STRUCTURE LINE MODELLING BASED ON TERRESTRIAL LASERSCANNER DATA

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ABSTRACT:

In the last years, terrestrial laser scanning (TLS) instruments are gaining more and more importance for the 3D data acquisition for a variety of applications. However, the subsequent modelling procedures are still not standardised for the different applications and often the result of a TLS project is a registered 3D point cloud. This form of object representation is often applicable for visualisation purposes, but for the mathematical analysis of the object, advanced representation forms are essential. For this aim, the meshing of the TLS point cloud is a common procedure. However, it has to be considered that this form of object representation can be directly altered by random, systematic, and gross errors included in the TLS data. Especially discontinuities are usually erroneously due to the complex interaction of the laser beam with the illuminated object surface.
Thus, methods that consider possible measurement errors within the process of 3D modelling are essential. Furthermore, an adequate representation of structure lines within the modelling procedure is important for a high quality object representation. For this aim, an explicit description of these linear features is necessary. Therefore, in order to enhance the models generated from a TLS point cloud, this paper focuses on the determination of structure lines. The method is based on a semi-automatic process originally developed for the modelling of breaklines from airborne laser scanner data. Within this paper, the adaptation of the modelling framework to the usage of TLS data is presented. Furthermore, it is extended to further types of structure lines. The modelling framework is based on the irregular distributed TLS point cloud. The usage of a robust estimation procedure together with a sensor specific stochastical model allows the consideration of measurement errors within the structure line modelling procedure. For the modelling concept, an approximation of the line is essential. In order to overcome this limitation the process of structure line growing is introduced. This process allows a semi-automated determination of linear features. Next to this approach, a section with practical examples demonstrates and discusses the capability of the methods. Finally, an outlook into ongoing research work and a summary conclude the paper.

1. MOTIVATION

Nowadays, an increasing demand of 3D representations of real-world scenes in many different fields can be recognised. The areas of interest are extremely wide, e.g., medicine, industrial and other technical applications, architecture, cultural heritage documentation, computer animation, and topographic information systems. In the focus of all these diverse applications are very different sized and shaped objects. Nevertheless, the general task of object model generation is usually very similar and can be divided - independent of the used sensor system - into three main phases: data acquisition, data orientation and the determination of a suitable object representation.

In the last years, in the area of data acquisition and orientation a significant development towards automation was achieved. This trend was mainly guided by the introduction of new sensor systems allowing a highly automated data acquisition procedure and a very detailed sampling of the object surface. Furthermore, procedures that allow reducing the manual effort for the data orientation were developed.

For the 3D data acquisition terrestrial laser scanning (TLS) systems are gaining more and more importance for a variety of tasks. One of the advantages of TLS sensors is the highly automated data acquisition procedure allowing a detailed sampling of the object surface. The resulting 3D point cloud can serve as a good basis for the following determination of a scene resp. object representation. However, the modelling procedures based on the TLS data are still not standardised for the different applications. Nowadays, the result of a TLS project is typically just a 3D point cloud that is frequently coloured using additional image data. While this form of representation might be efficient and suitable for visualisation tasks (e.g. using a view dependent point size in order to get a cohesive impression of the scene (cf. Wimmer and Scheiblauer, 2006)), this form of point cloud representation is not very suitable for mathematical analysis. Therefore, the meshing and the subsequent application of mesh refinement strategies in order to reduce the amount of data storage of the point cloud data is a widely used procedure. However, it has to be considered that within this process - next to possible errors caused by a wrong automatic point topology determination - the object representation can be directly altered by random, systematic, and gross errors in the TLS data. Furthermore, it has to be stressed that especially discontinuities are usually erroneously represented due to the complex interaction of the laser beam with the illuminated object surface. Therefore, methods that consider these possible measurement errors are essential.

In contrast to the direct meshing of the determined TLS point cloud this paper considers a different way of object representation. The aim is to first extract the relevant features, such as edges or corners, for an adequate object representation. Furthermore, - if necessary - the object surface in-between the features and considering the stochastic properties of the TLS data can be determined. Then, based on these features and surfaces, a certain representation form can be generated. According to Rottensteiner (2001) next to a point cloud representation, 3D objects can be described by a wire frame (points and edges), surface (points, edges, and faces), or volumetric (points, edges, faces and volumes) model. The advantage of these representation forms in respect to the point cloud representation is that these descriptions can be efficiently used for further subsequent mathematical analysis as well as for visualisation tasks.

