RE-ENGINEERING OF OBJECTS IN CONSTRUCTION DRAWINGS

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SUMMARY

A lot of drawings of existing or new buildings in civil engineering are only available in an analogous version. In order to realize a computer aided process during the planning, construction, building and utilization phases drawings in digital version are indispensable. Algorithms and software tools are available to convert a digitised paper based drawing into a vector plot. But these systems did not prove in practice to be suitable for the recognition of constructional objects within the drawings. In this paper an approach to convert digitised drawing data into lines and curves with topological information is presented. Based on this topological information the semantics of the drawing objects is recognised and is translated into building objects. The theoretical background as well as the practical use of the developed various algorithms are explained in detail. This approach is applied to a realistic example of ground-floor plan for a detached house. The results of this example show the suitability of the developed software tool for a medium sized drawing.

INTRODUCTION

In civil engineering technical information has to be exchanged between engineers, workers, clients and all other people involved in the building project. Often this exchange of information is carried out with drawings. Most times technical drawings are characterized by a high density of information which can easily be selected and understood by all people concerned with the project. These drawings are special views of the construction or building from different application oriented points of view. These technical drawings consist of a lot of curves with different shape, length, width, colour or constellation. These attributes of lines and circles imply the semantic meaning of the drawing objects. This semantic meaning of drawing objects can be interpreted with help from the engineering experience of different people involved in the building project. So it is quite easy for an civil engineer as well as for a worker on the building site to recognize two parallel lines in bold face with hatching lines as a wall in the ground-floor plan.

The digitisation of paper based drawings is often processed manually by the use of a graphical tablet or a background picture displayed at a monitor. Significant points and lines are selected manually and the corresponding coordinates are stored for a digital model. In the field of surveying and cartography or in medical sciences the process of digitisation and recognition of application specific objects is almost automated. Several commercial software systems and tools exist for different applications. The software package QGAR (Dosch et al. 2000) for graphics analysis and recognition offers a lot of functionality for the consideration of architectural drawings. Especially in the area of civil engineering these systems do not fulfil the requirements for practical usage, because the shape, scale and orientation of the objects may vary and therefore the methods of pattern recognition are not suitable. That is why the approach via line identification is preferred. Different methods like "orthogonal zig-zag" (Chai et al. 1992), "spare pixel tracking" (Yoo et al. 1998) or "visibility rays for contour points" (Esch 2001) are used in commercial systems. In contrast to this a novel method based on medial axes for discrete objects in a pixel grid is presented in this paper.

The traditional interpretation of a drawing is performed by the engineering understanding which will be improved with practical experience. In contrast to this a computer based interpretation of drawings is a process with different steps: A digitised drawing consists of enormous amount of pixels with different grey scale values. These pixels are ordered in a regular grid. These pixels are transformed in a first step into lines and circles. In a second step these linear geometry elements are analysed concerning their topology. Based on this information about the topology and neighbourhood of lines specific objects in civil engineering like hatching lines, dimension lines, walls, doors, windows etc. are

identifiable. If any information about a scale of the drawing and about the extension in the third dimension is available, the process of quantity survey can be performed very effectively.

