

Aspects on True-Orthophoto Production

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ABSTRACT

In many occasions orthophotos in the background of GIS applications enrich their presentation. Often they serve for data capturing. Geometrically such images possess a defined, homogeneous geometry. One produces orthophotos since several decades with ever increasing demands and performance in quality and quantity. However, large-scale city orthophotos using standard algorithms and procedures typically have following problems: (a) Displacements and occlusions make it difficult to superimpose vector data for checking and change detection purposes; (b) The orthorectification of the image is partly geometrically inaccurate and/or incomplete (i.e., buildings are distorted from their true location as they are not modelled in the DTM). By using Digital Surface Models (DSM) and considering occluded areas it is possible to generate True-Orthophotos which do not have above mentioned problems. In this article the aspects on the generation of True-Orthophotos will be discussed. Different methods and economical aspects to build up the DSM for the True-Orthophoto production will be mentioned.

1. INTRODUCTION

Orthophotos were initially made from aerial film images, i.e. aerial photographs and thus the name "orthophotos". The name is in so far misleading, as there exist no "ortho-photo-apparatus" but only ortho-projectors. In the early days the aerial image was projected onto a plane. This was the analog age and the process was named rectification. With the introduction of analytical devices, i.e. computer and servo controlled opto-mechanical devices, one achieved the next level of quality. One intensified the use of small, piecewise projection driven by terrain profiles. Digital terrain models (DTMs) were from then on part of the method, which was named "differential rectification". With the introduction of scanned aerial images "digital ortho-projection" came into use rather successfully. Digital ortho-projection can use finer, more detailed DTMs and thus increase in quality over analytical ortho-projection. Production speeded up significantly as well. But the real potential of digital ortho-projection was not yet exploited. The major artifact of geometrically inaccurately projected man-made objects such as buildings and bridges remained inherent through all of these evolutionary stages of ortho-projection, as DTMs model the earth surface without man-made objects.

Orthophotos generated with a DTM have typically following shortcomings:

- a) Perspective displacement and areas occluded by objects like buildings
- b) Partly geometrically inaccurate and/or incomplete orthophotos

Above mentioned shortcomings make it impossible to superimpose vector data of man-made objects for checking and change detection purposes and makes it impossible to measure the correct position of such objects in the orthophotos.

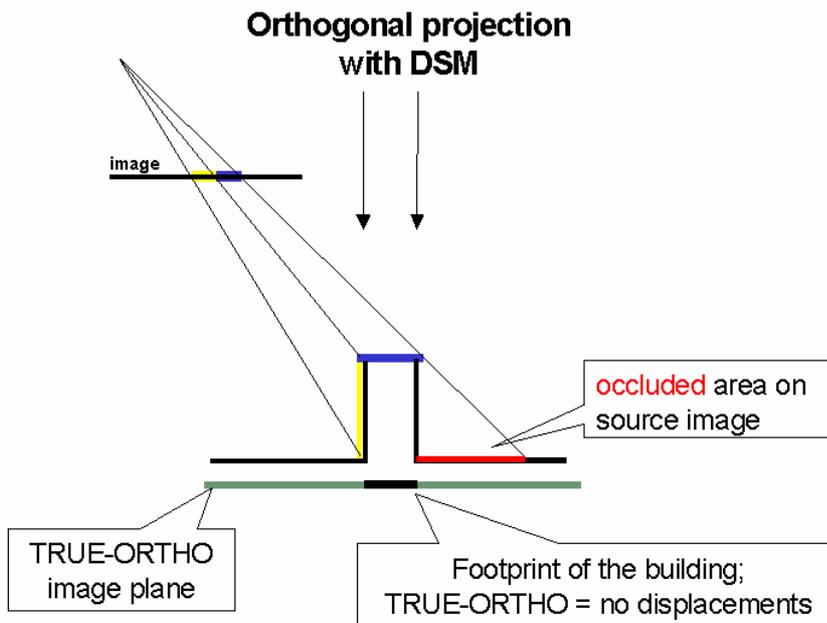
The use of Digital Surface Models (DSM) is the key for highest quality orthophotos. Orthophotos generated with a DSM overcome such shortcomings but raise the following problems:

- a) Occlusions which occur in the single images have to be filled up by combining several overlapping orthophotos. But often not all occluded areas can be filled up as not enough overlapping orthophotos are available.
- b) Rooftops have to be modeled in the correct way as otherwise they are distorted in the orthophotos or they show up with unsharp borders. To model all kind of rooftops accurately and in detail can be complicated if computed automatically or time consuming if measured interactively.