Up to now an automatic process that extracts all relevant object features from TLS data with an additional procedure that allows a user-defined and application dependent generalisation of the object is still not visible. Therefore, this paper focuses on a semi-automatic method for 3D structure line modelling. The result of this approach is an explicit description of these linear features, which can be used to enhance the models generated from a TLS point cloud.

In the following section 2, a short overview to related work is provided. Then, the proposed method for structure line modelling is presented in section 3. Subsequently, a section demonstrates its usage with the help of practical examples. Finally, section 5 concludes the paper with an outlook into ongoing research work.

2. RELATED WORK

While the extraction of structure lines from airborne laser scanner data is an active research topic since a few years (cf. Briese, 2004a&b, Brügelmann, 2000, and Bzank, 2005) within the community of photogrammetry and remote sensing the research in structure line extraction from TLS data is rather at the beginning. Therefore, capable processes developed for TLS data are still missing in practice. However, the extraction of feature lines is currently in other communities like computer vision or computer graphics an active issue of intensive research. One representative approach can be found in the paper of Yoshizawa et al. (2005) which furthermore provides literature references to several other approaches.

However, when looking at the literature one can see that most of these approaches try to extract linear features based on previously generated triangular meshes (cf. Hubeli and Gross, 2001 and Lee and Lee, 2002). Based on a specific neighbourhood defined in respect to the given surface topology, algorithms are developed which determine in a fist step geometric attributes that significantly indicate a feature line, whereas in the subsequent step approaches are used that allow to determine the whole connected feature resp. structure line. Typically, sensor specific measurement characteristics are not considered. Furthermore, the meshes are usually smoothed previously in order to eliminate errors (especially small triangles with a very steep slope in respect to the surrounding (often caused by random errors of the measurement device)). The result of these methods is typically one type of structure line that is described by a sequence of vertices (frequently already available points of the surface mesh are used). The final integration of the line information into the surface mesh is usually performed by a refined triangulation were the delineated structure lines act as constraints. In contrast to this group of approaches, the subsequently presented approach tries to consider the stochastic properties of the measurement device, operates on the original acquired point cloud, and does not need a previously calculated surface mesh. Furthermore, an extention of the modelling concept allows the consideration of different types of structure lines.

3. STRUCTURE LINE MODELLING

As mentioned in the introduction, current forms of object representation based on TLS data usually do not consider structure lines. However, for advanced representation forms the explicit description of structure lines is essential. Within this section, the general ideas for the modelling of structure lines based on TLS data are presented.

The basic concept for the modelling of the structure lines is a straightforward extension of an approach for break line modelling from airborne laser scanner data published in Briese (2004a&b). This basic modelling concept for ALS data uses a rough approximation of the break lines and the original unfiltered point data to describe the break lines with the help of overlapping patches along the break line. Within this method, the local break line segment per patch is described by the intersection line of two adjusting planes determined with the help of the point cloud data in the surrounding of the structure line. Special weight functions in conjunction with robust least-squares allow the removal of off-terrain resp. off-surface points (figure 1) and allow to consider the measurement accuracy of the sensor system. The refined 3D break line can be finally described by a sequence of representative points and tangent directions. Furthermore, the intersection angle is stored, which is a useful parameter describing the local quality of the intersection.

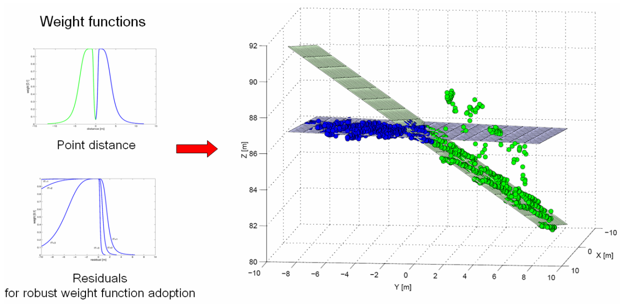
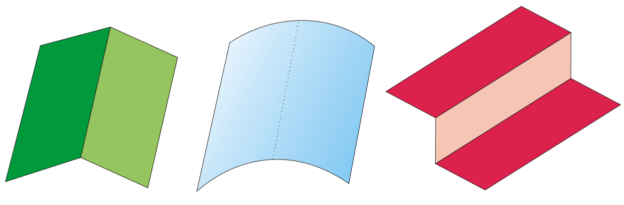


Figure 1: Robust break line modelling of one patch pair using self-adapting weight functions (cf. Briese, 2004b).



