3D approach in airport location studies

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Abstract

The article presents the use of advanced 3D techniques in airport location studies. Though specific to the airports only, the activities such as runway orientation and control of obstacles, could be supported by CAD tools originally developed for road design and ground remodeling. All these techniques are based on triangulated 3D models: triangulated models of the obstacle limitation surfaces and the TIN terrain model. Terrain protrusions through the obstacle limitation surfaces are tested by using relatively small subset of options used in ground remodeling. The extent of these protrusions is measured by using complex tools for volumetric analyses. "Shadow" terrain profiles in the airport approach zones are created by using modified profiling tools coming from road design. All these procedures are demonstrated on a relatively small and compact airport project located in the mountainous region of the Balkans.

Key words: Airport Design, Control of Obstacles, CAD, Digital Terrain Modeling

1. Introduction

Though primarily oriented to education and scientific research, The Faculty of Civil Engineering – University of Belgrade in Serbia is frequently engaged on projects, some of them airport projects. Most of these projects are expansions and reconstructions. Even when engaged on master plans, these master plans are usually confined to existing airport locations. Rarely do local engineers have the opportunity to participate on master plans which start with the search for an entirely new airport location or with the, so called, location study [1], [2], [3].

A few years ago, we have been engaged on a master plan for Trebinje airport (Figure 1). Trebinje is small city in southern Hercegovina with 25.000 residents, the number expands to 70.000 in summer months. It is merely 25km inland from the Croatian historical coastal city of Dubrovnik. The vicinity of Dubrovnik creates an opportunity for the new Trebinje airport to compete for passengers with the existing Dubrovnik airport.

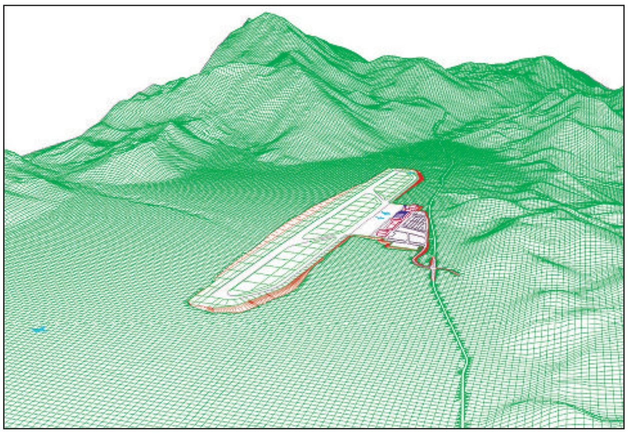

Figure 1. Future Trebinje International Airport (TIA)

There have been several attempts to find a suitable location for Trebinje airport. But primarily because of the exceptionally rough terrain, both in the approach zones and on the potential airport locations, an adequate solution was not found. Therefore, in late autumn 2008, The Faculty of Civil Engineering was asked by The Municipality of Trebinje to take the lead in master planning for a new airport. Though the well known fact that navigational, climatologic and environmental analyses together are crucial in the search for an optimal airport location, it immediately became apparent that the proper setting of the approach procedures in relation to the existing ground features would be decisive. The morphological features of the terrain were so tight, that immediate checking of a particular runway profile for any promising approach path was necessary. The vicinity of existing airports in Mostar, Podgorica, Tivat and Dubrovnik, as well as the recently created borders between Croatia, Montenegro and Bosnia and Hercegovina, imposed further limitations.

By tradition, design bureaus in former Yugoslavia are well equipped with software solutions for road design. Taking into account the fact the European design tradition imposes very demanding technical documentation (meticulous grading plans for crossroads and other planar facilities, detailed cross sections, specific superelevation concepts for pavement surfaces and pavement layers etc.) many bureaus developed their own software solutions. The years of crises and wars, during which it was hard to adequately validate the engineering profession, encouraged many young engineers to turn to software development instead. Thus, at any level of planning or design (master planning, conceptual design, preliminary design, or construction drawings), almost every element of the airside (runway, taxiway, holding bay or apron) is well supported with adequate software solutions, yet these software solutions were primarily intended for roads. Of course, there are many features that are specific to airports only: aircraft parking modules, fillets (inner taxiway edges at curves) etc. But, even these elements are covered with several domestic software solutions. All in all, only the early stages of airport location studies, dealing with the approaches and general terrain limitations, are not adequately covered with the specific software tools. And that is what this particular article is about: how to resolve problems in runway/approach orientation by using software tools for general geometrical analyses developed for road design.

2. Digital terrain modelling

Any serious planning or design activity starts from the digital terrain modeling (see Figure 2). The most widely adopted terrain model for civil engineering purposes is TIN (Triangulated Irregular Network) model. By definition, TIN model connects terrain points by using non-overlapping triangles tending to be as much equiangular as possible [4], [5] .