2. TRUE-ORTHOPHOTO GENERATION

The generation of True-Orthophotos (Mayr, 2002a,b) has to consider the orthogonal projection with a DSM, the detection of occluded areas and the filling up of the occluded areas by taking the missing image parts from overlapping orthophotos. All examples below are generated with OrthoBox from INPHO GmbH. OrthoBox consists of OrthoMaster for orthophoto generation and OrthoVista for orthophoto mosaicking and radiometric image enhancement.

2.1. Orthogonal projection with DSM



Assuming an error free georeference of the source image, e.g. aerial image, the ortho-projection basically is as accurate as its underlying surface model. And this phrase contains already the main topic, i.e. "surface model". In case of having a DSM available the man-made objects will be projected to the geometrically correct position. Figure 1 shows the scheme of the ortho-projection with a DSM, which is a perpendicular parallel-projection.

Figure 1 Scheme of TRUE-ORTHO projection with a DSM



Figure 2 Ghosting effect due to the use of a DSM in a city without detection of occluded areas, even if the building is correctly rectified

The problem is that areas occluded by the man-made objects are not visible in the image. In Figure 1 the roof of the building also covers the occlusion area in the aerial source image. If such areas are not detected by the orthophoto rectification software the ortho-projection will just fill it up with image content from the same image. This then leads to so-called ghosting effects. The orthophoto in Figure 2 shows such ghosting effects.

2.2. Detection of occluded areas



Figure 3 Orthophoto with occluded areas marked in white

In order to overcome such ghosting effects one has to detect the occluded areas. This is done by considering the line of sight from the projection center to a specific object point on the DSM. With one source image and a DSM it is possible to mark occlusion areas in the orthophoto.

2.3. Filling up occlusion areas

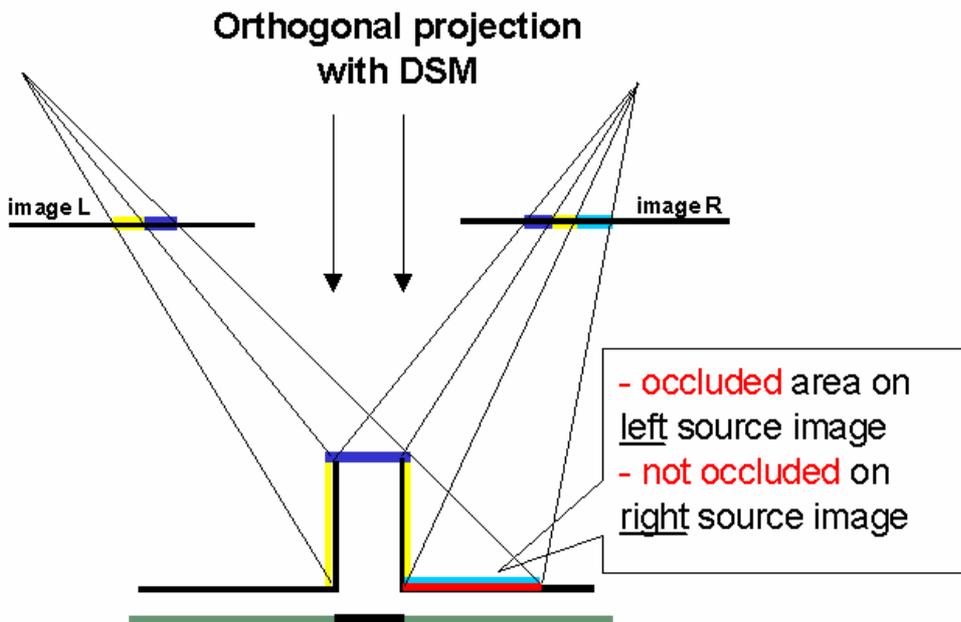


Figure 4 Occlusion area in left image can be filled by using image contents from right image

By combining image information coming from several source images it is possible to fill up occlusion areas.

With a DSM and overlapping source images from different views, e.g. an aerial image block, one can generate overlapping orthophotos all of them having the occlusion areas marked. By fusing them in overlapping areas, all parts of occluded areas which are visible in one of the orthophoto can be filled up with real image information. This process must be very intelligent as all images with their different radiometry have to be considered, the seam lines have to be found automatically and the orthophotos have to be fused in a way that later on it is no more possible to see that the final mosaic was computed with image content coming from several images. Otherwise the mosaic would be a patchy carpet.