(a) (b) (c)

Figure 2: Types of structure lines: break line (a), form line (b), and step edge (c).

In the following, the adoption of this approach for the usage with TLS data is presented. Additionally, the modelling of different types of structure lines is outlined (cf. figure 2). In the following, next to break lines, which describe a linear surface discontinuity, the description of form lines (often also referred to as "smooth structure lines"), which allow the description of a linear local main surface curvature, is presented. Furthermore, the modelling of step edges is considered in the following subsections. Finally, the process of structure line growing that allows an automatisation of the process is introduced for all line types.

3.1 Structure Line Modelling Concept for TLS data

For the 3D structure line modelling with TLS data the same basic ideas as already published for ALS data can be considered. In the first step the original TLS point cloud in a buffer zone around the break line approximation is necessary. Next, the selected points are assigned to the individual patches along the line and for the break line determination two intersecting 3D planes per patch – representing the 3D break line locally – can be iteratively determined. Furthermore, like in the ALS case, the approximation of the break line can be integrated in the adjustment procedure as additional observation with a certain a priori accuracy. These additional observations help to stabilise the adjustment, especially in the occurrence of gross errors. In a similar way like the break line approximation, image observations or other direct observations of the break line with their individual weights can be integrated with their stochastic properties in the robust plane pair adjustment procedure (cf. Briese, 2004b).

Point Cloud Topology

For the usage of TLS data, it has to be considered that in the 3D case the approximation of the break line has to be provided in 3D in order to select the points in the neighbourhood. Therefore, an efficient 3D organisation of the TLS point seems to be essential. However, this step of 3D point cloud selection can be reduced for many applications by organising the TLS data in the polar domain of each scan position (cf. figure 8). In that way the selection of the 3D points in the Cartesian co-ordinate system can be replaced by a simple 2D selection using the implicit given topology of the acquired point cloud provided by the TLS measurement process. In this way, the line approximation can be defined in the 2D polar domain of one reference scan position and a 2D point selection can be performed. However, this process is just straightforward for one scan position. For the consideration of additional data from further available scan positions, a 3D definition of the line is essential. In order to solve this the range values provided in the polar representation of the first reference scan can be used as approximate values. In that way the 2D break line approximation with the approximate ranges can be transformed into the other local polar domain. In this manner, a fast and simple 2D selection of the points near the line can be performed using the implicit given topology of each TLS scan position. Additionally, in order to exclude points far away from the first break line approximation, the definition of a range tolerance in each individual 2D polar selection in respect to the approximate line leading to a 2,5D selection procedure is typically useful.

3.2 Further types of structure lines

As mentioned before, different types of structure lines have to be considered within the modelling procedure. Therefore, in the following paragraphs the necessary adoptions for the consideration of additional structure line types are summarised.

Form lines

Whereas break lines are locally described within each patch by two intersecting surfaces (cf. figure 1) for the description of form lines the position and orientation of the local main curvature direction has to be determined. For this aim, second order algebraic surfaces can be used. In order to apply this strategy in 3D space a two-step procedure was developed: In the first step, a general robust 3D quadric adjustment per patch is calculated. Based on this result the main curvature direction can be determined by the main axis transformation. Then, in the second step, a robust 2D second order adjustment in the eigenvector space is determined in order to determine the main curvature position. With the help of this procedure, the main curvature direction and a representative point can be estimated (cf. figure 3). Moreover, the radius of curvature is stored as further additional information for the subsequent determination of an object representation.

In figure 4 an interesting comparison of the results using different types of structure lines is displayed. The selected point cloud in the neighbourhood of the structure line rather describes a smooth form line. Therefore, the result using the concept for break line modelling with two intersecting surfaces produces a sharp edge that – compared to the form line result – deviates significantly from the object surface sampled by the point cloud. In this example, the break line formulation seems to be quite inadequate and the result from the form line adjustment represents the surface in a better way.

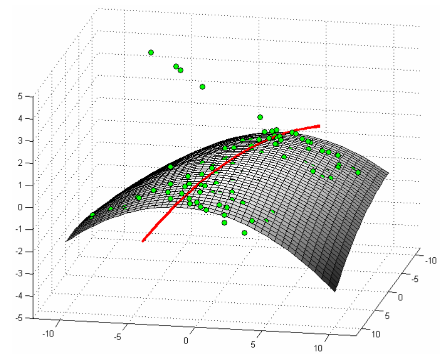


Figure 3: Robust determination of a form line patch based on second order algebraic surfaces.