By simple editing (switching triangles' edges) it is possible to incorporate any kind of manmade or natural feature (ridge, escarpment, pavement edge) into the TIN, making the model identical to the natural surfaces. For rough examination of large areas of the terrain, the grid model could be quite appropriate (Figure 3) [5],[6]. The generation of a grid model is much easier to program than that of a TIN model. But, for subsequent geometrical analyses, the TIN model is much simpler to work with. In fact, each triangular facet is a part of a simple plane (as the three triangle's vertices define the perfect plane), while the grid cell is a part of a curved (twisted) surface. Since the cutting of the longitudinal profiles and cross sections, volume calculations and other geometrical analyses are much easier to program on simple triangular facets, even when we are given grid terrain models, we "explode" them into triangles. In fact, each "twisted" grid cell (defined with four points) could be easily exploded into two triangles (each one defined with three points).

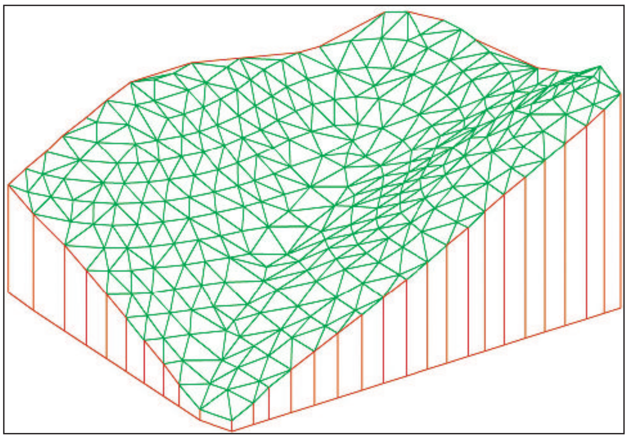

Figure 2. TIN terrain model

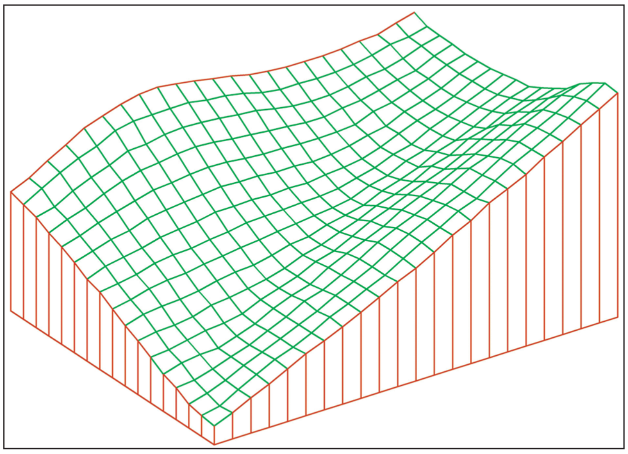

Figure 3. Grid terrain model [5], [6]

3. Obstacle limitation surfaces' modelling

With the terrain model ready, our design team moved to tackle the control of obstacle limitation surfaces, which proved to be crucial for the entire design solution. The shape and size of obstacle limitation surfaces were taken from ICAO (International Civil Aviation Organization) manuals [7]. In general, these are imaginary surfaces constructed around a particular runway. These are approach and take-off surfaces (extending up to 15km in front of each runway's threshold), the inner horizontal surface (circular surface with the radius of 4km, 45m above the lower threshold), the conical surface (climbing at the grade of 20% around the perimeter of an inner horizontal surface, and having the width of 2km) and the transitional surface climbing from the runway strip up to the inner horizontal surface at the rate of 1:7 (7:1 in American format, or cca 14%). The entire set of surfaces is moved and rotated (together with the runway) in order to minimize terrain protrusions. Obstacle limitation surfaces are also checked against the natural (trees) and man-made (buildings, towers, power lines) features.

To be operational, a triangulated model of obstacle limitation surfaces was needed (Figure 4). In essence, these surfaces could be easily modeled by using general purpose CAD systems. Curved approach or take-off paths could be modeled by using software solutions intended for road modeling. In fact, we even have simple software solutions for generating triangulated obstacle limitation surfaces developed 15 years ago and used only twice till now [5].