Figure 5 True-Orthophoto produced with OrthoBox. Occlusions automatically replaced by using several overlapping orthophotos.

An orthophoto based on a DSM and with replaced (fused) occlusion areas is known as “True-Orthophoto”. It is “true”, since it truly projects man-made objects, e.g. buildings, in the perpendicular parallel direction onto the orthophoto plane.

3. MODELLING OF MAN-MADE OBJECTS

The man-made objects, to be modeled for True-Orthophotos can be very versatile. All kind of bridges, buildings with saddleback or hipped roofs, but also towers and steeples could occur. The objects could have any kind of forms like rectangular, irregular or round. One has to answer the question with which level of detail man-made objects have to be modeled. Is it necessary to measure object borders and if yes how accurately do they have to be measured and how detailed? Furthermore the models of the man-made objects have to be blended with a DTM, which is built with e.g. mass-points, single-points and breaklines.

3.1. Requirements on the modelling of man-made objects

Experience with different data sets have shown, that it is not enough to model the objects just by using a simple box around the buildings. All superstructures of the objects which are not modeled will be rectified to a wrong position in the True-Orthophoto, which will be offended by the customers as such objects appear disturbed and look unnatural. Object borders which are inaccurately measured and thus inaccurately modeled appear in the orthophoto blurred and odd. The following examples of one building block shall demonstrate these problems. To present the problem more clearly here, the occluded areas in these examples are not filled up by image information.

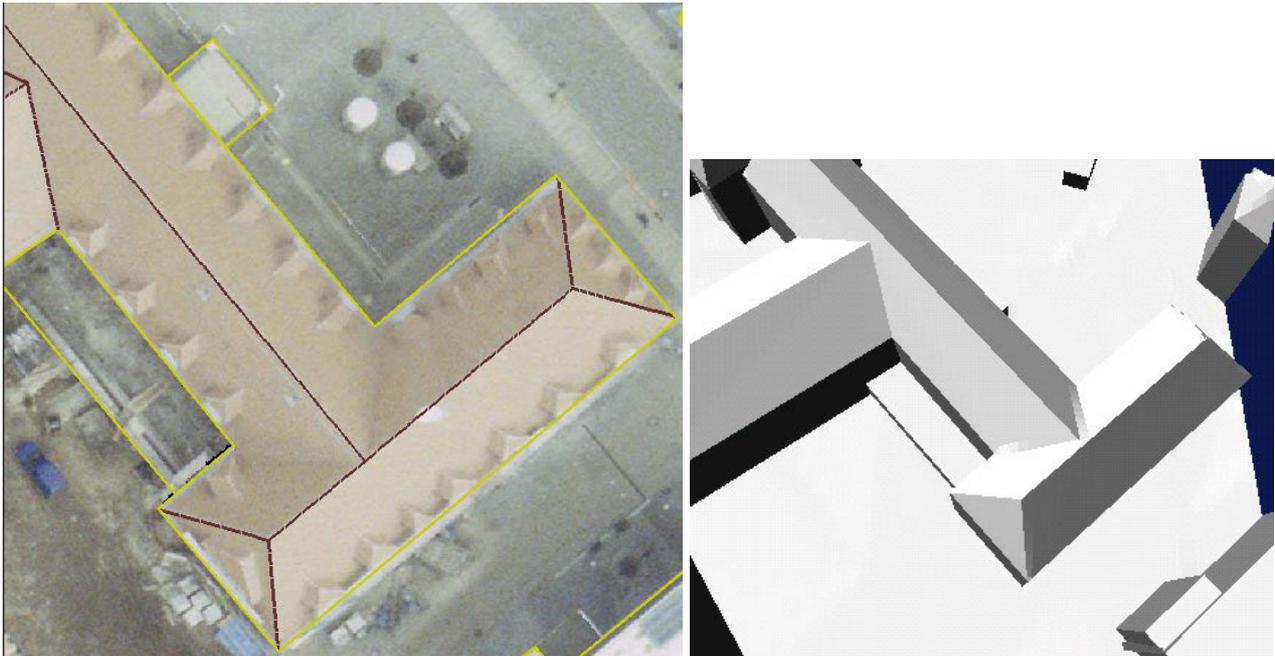


Figure 6 Left image: True-Orthophoto detail with modeled roof top.
Right image: Corresponding building model.