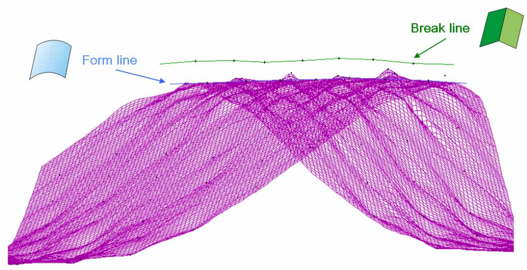


Figure 4: Result of 3D structure line modelling using two different line types. The point cloud is rather describing a form line. Therefore, the estimated break line (green) deviates from the surface interpolated from the TLS points (black dots), whereas the estimated structure line using the form line determination process (blue) represents the linear surface feature in a better way.

Step edge

Step edges are one special case in the modelling of discontinuity lines that appear in areas were the surface normal vector is more or less orthogonal to the direction of the laser beam or due to hidden surface parts. The basic concept together with a practical example from a part of a jump edge of the Bergl Room (sec. 4.1) is presented in figure 5. The jump edges are described in a similar way than break lines. On both sides of the step edge robust surface patch pairs are determined. However, in contrast to the break line modelling no intersection of the two surfaces near the approximate line has to be enforced. The local representation of the step edge can be determined by an analysis of the residuals of all points in respect to both determined surfaces. In this manner, all the points within a three times sigma threshold are assigned to one of the both surfaces. Then for the left surface in respect to the approximate line, the three rightmost points along the line are determined and the resulting adjusted 3D line through these points is selected as the representative left step edge. In an analogue way the right step edge can be determined, which finally leads to two 3D lines representing the step edge locally per patch.

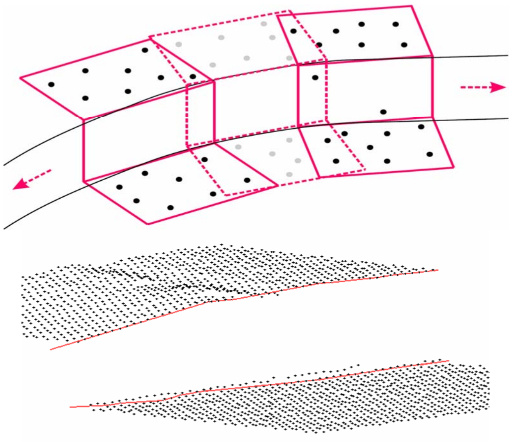


Figure 5: Step edge modelling. Basic concept (top) and practical example (bottom) with eliminated off-surface points near the step edge.

3.3 Automatisation – Structure Line Growing

The previous presented approach for structure line modelling using different line types relies on an approximation of the structure lines. These initial lines are necessary in order to select the data in the neighbourhood of the lines. For the practical application of the modelling framework, there is a need for a higher degree of automatisation. In contrast to other very common approaches that try to extract whole structure lines based on a local geometric criteria (cf. section 2) within this subsection the application of structure line growing is proposed (introduced for break lines in Briese, 2004a&b).

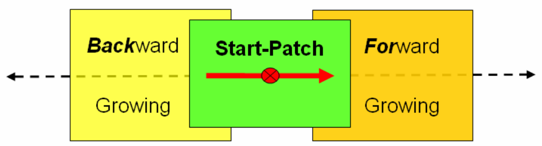


Figure 6: Structure line growing for all line types (introduced for break lines in Briese (2004a&b)).

The scheme for structure line growing is presented in figure 6. The basic idea is a growing process based on a step-by-step expansion of previously delineated line segments in forward and backward direction starting from one initial segment. This process is repeated as long as the line determination within the patches is successful or a certain break off point is reached. In that way, this approach allows to overcome the must for a complete approximation of the structure line. For the break off point a geometric evaluation criteria depending on the structure line type is essential. For example, in the case of the break line the intersection angle between the two surfaces can be analysed, whereas in the case of the form line a threshold for the curvature radius, which indicates the significance of the form line, can be set as break off criteria. A practical example demonstrating the capability of structure line growing can be found in the following examples section (cf. figure 7).

4. EXAMPLES

This section presents some results of the previously presented methods for structure line modelling based on TLS data. In the first example the modelling of an indoor room is presented, whereas in a short second example a scan from a small church is the input for the structure line modelling process.