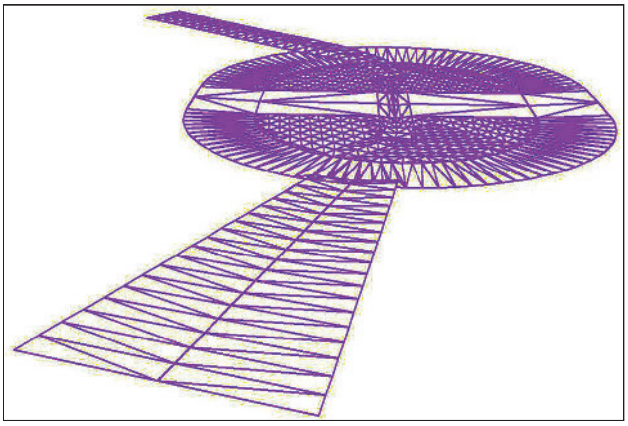

Figure 4. Obstacle limitation surfaces – Triangulated model

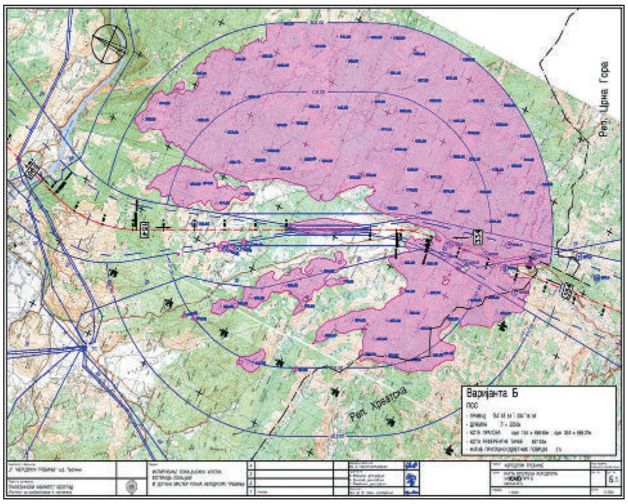

Figure 5. Aerodrome Obstruction Chart – Type B

4. Control of obstacles in 3D

The existence of both models, terrain and obstacle limitation surfaces, opens the way for their comparison. The graphical documents representing the relation between the obstacles and the obstacle limitation surfaces are The Aerodrome Obstruction Chart – Type A and The Aerodrome Obstruction Chart – Type B. Aerodrome Obstruction Chart – Type B is more illustrative (Figure 5) [8],[9]. This is the map representing obstacle limitation surfaces in plan projection, as well as all natural and man-made obstacles in the area. Apart from being a crucial element of the airport location study, the Type B map accompanies the flight crew on the route to a particular airport. The map informs the crew on the most prominent obstacles surrounding the airport. Based on these obstacles the crew decides upon the procedures (turns) to be performed in the case of the abandoned approach etc.

One of the most important features of The Aerodrome Obstruction Chart – Type B are the thick blue lines indicating terrain penetration through the obstacle limitation surfaces. While positioning the runway centerline, the model of these surfaces is moved and rotated along with the runway. For each promising position of the runway, hidden line removal should be called in plan projection, thus indicating areas where obstacle limitation surfaces sink beneath the terrain surface.

To sharply delineate the terrain penetration line, it is necessary to deploy specific tools. These are the tools dealing with the penetrating triangles, in this case the terrain triangles and the triangles forming the model of the obstacle limitation surfaces. We had at our disposal such a tool. It was the software for decomposing penetrating triangles into the subtriangles that do not intersect any more, but touch each other along the lines of intersection. We had been using this tool for years for the modeling of intersecting cut and fill slopes (Figure 6) [5], [10].

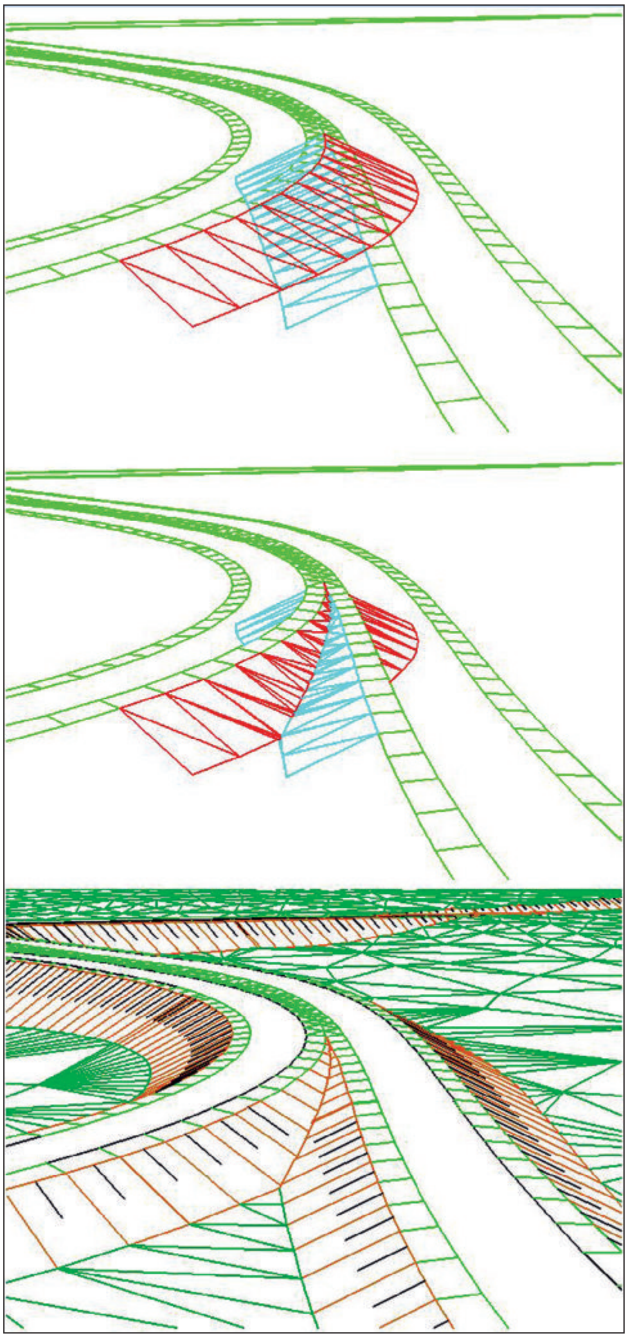

Figure 6. Decomposition of triangulated intersecting fill slopes [5], [10].