In Figure 6 the roof border and ridges of the building block are exactly measured. This leads to a correct positioned building in the True-Orthophoto. The True-Orthophoto has the building borders (yellow vectors) and roof ridges (brown vectors) overlaid. The measured borders of the building and the roof ridges are sharp in the building model (shown on the right) and therefore also in the True-Orthophoto. The dormers are not measured as they are quite small which is not disturbing.

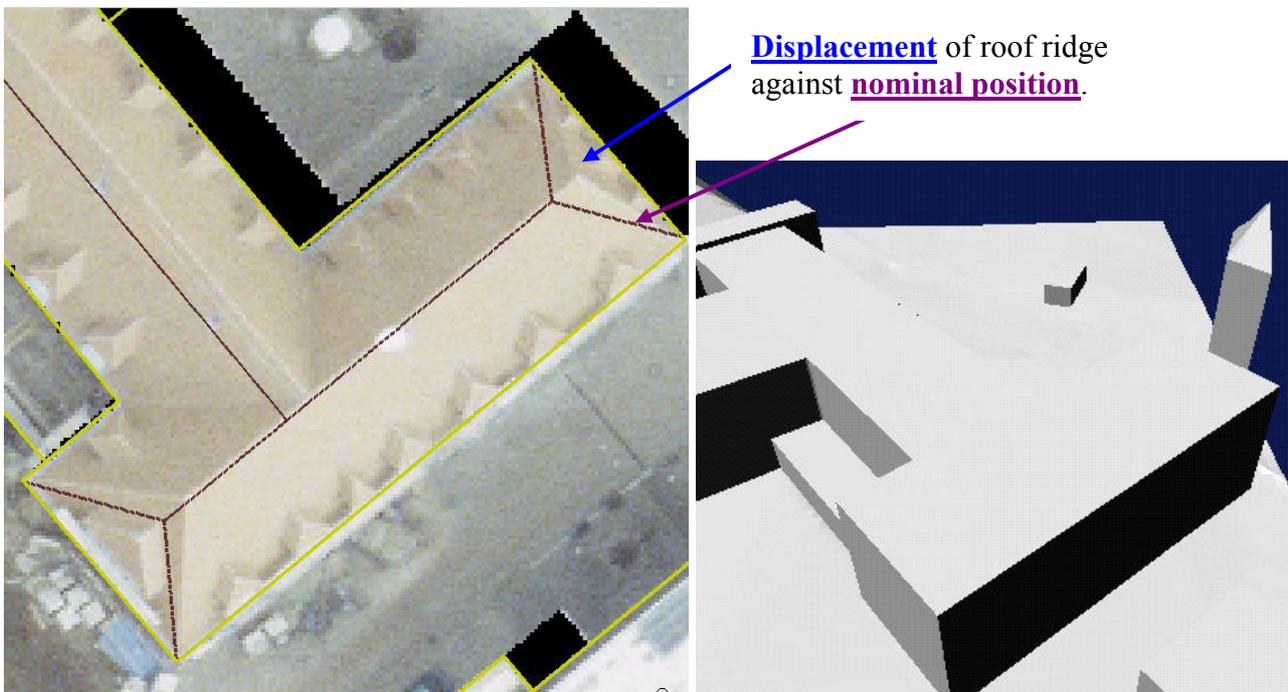


Figure 7 Left image: Orthophoto detail with roof top not measured. The nominal roof ridge position is superimposed to show the displacement effect.
Right image: Corresponding building model.

Figure 7 shows a situation with the same building block as in Figure 6 but without measured roof ridges. It is clearly visible that, because of this, the ridge is shifted against the nominal position. In particular negative is, that because of the perspective view, this wrong position of the ridge changes from image to image and makes it difficult to mosaic the orthophotos.



Figure 8 Left image: Orthophoto detail with coarse measurement of the roof ridge.
Right image: Accurately measured roof ridge.

The left orthophoto in Figure 8 shows an example with an inaccurately measured roof ridge, with the effect that the roof ridge is displaced against the nominal position. The right image shows the same situation with an accurately measured roof ridge. Again such inaccurate roof ridges make the mosaicking difficult and reduce the quality of the True-Orthophoto.