## DIGITISED DRAWINGS

Scans of drawings

The paper based drawings presented in this contribution are digitised with a simple scanner which is usually available in every engineering office. The results of this scanning process are files in GIF- or JPG-format with different resolutions and different colour depth. In test cases a resolution of 200 up to 300 dots per inch has proven to be sufficient for the re-engineering process. Most times drawings in civil engineering are in black and white or grey scale. Therefore a colour depth of 8 bits which means 256 different colours is satisfactory.
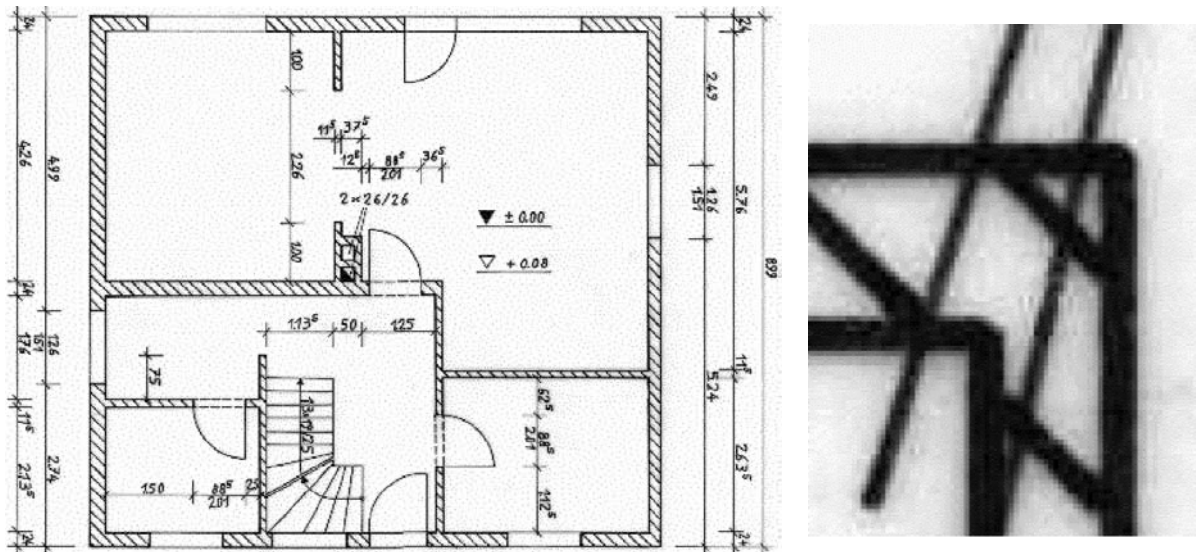
Figure 1 Ground-floor plan and detail of a detached house

On the left hand side figure 1 shows a ground-floor plan of a detached house. A detail of the chimney area is illustrated on the right hand side of figure 1. These two illustrations demonstrate the dirtiness of the drawing and the scanned drawings: pixels which are supposed to be white are grey or pixels which are supposed to be black are also grey. In some cases it is hard to decide whether a single pixel represents a part of a drawing object or of the background. This decision has to be performed within the context of the pixels in the neighbourhood. In addition the axes of the drawing are not fully justified to the scan axes. At last the lines are not connected properly in every case and additional inaccuracies are evident because this plan is drawn manually.

Lines in raster graphics
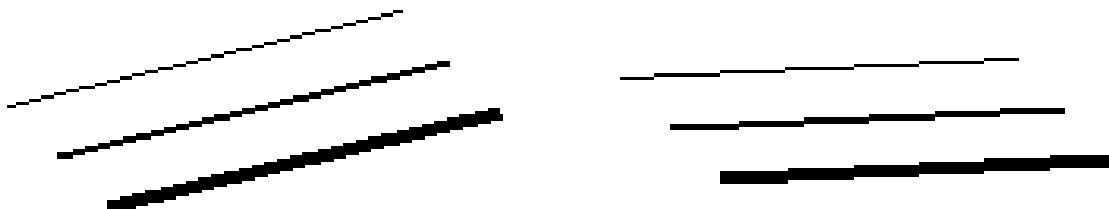
Figure 2 Straight lines in raster graphics

From the mathematical point of view a straight line is defined by two points. A look in detail to a line displayed in a raster graphic shows the typical stairs of pixels. In dependence of the pitch and the

thickness of the line different pixel pattern appear as shown in figure 2. Within the identification process a pixel is recognized to be in the interior of a line if at least two of the eight pixel in the neighbourhood belong to the same line.