The software is supposed to work on triangulated cut/fill slope models. After decomposing the fill slopes' triangles, the lower subtriangles (below the intersection lines) are to be removed, while modeling cut slopes, the upper triangles are the surplus triangles. In essence, one particular triangle could be decomposed in only three ways, while intersecting with another one (Figure 7).

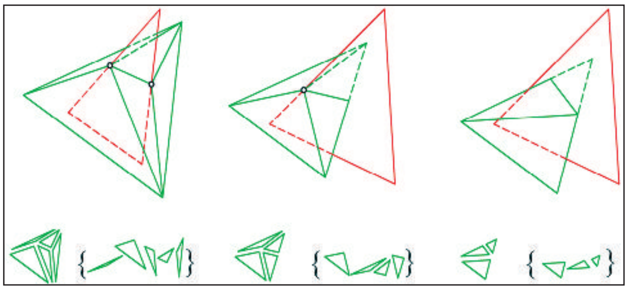

Figure 7. The three cases of triangles' explosions

Despite that fact, the algorithm that handles intersection of multiple triangles is a sophisticated one, because the subtriangles deriving from one "explosion" (between two particular triangles) and touching each other perfectly, must be checked for potential "explosions" with the rest of the starting triangles. To speed up the process, family relations are introduced between the triangles. The pretriangles are the triangles belonging to the starting set of triangles, while the subtriangles created in the explosion of one particular triangle are brothers (or sisters). Besides the brothers and the sisters, each subtriangle has its mother and father: the triangle of origination and the triangle in relation to which the originating triangle was exploded. As the algorithm starts to dissipate the triangles, the number of candidates for the "explosion" grows rapidly. Keeping track of family relations, unnecessary (impossible) "explosions" are skipped, making the software run faster. But, to cut the long story short, to delineate the intersection between the terrain triangles and the triangulated model of the obstacle limitation surfaces only a small fraction of this algorithm should be deployed. Only the intersection lines between the pretraingles (deriving from the three cases illustrated on Figure 7) are generated.

Besides the plan projection presented on The Aerodrome Obstruction Chart – Type B, some cross sections (perpendicular to the runway centerline) are always helpful (Figure 8). These cross sections usually contain terrain and the obstacle limitation surfaces. But, in the case of Trebinje airport we came to a conclusion that isopachytes' projection would give a much clearer picture than any set of cross sections. Till now, we have been using isopachytes only on resurfacing and ground remodeling projects. Isopachytes are the contour lines delineating equal differences in elevation between the two triangulated surfaces (the proposed and the existing surface). At the location of each node (from both triangulated surfaces) the difference between the two surfaces is measured and the new point, having the elevation equal to that difference, is set at this position. The TIN model generated from these new points represent the thickness between the two surfaces. On grading projects, the model is negative in cut areas and positive in areas to be filled. Contours generated from such a TIN model are isopachytes (Figure 9) [10].

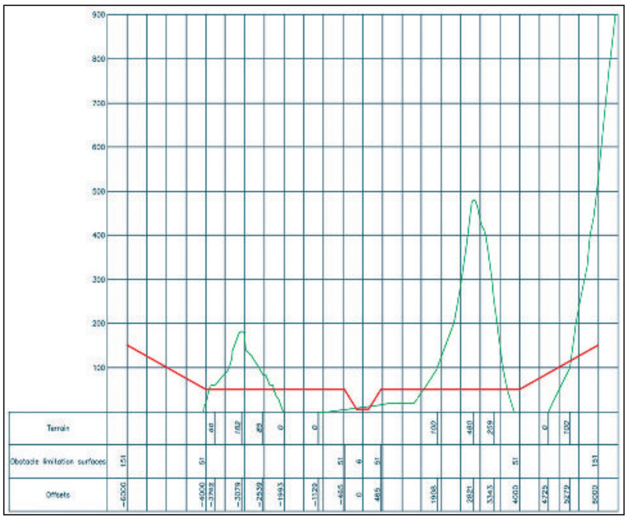

Figure 8. Cross section through the obstacle limitation surfaces

For construction purposes, 1.0m isopachytes are suitable for grading projects, while the interval of 1.0 cm is suitable for road resurfacing projects. On road resurfacing projects isopachytes may be used to represent the variable thickness of the leveling course (the course laid after the scraping of the existing pavement and beneath the newly applied wearing course).

In addition, highly accurate volumes can be calculated between the TIN model representing the thickness and the formal horizontal plane placed at the zero level, as the TIN itself ideally represents cut/fill thickness.