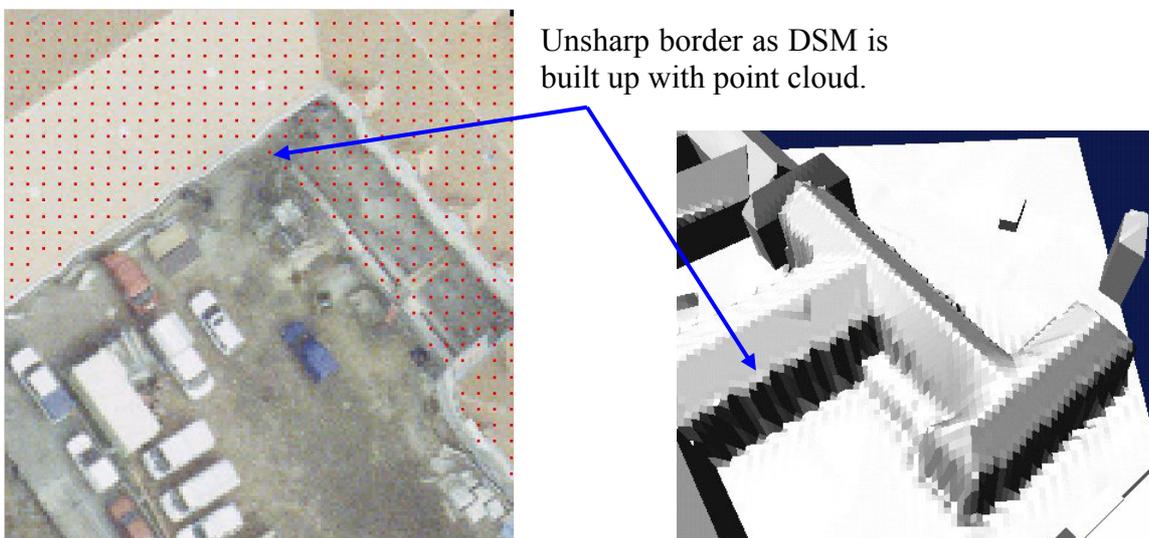


Figure 9 Left image: Orthophoto detail modeled with a point cloud of ~ 1 m density.
Right image: Corresponding building model.

Figure 9 shows a situation of the same building block as above but this time the DSM is build up by using a point cloud with an approximate point distribution of 1 point/m^2 . Only points on the roof are displayed. The whole DSM is build up with a point cloud (no breaklines, border lines etc. are given). It is clearly visible that according to the point cloud distribution and density the border of the building block is more or less undulated which is very disturbing and unacceptable. Furthermore

one can see that objects near the man-made objects are due to the used DSM also undulated (e.g. red car).

3.2. Modelling of DSM by blending vector data with a DTM

This method is supported by OrthoBox and allows to blend borders of objects like bridges, buildings but also object superstructures like ridges and towers with a standard DTM. The object structures and superstructures can be measured with an analytical or digital stereoplotter. OrthoBox from INPHO is able to compute with the help of this vector data the object models in an easy and flexible way. Above Figures 6 to 9 show such object models displayed with an VRML viewer. The DTM can be buildup with classical data elements like masspoints, breaklines, formlines. The vector data set characterizing the building models has to be imported via a DXF file. This method allows to build up nearly all kind of object models and nested building models which occur in any combinations in downtown areas. As the data used for the building models can be used also for other tasks and the measurement of the vector data is straight forward, this method is very effective.

3.3. Modelling of DSM by using city models

Different software packages are on the market to acquire and manage city models. One such software package is inJECT from INPHO (INPHO, 2003). They allow to measure semi-automatically objects in full 3D. Unfortunately there does not exist a common standard for the 3D data storage. This makes it so far very difficult to use the 3D city models in this context. Therefore OrthoBox is at time not prepared to import, in a direct way, 3D city models. Solely via the indirect way of the DXF file import, OrthoBox allows to process such data sets.

3.4. Modelling of DSM by using point clouds coming from LIDAR/SAR/INSAR or image matching systems

Point clouds are for instance delivered by LIDAR (e.g. TopScan, 2003; TopoSys, 2003), SAR/INSAR or image matching systems like MATCH-T (INPHO, 2003). The data sets of such systems deliver dependent on the filtering of the data either the DTM or DSM. The density of the point cloud can differ very much but can have a density ≥ 1 point/m². The data sets is either delivered as a very dense point cloud which can contain gaps or could be still erroneous or it is delivered as a more or less dense grid. Figure 9 shows clearly that in at least large scale True-Orthophotos the borders of objects are undulated which leads to an unacceptable quality of the True-Orthophoto. Different institutes and companies (Elaksher et. al (2002), Guoqing et. al (2003), Haala et. al (1999), Hu et. al (2003), Vosselman et. al (2001), Weidner et. al (1995)) have been or are working on algorithms which try to detect borders of objects automatically in point clouds. This is not an easy task as the point cloud itself does not allow to detect the borders accurately. In addition it is very difficult to detect the borders without gaps. Furthermore all the complex and nested buildings in downtown areas have to be detected and modeled. To our knowledge there exists at time no system which can fulfill the task effectively only on the basis of LIDAR data.