In order to classify a pixel to a drawing object or to the drawing background the scale of the colours between black and white is divided into ranges: The range for lines and the range for the background. In addition a third range is dedicated to the remaining pixels which must be considered within the context of the pixels in the neighbourhood. These pixels are used to close gaps within a line which may appear because of the dirtiness of the scan.
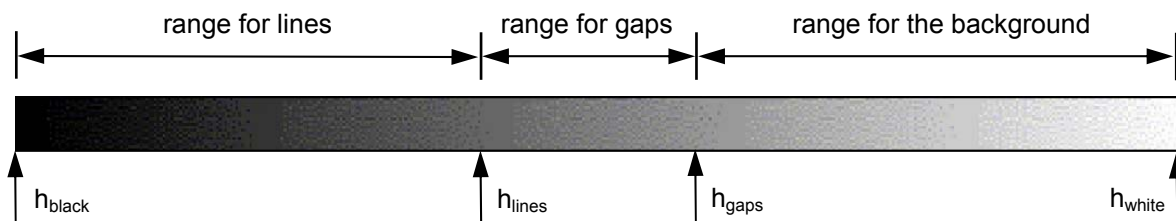

Figure 3 Scale of grey values for lines, gaps and background

In the following line pixels are defined as pixels with a grey scale value between h_{black} and h_{lines}. The pixels with a grey scale value between h_{white} and h_{gaps} will be called background pixels. And at last the remaining pixels with grey scale value between h_{gaps} and h_{lines} are called gap pixels. In dependence of the scan quality and brightness these ranges are defined and adjusted by the user. This adjustment of the grey scale ranges is one of the most important parts in the process of line recognition.

IDENTIFICATION OF LINES

In this chapter a novel method to identify lines within scanned drawings is presented. The algorithms developed for this method are using contour pixels. These contour pixels lie on the contour of a drawing object. Within this context contour pixels are characterized by a grey value between h_{black} and h_{lines} and in addition at least one pixel of the eight pixels in the neighbourhood has a grey value between h_{white} and h_{lines}.

Method based on medial axes
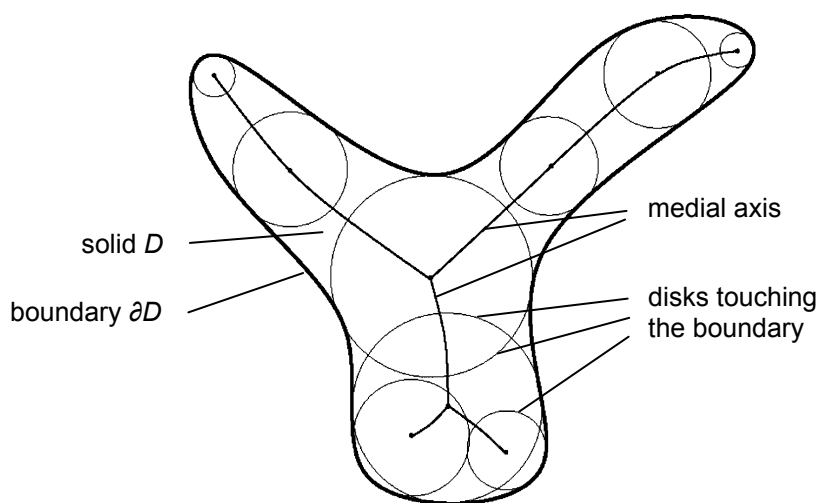
Figure 4 Medial axes in an Euclidean space (Wolter 2000)

In an Euclidian space *E* the medial axis of a solid *D* is defined as a subset of *D* containing all centre points of disks which touch the boundary ∂*D* of *D* at least at two points (Wolter 2000). In figure 4 an exemplary medial axis in the two dimensional Euclidean space is shown.

The mathematical theory of medial axes is transferred to the more practical application of line identification within scanned technical drawings. In the two dimensional Euclidean space a distance between two points *A* and *B* is defined as the square root of the sum of coordinates differences of *A* and *B*. Instead of the Euclidean space a pixel grid has to be concerned. In analogy to the city-block distance in Euclidean space the distance between two pixels *a* and *b* in the pixel grid is defined as the sum of the positive differences of the pixel grid indices of *a* and *b*. The distances from pixel *a* to any other pixel are illustrated on the left hand side of figure 5.