In this particular case, apart from the terrain penetration line through the obstacle limitation surfaces, the idea was to somehow depict the sheer extent of this penetration. Therefore, the TIN model representing the "thickness" of the penetration was created and contours were generated from such a model. By definition, these contours were isopachytes. Bearing in mind the area to be covered, the scale of Type B map and the sole purpose of these isopachytes, the interval of 50m was adopted (Figure 10).

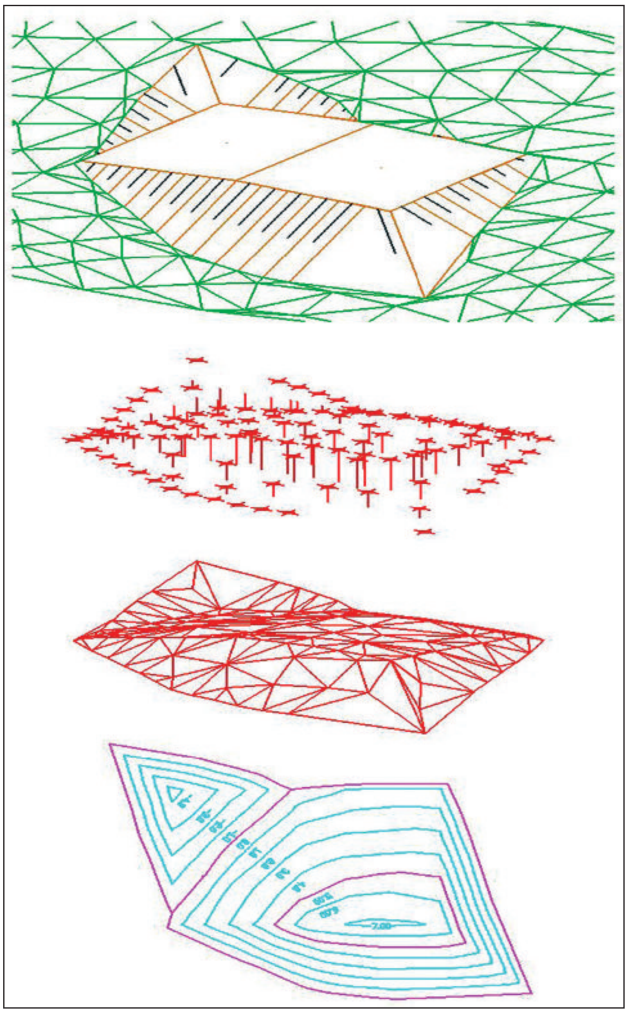

Figure 9. Isopachytes' generation [10]

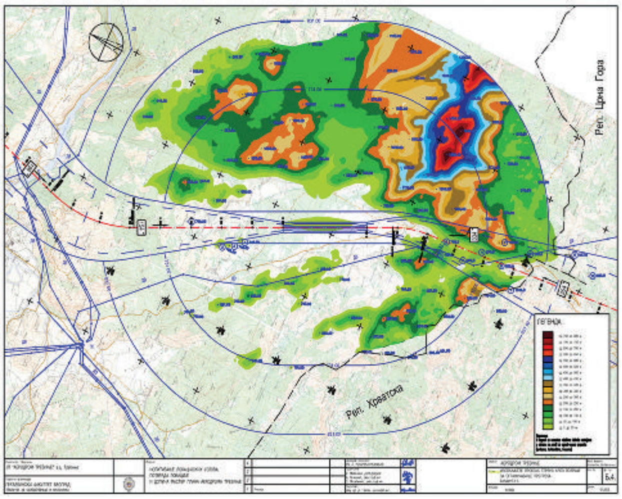

Figure 10. Isopachytes representing terrain protrusions through the obstacle limitation surfaces

As the isopachytes resemble the general morphology of the terrain, the picture of the terrain penetration extent becomes quite clear. When one of the two surfaces to be compared is rather flat, then the general flow of the isopachytes resembles the contours of the opposing surface.

Though aware of the value of the isopachytes on grading projects, in some cases we were not thoroughly satisfied with their application. When the first author of this article was engaged on a dredging plan for Kuwait harbor, the isopachytes generated between the existing and the proposed bottom of the harbor were hard to follow even for the eye of the professional. This happens whenever the vertical differences between the two surfaces are relatively small and when the surfaces frequently change sides in the vertical sense (between cut and fill). Even when there is no vertical change in sides, the isopachytes may produce quite a vague picture. The first author of this article also recalls the project of a landfill in Switzerland, when large quantities of material excavated from the tunnel had to be disposed of in a valley. Though there was only a fill to depict (no cut), the undulated valley bottom caused rather irregular shapes of the isopachytes. Anyway, while the isopachytes may produce a graphical "nightmare" on simple grading and resurfacing projects, their shapes are nice when applied on the differences between the terrain surface and the obstacle limitation surfaces surrounding the airport. In this case, obstacle limitation surfaces make the unique surface that is a flat one and to make the picture even clearer, only the ishopachytes in the areas where the terrain is higher than the obstacle limitation surfaces, are needed. Thus, if assigned a similar project in the future, we will surely be using isopachytes again, as no set of cross sections contains more (and more readable) data than a single plan with the isopachytes.