4.1 Bergl Room - Schönbrunn Palace

Within this subsection the structure line modelling of one of the Bergl rooms in Schönbrunn Palace, Vienna is presented. The TLS data was acquired with a Riegl LMS Z-420i with a mounted digital camera. The average point spacing of the TLS point cloud on the surface is about 1cm. Based on that data the process of structure line growing is displayed in figure 7. Starting from just one initial point near the line, in a first step the main curvature direction is determined in order to define the start patch. Then the modelling using the break line concept is performed for that first patch. Subsequently, the growing procedure starts into both directions. The resulting break line can be inspected in the lower part of figure 7 in a 3D view. It can be seen that the growing was successfully. Overall, 298 growing steps were necessary for the delineation of the whole line. In figure 8 further results are displayed in the polar view of one scan. Based on the previously presented modelling concept the structure lines of the whole room are determined and form the basis for a final geometric model of the room (cf. figure 9).

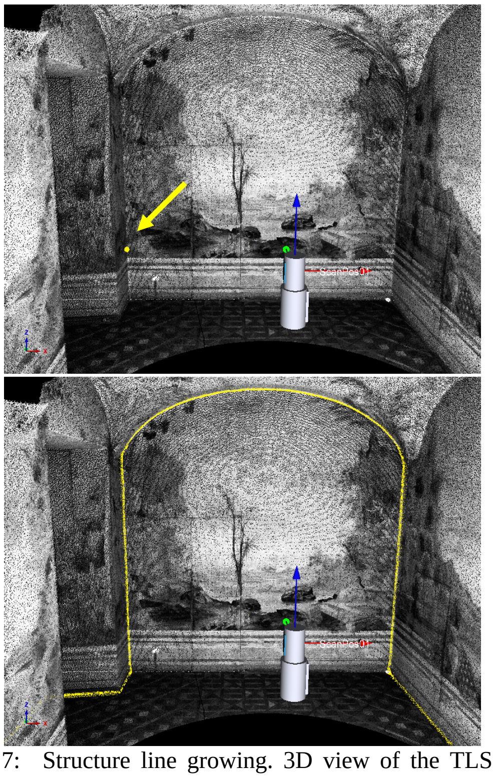


Figure 7: Structure line growing. 3D view of the TLS point cloud recorded in the Bergl room. The point cloud is coloured with the recorded intensity information. The growing process is initialised with the help of one 2D start point (yellow dot, top). The resulting refined structure line (yellow) is displayed at the bottom.

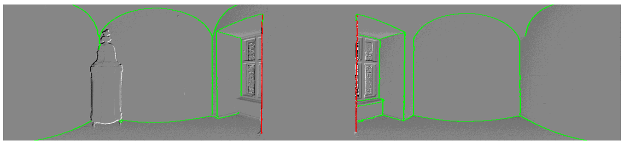


Figure 8: Structure lines (break lines: green, step edges: red) in the polar domain (horizontal: 360°, vertical: 80°) of one scan of the Bergl room acquired with the Riegl scanner LMS-Z420i.

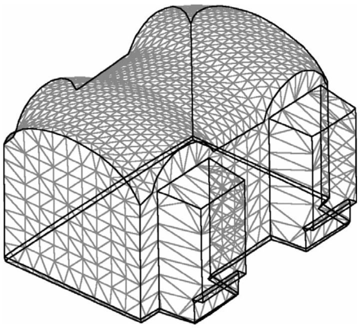


Figure 9: Final geometric room model (Dorninger and Briese, 2005) with structure lines and representative points within the line information.

4.2 Church – Gauderndorf

The data of the second example was recently acquired during a field exercise with our students with the Riegl LMS-Z420i. In figure 10 some of the resulting structure lines are presented. In the top left image, the original points describing the lines are displayed, whereas a thinned out version of the breaklines can be seen in the top right part of the figure. In this case, a high amount of reduction using a threshold value of ±3cm was achieved. Furthermore, in the lower part of the figure a detail view of the structure modelling result with the point data in the surrounding is presented.