Figure 5 Pixel distances to pixel *a* (left) and the shortest distances to contour pixels (right)

On the right hand side of figure 5 the shortest distances of all line pixels to a background pixel or gap pixel are annotated. All contour pixels are marked with the distance value of 1, which means a contour pixel is in the direct neighbourhood of a background pixel. The medial axis is defined as the subset of all line pixels with no pixel in the direct neighbourhood having a greater distance value. The pixels representing the medial axis for this example are indicated by white squares. The medial axes can be considered as the skeleton of the line to be identified.

In figure 6 all contour pixels are displayed in black. In dependence on the distance values the pixels in the interior of lines are displayed in different grey colours. Starting from any pixel on the medial axis a potential line is extended and rotated with the objective to maximize the sum of distance values of pixels lying under this potential line. This extension process of the potential straight line is performed into both directions from the starting pixel as shown on the left hand side of figure 6.
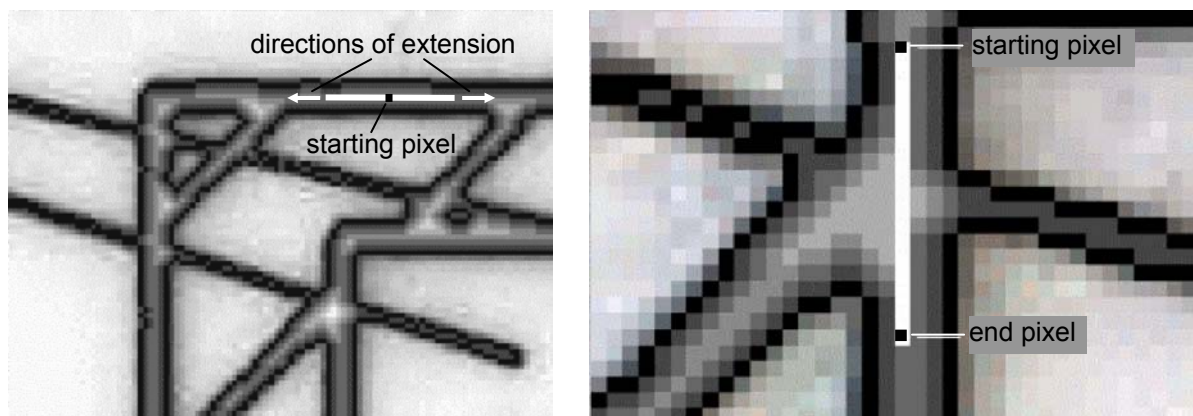
Figure 6 Creation process of a potential line (left) and the limitation of distance values (right)

At a connection of several scanned lines a hot spot of distance values occurs. This may lead to a deflection of the potential line towards the hot spot area and the extension process may stop too early. As shown on the right hand side this problem can be avoided by cutting off the highest distance values at the hot spots. The extension process is continued until a contour pixel is reached in both directions. The potential line will be refused if its length does not exceeds a minimum length. In figure 7 some exemplary details of the ground-floor plan with the identified lines are illustrated. The dirtiness of these lines is evident and has to be corrected in the following steps of recognition of objects in drawings.
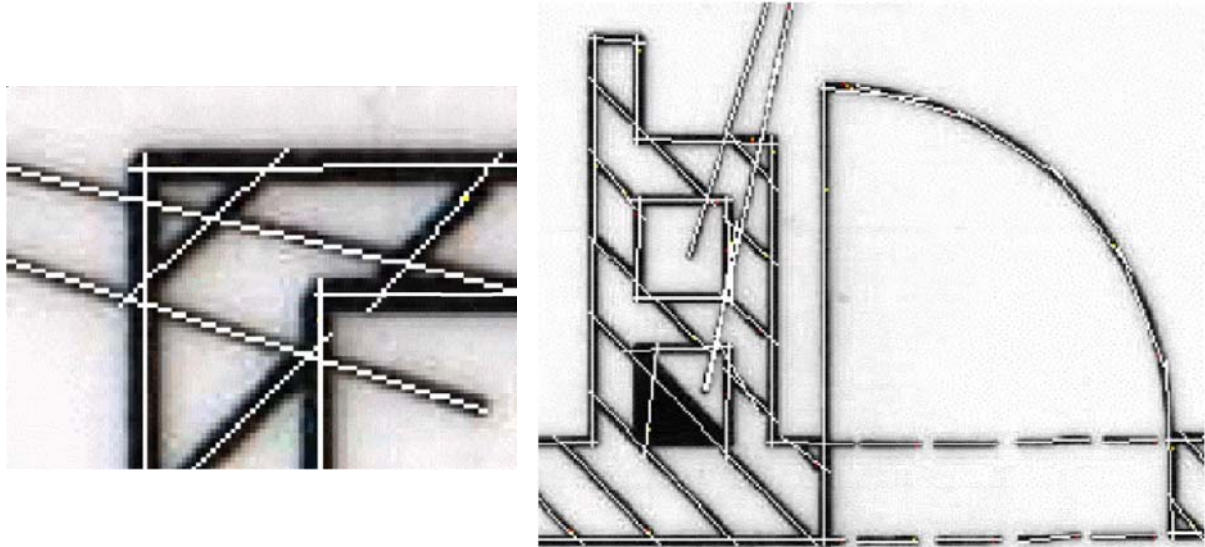
Figure 7 Identified lines in the ground-floor plan