Contours generated from the obstacle limitation surfaces are always welcome. In plan projection they give a general three-dimensional picture of the entire assembly of obstacle limitation surfaces. In municipality plans they impose vertical limits on the structures planned in the area surrounding the airport. With the triangulated 3D model of the obstacle limitation surfaces completed, it is exceptionally easy to generate contours from such a model (Figure 11). Bearing in mind that the triangles are parts of the planes, it is very easy to develop the software tool which incrementally moves the imaginary horizontal plane upwards, intersecting this plane with the models' triangles [5], [10] . The set of straight intersecting lines generated at each incremental elevation presents contours (at a particular elevation). A serious numerical problem is not to generate intersecting lines at each incremental elevation, but to connect these scattered lines in continuous (open or closed) chains that can be further splined, in order to produce smooth contours. In fact, contours generated from obstacle limitation surfaces could be left unsplined.

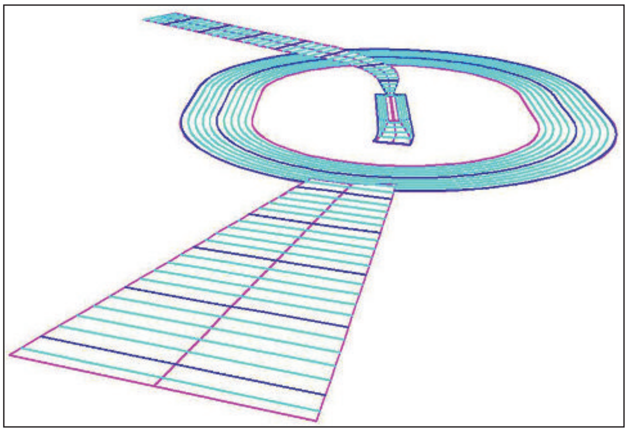

Figure 11. Contours generated from the obstacle limitation surfaces

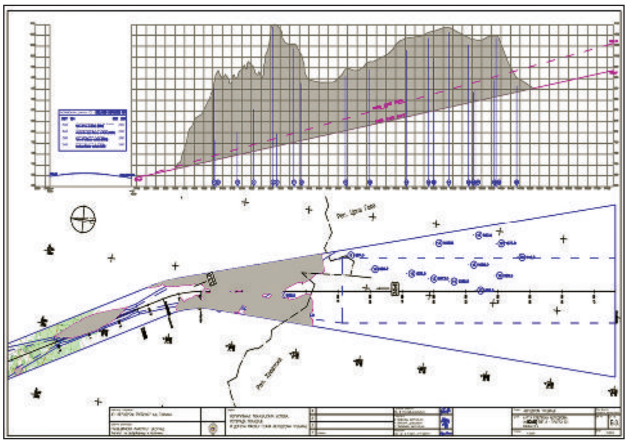

Figure 12. Aerodrome Obstruction Chart – Type A

5. Profiles of obstacles

The Aerodrome Obstruction Chart – Type A is a combination of plan and profile projection (Figure 12). In the lower part of the document there is a relatively narrow plan depicting the approach surface, with all the obstacles marked with the symbols proposed by ICAO. The longitudinal profile resides in the upper part of the drawing. The profile spans the length of the approach path. All the obstacles marked in the plan projection are placed at their distinctive elevations in the profile. Runway and approach surface profiles are also superimposed.

The software for marking the obstacles and the correlation of obstacles in plan and profile projections had already been developed [5],[10]. But the most interesting part of the obstacle profile is the terrain itself. The terrain profile is not a simple longitudinal profile cut along the extended runway centerline and following the approach path, nor a kind of combination of the profiles generated along the diverging edges of the approach path. The terrain profile is supposed to be a kind of a shadow profile [8] . At each incremental step along the centerline of the approach path, the maximum terrain elevation is taken from the terrain cross section, providing the cross section spans the exact width of the approach path at this particular location. The profile outlines the exact terrain shadow for the observer standing aside the approach path (Figure 13). To produce such a profile, we turned again to the existing software tools intended primarily for road design.

When setting the vertical alignment of the street, we do not rely only on terrain profiles (or existing pavement profiles) cut along the centerline or the profiles taken at some specific lateral offset in relation to the centerline (when setting the new pavement edges on resurfacing projects). There are always some points scattered in the vicinity of the centerline that are not positioned at some constant lateral offset and have to be observed while setting the vertical alignment of the street. These might be entrances to nearby buildings, shop windows etc. Each of these points is present in 3D either as a point surveyed in the field and imported into the CAD drawing, or as a part of the TIN model. By using simple tools [5], these 3D locations are labeled with the station and lateral offset in relation to the centerline. Then comes the tool that reads the station and the elevation of each point (lateral offset is not needed for this operation) and transfers the points into the longitudinal profile accordingly (Figure 14).