4. MOSAICKING AND RADIOMETRIC ADJUSTMENT

As shown in chapter 2.3. respectively Figure 4 occluded areas have to be filled by taking image parts from overlapping orthophotos. Often an occluded area can only filled by using several overlapping images. The image parts are often different in radiometry and they might be in shadows. Which means that it is very important that the parts which are combined must be radiometrically adapted to each other to get a homogeneous True-Orthophoto mosaic. Seamlines

have to be found for many such small occluded areas. All this would be very time consuming and very expensive if an operator would have to do it manually. OrthoBox is doing all this automatically and achieves very good results. The following example in Figure 10 shows the True-Orthophoto mosaic of a church. Four images had to be combined as the church tower occluded parts of the roof in the different images. The roof has in the overlapping images different brightness and contrast values. The yellow vectors are the automatically found seam lines. Different areas are formed which are then filled from all overlapping images. The rooftop is very homogenous without any visible differences in brightness or color.



Figure 10 True-Orthophoto mosaic with automatically detected seam lines.

5. ECONOMICAL ASPECTS AND PRODUCTION APPLICATIONS

In order to implement True-Orthophoto projection in a production environment one needs to have proper software and procedures in place. INPHO's OrthoBox is prepared to handle True-Orthophotos and thus DSMs, see www.INPHO.de. One imports man-made object models and combines them on the fly with a given DTM. The resulting DSM then facilitates the generation of orthophotos with occlusions especially coded. INPHO's OrthoVista for mosaicking adjacent or overlapping orthophotos interprets the occlusions code and picks True-Orthophoto contents from valid orthophotos automatically. This way a True-Orthophoto is actually constructed.

Economically, True-Orthophoto production can however be expensive, as one has to consider following facts.

- In case all occlusion areas have to be filled automatically and completely it is necessary to fly with a higher side overlap. Usually 60%.
- If a DSM shall be build up by using a DTM and vector data representing the object shape lines, the shape lines have to be interactively measured if not available. This can be time consuming in urban areas if many details have to be modeled. This statement is not valid for bridges. The measurement of the shape of bridges is quite simple and fast.
- If a DSM shall be build up by using LIDAR/SAR/INSAR data, the flight, the data management, the editing of the data and especially the necessary interactive measurement of object shape lines can be expensive.

Because of the eventually high production costs, in our opinion the production of True-Orthophotos of building models makes sense for areas of main interest, e.g. downtown areas. For bridges

however this is completely different. Bridges in Orthophotos make often problems as if not modeled they are either shifted against the true position but more worse they are displayed curved and/or twisted. The bridges have to be therefore corrected interactively with image manipulation tools, which is usually more expensive than just measuring the border of the bridge and introduce it into the DTM analog to buildings as described above.



Figure 11 Left image: Bridge in classical orthophoto shifted and twisted (marked by ellipse).
Right image: Bridge in True-Orthophoto at correct position (see overlaid vector data).

6. CONCLUSIONS

The importance of True-Orthophotos is increasing. Systems like INPHO's OrthoBox allow to generate True-Orthophotos automatically. As shown, for high quality True-Orthophotos it is essential to build up high quality DSM's and use a highly sophisticated software package to find and fill up occluded areas automatically. The compilation of object models via point clouds alone (LIDAR/SAR/INSAR/Matching) is not sufficient such kind of data must be expanded by introducing object borders. OrthoBox allows to build up object models by blending DTM data with vector data representing the border of the objects and their superstructures.

The True-Orthophoto production is more expensive compared to the standard orthophoto production. The higher costs are caused by the need of a DSM and a higher overlap of images across the flight direction to be able to fill up the occluded areas. In case of True-Orthophotos for city models a flight overlap of 60% length and 60% side overlap is necessary. From the economical point of view the True-Orthophoto production of building models is in our opinion only worthwhile in downtown areas or limited areas of high interest. This statement is not valid for bridge models. The modeling of bridges is cost-effective as the contour measurement of bridges is quite easy and requires very few efforts. Even if not all occluded areas below the bridge can be filled up automatically, the interactive correction of such occluded areas is much faster and easier than to correct the whole bridge with image manipulation tools.

7. ACKNOWLEDGEMENTS

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