthermore the laser data deliver very accurate relative height information of the buildings. This information is used to raise the ground sketch, thus obtaining the horizontal upper edges of the façades.

The next step is to complete the block building model with its appropriate roof model. The generation of the eave lines can be done assuming a constant protrusion. Furthermore some information about the ridge lines is necessary. For this task, additional information about the roof structure is needed. This information can be obtained by a knowledge based approach. Practical experience shows that scanning the buildings from raised scanpositions usually delivers some information about the roof. Approximation of additional parameters, such as slope, in combination with a general knowledge about the roof forms can be used for quite accurate reconstruction of the ridge lines.



Figure 3-2. Simple building model: planar façades with textures from single photos

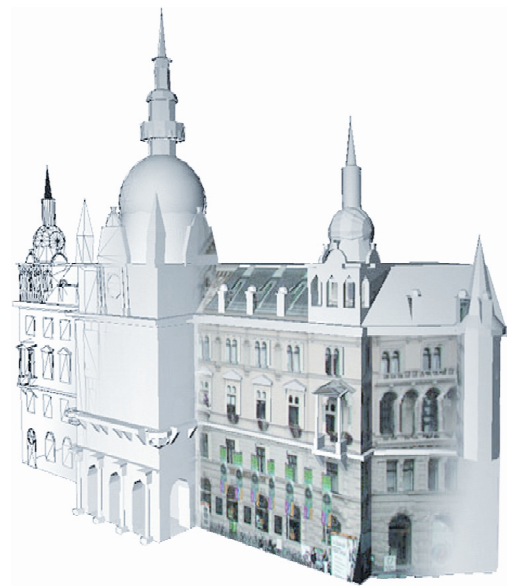
Finally CityGRID Modeler creates wire frame models of the buildings to store in the data base. For visualization purposes, surface models can be derived automatically.

Additionally CityGRID Modeler provides a built-in texturing module, where the photos taken during the scanning process can be used to map textures onto façade surfaces.

Maintenance of the city model is done by CityGRID Manager.

### 3.4. Complex Building Model

For objects of special interest, it is possible to generate a more complex model. As a matter of fact this modelling process is more time consuming than the simple model approach described above. It has to be stressed out, that complex modelling as well is based on the pointcloud 'building' as data source. Therefore simple building models can be refined as complex models later on. In contrast to the flat façades of the simple model as described in sec.3.3 the complex model approach deals with more structured façade and roof geometries. The key elements of this modelling are break lines. This necessary information can be obtained by analysis of 3D Orthophotos of the objects. Importing all break lines of a building into CityGRID Modeler results in a complex wire frame model of the building. For a more detailed description of 3D Orthophoto computation, please refer to sec 3.5



(a) (b) (c)

Figure 3-1. Representation of a complex building model, showing from left to right: (a) wireframe model, (b) surface model, (c) textured model

### 3.5. Architectural Restitution

The 3D Orthophoto is suitable for architectural restitution as well. All relevant line information can be mapped in addition to the break lines mentioned above. Collateral profiles may be derived from typical sections of the façade by simply drawing a line on the 3D Orthophoto. Furthermore solid models of architectural elements can be derived interactively. The following subsections sets focus on the computation of 3D Orthophotos for architectural restitution and 3D Orthophoto analysis.

Generation of orthophotos with depth information (3D Orthophotos):

Orthophotos are widely used in the field of architecture. Orthophotos have been generated usually by applying a perspective image to a coarse geometrical model, in the simplest case to a plane representing, e.g., a façade. However, distinct distortion can be observed when the

geometry is not modelled accurate enough. The combination of laser scanning and imaging by using a hybrid sensor enables the automatic generation of high-quality orthophotos by modelling the geometry from the scan data and by applying the images as a texture to the modelled surface. The resulting image is addressed also as a True Orthophoto. In this paper the combination of the pictorial information of the True Orthophoto with its underlying geometry/depth information is addressed as 3D Orthophoto. Generation starts with defining the projection plane, the front and back clipping planes, the extent of the orthophoto, and its resolution. The user specifies the scan positions which should contribute to the orthophoto. The implemented orthophoto algorithm follows a two step strategy. The first part can be interpreted as the 3D path, where all necessary 3D operations are done. The second part is referred as 2D path, where the final texturing takes place. First of all, all selected scans have to be transformed into one common coordinate system. Usually, this is the project coordinate system. This step is followed by the triangulation of all scans. Due to the basically regular data structure, this task is done by a simple examination of the scandata topology.