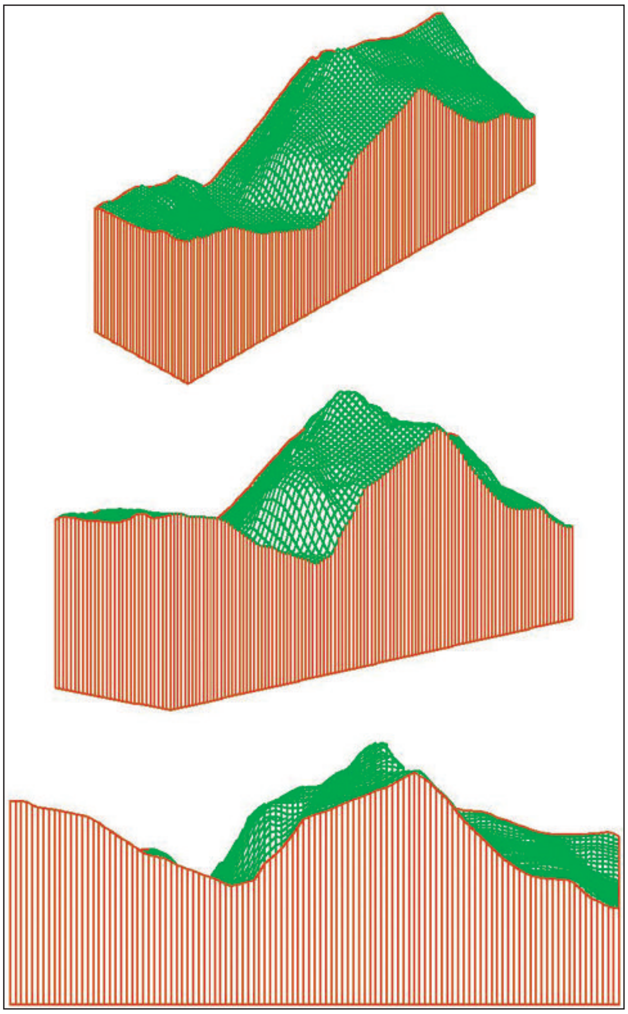

Figure 13. Shadow terrain profile

For the creation of a shadow terrain profile along the approach path, only a small automation is added to the existing tools. Points are now automatically attached to every vertex of each terrain triangle enclosed within the approach path and then labeled with station/offset pairs in relation to the centerline of the approach path. The entire "cloud" of points is generated in this manner. Then this "cloud" is transferred into the longitudinal profile developed along the centerline of the approach path. When taken from the TIN model produced by exploding the grid model into triangles, this cloud nicely reflects the terrain morphology (Figure 15). Finally, the outline of the shadow profile is redrawn manually, through the highest points within the profile.