TOPOLOGICAL ANALYSIS

At the first step of the topological clean up process the intersection pixels of all potential lines are determined. The resulting intersection pixels are regarded as topological nodes which divide the potential lines into topological edges. In addition all end pixels of potential lines are also defined as nodes. This ensures that every edge is related with two nodes. Every edge is attributed with the thickness of the potential line.
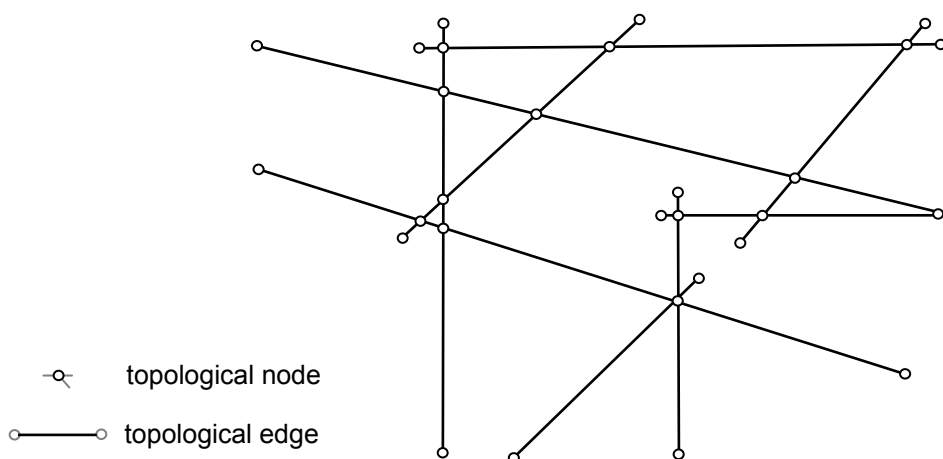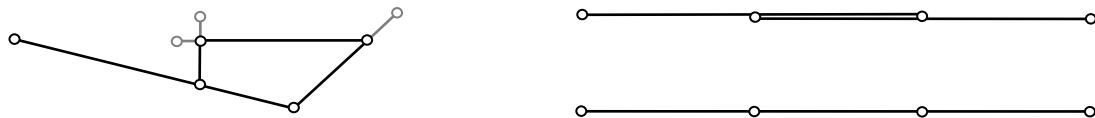

Figure 8 Topological structure for potential lines

All nodes with a distance smaller than a user defined limit ε are concentrated to one single node. In figure 8 the topological structure for the detail displayed on the left hand side of figure 7 is shown. Based on this topological structure consisting of topological nodes and edges an analysis and correction of the potential lines is performed.