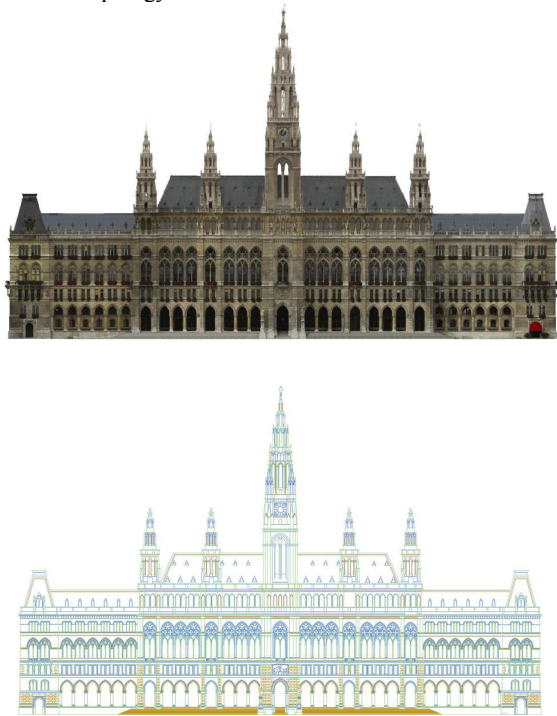


Figure 3-2. 3D Orthophoto computed out of 83 single scans and 88 photos with an overall length of 155 metres and 98 metres in height.

The resulting mesh also contains triangles not situated on the object's surface. This often occurs at the edges of a building. Therefore all triangles have to be validated regarding this criterion. All following steps aim at the selection of all valid triangles. To speed up computation time, this task gets inverted to the disclosure of all invalid triangles, regarding the clipping/projection planes and their spatial orientation. All triangles having passed this test, contribute to the final orthophoto and thus need to be textured. This is done in the second part of the algorithm – the 2D path. Knowing all triangles to be textured, inevitably leads to the problem of finding proper photos showing the suitable content. Due to the used scanning strategy, overlapping series of pictures are quite usual,

hence yielding to several candidate pictures for texturing. As a matter of fact, this photos show different colouring, due to different exposure times, what necessarily requires some colour selection/averaging processing. In the end, the surface is rendered using an orthogonal camera model viewing the projection plane. After completion of rendering, the rendering context holds the orthophoto. The z-buffer used for rendering can be used to generate a relief. Additionally to the image data, CityGRID Ortho generates a so-called ZOP file containing the depth information for every pixel of the image and additional parameters to locate every pixel in the project coordinate system. This data set, image and depth information can be imported to CAD systems with the help of third party plug-ins, so the user can easily digitize elements based on the orthophoto in 3D. As mentioned before a powerful tool for this task, is ScanDig3D. This software is available as AutoCAD plug-in and fully supports the 3D Orthophoto concept. ScanDig3D acts like an optimized toolbox which makes work easy. Even persons unfamiliar with AutoCAD can easily query 3D Orthophotos. All functions are combined in a single menu point, a single object oriented form provides all necessary functions in a context sensitive manner. ScanDig3D offers points, lines, isolines, areas and 3D solids. These data types are administrated as thematical layers, enabling the straightforward representation of complex 3D structures. ScanDig3D tools are integrated in the drawing. Therefore, all AutoCAD users can work with ScanDig3D data structures and query data.

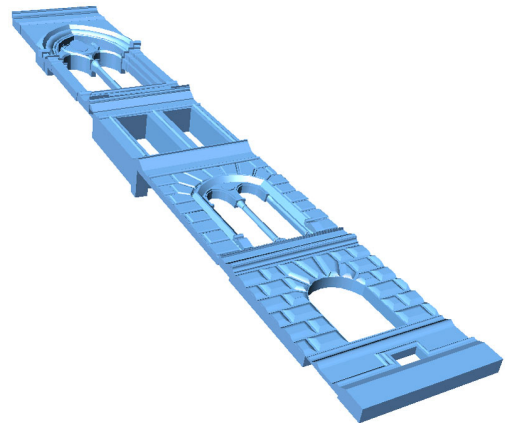


Figure 3-3. 3D solid model of a scanned facade

### 3.6. Street Scene

The pointcloud 'street scene' acts as a container for all yet non-shapeable objects. It does not matter, whether the reason for why they are not modelled is to speed up time for building up a city model (e.g. street illumination), or they are simply too complex (trees). Due to the underlying database, objects can be easily moved into other containers later on.

Nevertheless this data already exist and there is no reason not to use it. We therefore prefer a hybrid representation of modelled objects and non-modelled objects. This hybrid representation can be done in CityGRID Explorer.