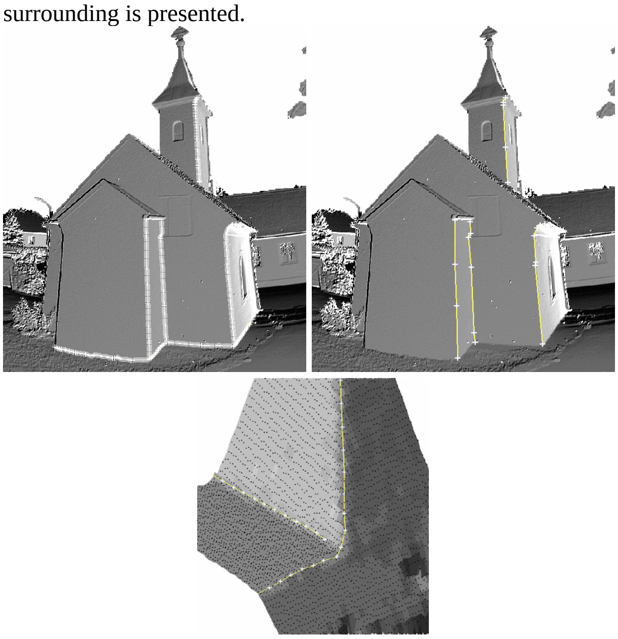


Figure 10: Shading of a 2.5D surface model of the church Gauderndorf in polar domain with structure lines (top left: original structure line, top right: thinned lines according to a max. threshold value). Bottom: 3D detail view of the structure line modelling result with the surrounding point cloud (black).

5. SUMMARY AND OUTLOOK

This paper presents an approach for the 3D structure line modelling based on TLS data. The approach - originally developed for ALS data - turned out to be easily adaptable to the needs for close range applications. Furthermore, the paper considers different types of structure lines that allow an advanced modelling of the lines based on the original acquired point cloud.

The example section demonstrates that the approach can already be used within practical TLS applications. However, many further improvements and extensions have to be considered in the future work: Up to now, the automatic discrimination of the structure line types break line and form line is still unsolved. Maybe one practical way to discriminate both might be the analysis of the residuals near the intersection line within the break line approach. In this way, a systematic modelling error (false model) should be determinable. Furthermore, a detailed accuracy assessment is missing. Up to now, only the inner precision was checked by comparing the results of different scan positions to each other. Within this analysis a mean difference of approximately ±1cm (in this case approx. the TLS point sampling distance) between the lines modelled based on different scans was determined.

Finally, it has to be mentioned that especially in the area of TLS applications the determination of the line topology is very important. In the current approach, the relation from one line to the other is neglected. The processing is strictly performed line wise. Therefore, lines that should intersect must not have a common intersection point (cf. lower part of the figure 10). Currently, the intersection of the lines is performed manually. Therefore, the consideration of line intersections and other line relations will be one very important issue for future research in the area of structure line modelling from TLS data.

ACKNOWLEDGEMENT

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REFERENCES

Briese, C. ,2004a. Three-dimensional modelling of breaklines from airborne laser scanner data. In International Archives of Photogrammetry and Remote Sensing, Vol.XXXV, B3, Istanbul, Turky.

Briese, C., 2004b. Breakline Modelling from Airborne Laser Scanner Data, PHD Thesis, Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, October 2004.

Brügelmann, R., 2000. Automatic breakline detection from airborne laser range data. In International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, B3, Amsterdam, Netherlands, pp. 109-115.

Brzank, A., Lohmann, P., Heipke C., 2005. Automated extraction of pair wise structure lines using airborne laserscanner data in coastal areas. ISPRS WG III/3, III/4, V/3 Workshop "Laser scanning 2005", Enschede, the Netherlands.

Dorninger, P., Briese, Ch., 2005. Advanced Geometric Modelling of Historical Rooms. XX Symposium of CIPA, ICOMOS & ISPRS Committee on Documentation of Cultural Heritage, Turin, Italy.

Hubeli, A., Gross, M., 2001. Multiresolution feature extraction from unstructured meshes. In Proc. IEEE Visualization, p. 287-294.

Lee, Y., Lee, S., 2002. Geometric snakes for triangular meshes. Computer Graphics Forum 21, P 229-238. Eurographics 2002 issue.

Riegl, 2006. http://www.riegl.co.at/ [Accessed: 2006-03-24]

Rottensteiner F., 2001. Semi-automatic extraction of buildings based on hybrid adjustment using 3D surface models and management of building data in a TIS, PhD Thesis, Institute of Photogrammetry and Remote Sensing, Vienna, 189 pages.

Wimmer, M., Scheiblauer, C., 2006. Instant Points. In *Proceedings Symposium on Point-Based Graphics 2006*, July 2006, Boston.

Yoshizawa, S., Belyaev, A., Seidel, H., 2005. Fast and Robust Detection of Crest Lines on Meshes. Proceedings of the 2005 ACM symposium on Solid and physical modelling, pages pages: 227 – 232.