Cut off of small excess edges

The ends of potential lines often do not fit together exactly. These inaccuracies are characterized by small edges which do not exceed the minimum length of lines. In addition one of the topological nodes of these edges has no relation to any other edge. Within the topological clean up process the small edges and the corresponding single relation nodes are deleted as shown on the left hand side of figure 8.
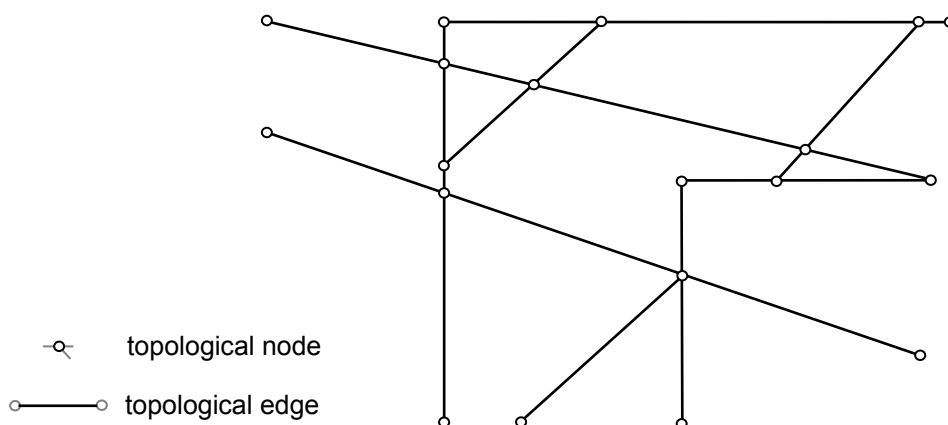

Figure 8 Clean up of topological structure for potential lines

Neighbourhood of edges

After the process of line identification two or even more potential lines may overlap partially. Within the topological structure this leads to edges with two identical nodes. If all multiple edges obtain the same thickness value for the potential line, these multiple edges are joined together to one single edge as shown on the right hand side of figure 8.

Adjustment of edges and nodes

Technical drawings especially in civil engineering are characterized by a frequent occurrence of right angles between lines. Usually these right angles are achieved by a rectangular raster for the location of nodes. Therefore the user has the possibility to choose a raster resolution as well as to adjust the raster and the topological structure of the potential lines. If the user does not agree with the results in special cases he has the opportunity to edit the location of a node manually. The topological edges and nodes after the clean up process are shown in figure 9.

topological node

topological edge

Figure 9 Topological structure for potential lines after the clean up process

Assembly of edges and generation of lines

After the rastering process of nodes all edges connected with a zero angle and with the same thickness value are transformed into lines with a specified thickness. The result for the detail of the drawing shown on the left hand side of figure 6 and for the topological structure shown in figure 7 is illustrated in figure 10. The topological information of the generated lines is stored for the use within the recognition of drawing objects.
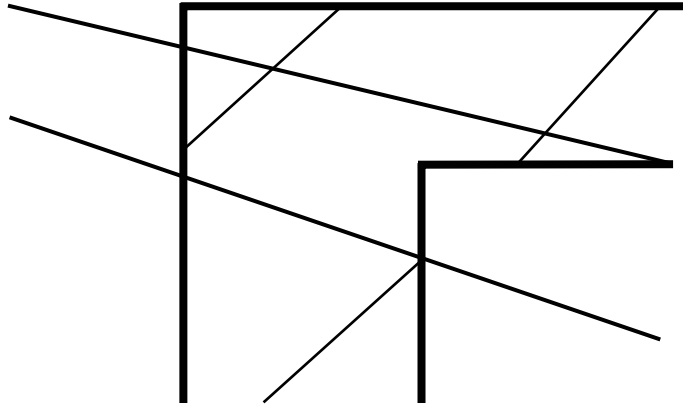
Figure 10 Topological structure for potential lines after the clean up process

RECOGNITION OF OBJECTS

The characteristic properties and criteria for each class of objects have to be defined. These characteristic properties and criteria are explained for the following exemplary classes, which might be adapted easily to other requirements. Properties like "parallel with" or "angle of 45º " do not have to be satisfied exactly but within a user specified rage. Properties like "is connected with" or "has an intersection point with" can easily be verified with help of the topological structure of lines. Some criteria and properties for exemplary classes of objects are defined as follows. Not all of these criteria have to be inevitable fulfilled for assignment to a class.