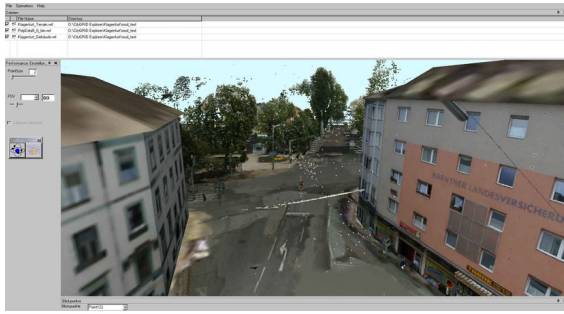
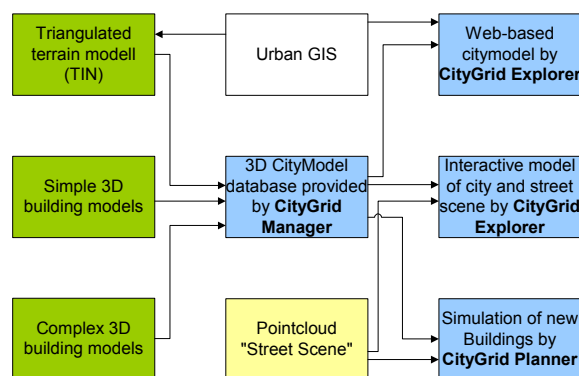


Figure 3-4. CityGRID Explorer showing a hybrid visualization of a city model. Buildings are modelled as 'simple buildings' with CityGRID Modeler out of scandata taken with CityGRID Scanner. Trees and traffic signs are shown as pointcloud 'street scene'

This system module was designed to handle huge amounts of pointdata, in addition to virtual city models.

Models and pointdata can simply be loaded and unloaded at any time. The basic interface is the VRML standard. Augmenting a conventional made city model with actual pointdata achieved by a laserscanner significantly increases the level of reality and recognition. Regarding single buildings, it is possible to visualize any changes of the building fabric, due to some reconstruction or civil works.

#### 4 MANAGEMENT AND REPRESENTATION OF CITY MODELS



The very goal of the CityGRID Manager is to store and maintain large area city models, consisting of several 100000 buildings. (E.g. Vienna: 300000)

Thus the CityGRID Manager is based upon a commercial data base management system (Oracle, SQL). It has to be pointed out, that the wire-frame model –in opposite to a surface model- is optimally suited for being maintained in relational databases.

For smaller applications the database management system can be replaced by a XML based file system.

For representation of citymodels the software package contains the module called CityGRID Explorer. As said before this tool is for visualization of single/hybrid data models. Its worth mentioning, that this software does not rely on the data base. Therefore and because of its full interactive capabilities CityGRID Explorer meets the requirements for a useful stand-alone pack-and-go tool for visualization and presentation.

CityGRID Planner was designed to help planning authorities to insert CAD models of new buildings into the city model. Equipped with drawing and construction

facilities it is possible to visualize variants of civil constructions regarding existing objects.

Summing up, the Manager module is the core of the CityGRID system, which guarantees sustainability when operating a city model. It handles the TIN and the simple/complex building models and provides this data for applications like CityGRID Explorer or Planner or third party applications communicating via XML interface. Actually the management of pointclouds is not implemented yet, so this task has to be done by conventional GIS

#### 5 SUMMARY

Generally we deem the combination of photogrammetry and laserscanning best for large area building survey. Taking the geometry from laserscanning and the pictorial information from the photos, delivers a rather complete dataset for photorealistic modelling. A further advantage is the rapid and reliable data acquisition. On the other hand it is quite evident, that this method of surveying needs an extra eye on data management. Handling several gigabytes of data, we consider a data base driven software package as inevitable.

Thanks to ongoing research and development, the present lack of data management and postprocessing software is more and more diminishing. As our contribution, this paper tried to introduce the RIEGL and CityGRID software package consisting of several modules:

- The RIEGL mobile scanning platform MSP-250 and the CityGRID Scanner for data acquisition.
- CityGRID Modeler for building modelling
- CITYGRID Ortho for Orthophoto computation
- ScanDig3D for architectural restitution
- CityGRID Manager for model maintenance
- CityGRID Planner for simulations of what-if situations
- CityGRID Explorer for visualization

#### References

CityGRID by GeoDATA IT, <http://www.citygrid.at>

RIEGL Laser Measurement Systems, <http://www.riegl.co.at>

ScanDig3D by Christe, <http://www.scandig3d.com>

Kerschner, M., Sükar, G., 2004. Generating, managing, and utilising, 3D city models with CityGRID system. In: Proc. 1<sup>st</sup> International conference on virtual city and territory.