Dimension lines: Small thickness value, rectangular intersections with other dimension lines, 45º intersections with small lines, these intersection points are in the middle of these small lines, no endpoint is an intersection point.

Hatching lines: Small thickness value, hatching lines for the same object are parallel, no intersection point with other hatching lines, 45º intersections with wall lines at the endpoints of the hatching line.

Walls lines: Large thickness value, at least two pairs of parallel lines, intersection points with other wall lines only at the endpoints, all wall lines of one wall object form a closed loop.

Windows and doors lines: Medium thickness value, a pair of parallel lines (door lines: dashed lines), at the endpoint rectangular intersection with wall lines, a pair of window / door lines and a pair of walls form a closed loop.

CONCLUSION

In this paper a software tool to identify lines within scanned technical drawings, to clean up the identified lines via topological information and to recognize drawing objects is presented. All methods presented in this paper are realized within a software tool based on JAVA. At the present state this software tool is a prototype which may be adapted to other user specific requirements. Writings and especially handwritings within drawings are a topic of the ongoing work.

Figure 11 shows the user interface of the developed tool for the re-engineering process of technical drawings. In the display area of the user interface a part of a more complex example is presented. This example demonstrates two remarkable differences compared with the previous example: At first this example shows a quarter part of roof framework. In order to identify objects within this roof construction new criteria and properties for rafters, purlins, timber pillars etc must be developed. Secondly the process of identifying drawing objects for the whole roof system takes more than an hour on an usual personal computer. In the case of uncertainties the user has to decide about the way of interpretation. This time consuming identification process combined with probable necessary user interactions is not yet acceptable for practical usage. A the actual state of the development this tool is suitable for drawings of medium sized buildings like a detached house.
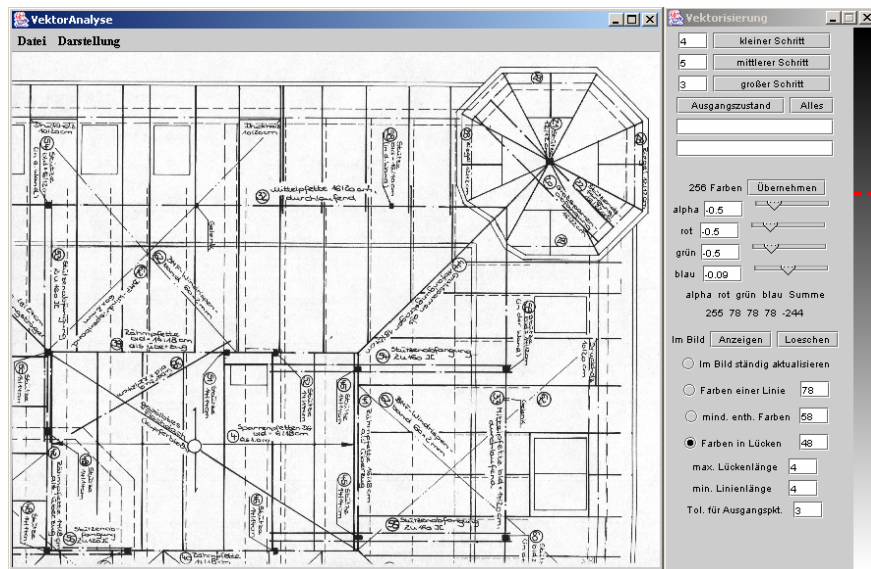
Figure 11 User interface of the software tool for re-engineering technical drawings

The results and most of the pictures presented in this paper are based on the diploma thesis of the co-author Christian Esch, which was performed under the supervision of Volker Berkhahn. Both authors would welcome new collaborations for a further development of the presented software tool.

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