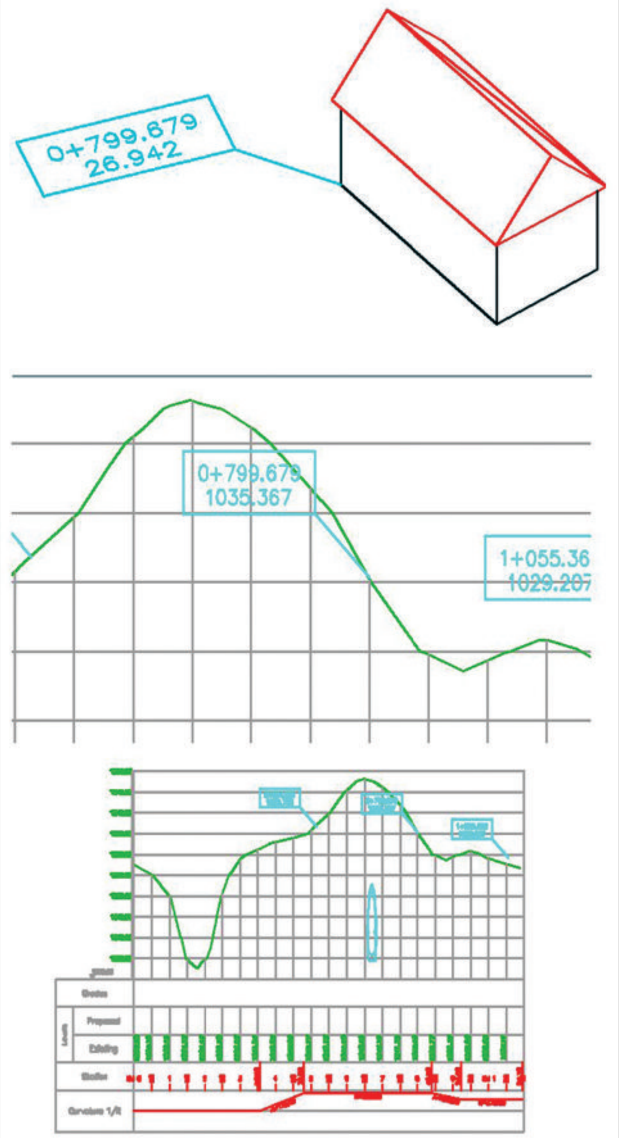

Figure 14. Transferring point from 3D to the longitudinal profile

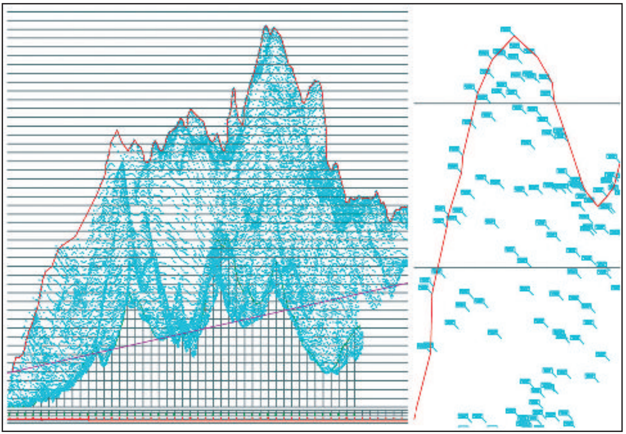

Figure 15. Cloud of terrain points transferred into the profile

6. Runway site distance analysis

After resolving the general orientation of the runway, we moved to the general design activities. Except aircraft parking maneuvers, taxiway fillets and similar details, these design activities are supported with software tools and the procedures that are more or less standard in both road and airport engineering. But, on this particular project, the roughness of the terrain, not only in the approach zones, but even in the airport zone, seduced us to deploy more powerful tools than needed. It immediately became apparent that the sight distance along the convex vertical alignment of the runway may impose visibility problems. By ICAO regulations, from each point along the runway centerline that is 3m above the pavement surface, any point within the distance of at least half the length of the runway and which is also 3m above the pavement surface must be clearly visible. In other words, the pilot, whose eye level is 3m above the pavement, must see the obstacle 3m high at the distance which is at least half the length of the runway [11], [12] .

We even have the tools for checking the available sight distance along the 3D road model [10] . The necessary prerequisite for such an analysis is the existence of the two strings of points, one generated along the driver's eye trajectory (1.1m above the pavement surface and 1.5m from the right pavement edge) and another one generated over the trajectory of a potential obstacle (0.1m above the road surface and 1.5m from the right pavement edge). Launching the straight lines of sight between the two groups of points and searching for the potential penetrations through the complex triangulated model tells what the available sight distance at each stationing interval along the road is (Figure 16).

But, taking into account the fact that the centerline of the runway is an absolutely straight line, any influence on the sight distance may come from the elements of the vertical alignment only and not from the terrain or airside features on either side of the runway pavement. Thus, to check the available sight distance, it is absolutely unnecessary to carry out 3D model analyses. It is enough to concentrate on the longitudinal profile. First, the vertical alignment of the runway should be copied for 3m up. Then, the lines of sight (half the length of the runway long) are drawn between the points of the copied alignment. If no intersection with the actual vertical alignment of the runway exists, then the available sight distance is satisfactory.

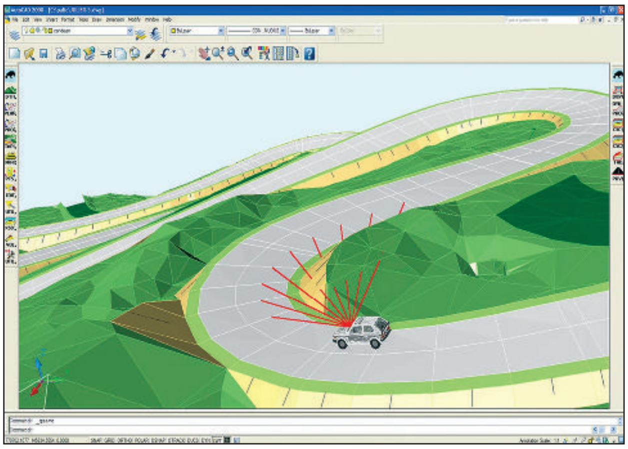

Figure 16. Calculating the available sight distance from the 3D model

7. Conclusion

The 3D control of obstacles, surrouding the airports, starts with the creation of the TIN terrain model followed by the triangulated model of the obstacle limitation surfaces. Terrain protrusions through the obstacle limitation surfaces are calculated by using the relatively small subset of tools intended for modeling complex intersections among the cut and fill slopes. The extent of these protrusions was illustrated by using isopachytes generated between the TIN terrain model and the 3D model of the obstacle limitation surfaces. In essence, the isopachytes are the contour lines delineating equal differences in elevation between the two triangulated surfaces. As the obstacle limitation surfaces in plan projection, together with the terrain protrusion lines, constitute the Aerodrome obstruction chart – Type B, the shadow profile of the obstacles presents the main portion of the Aerodrome obstruction chart – Type A. These shadow profiles are automatically generated by using the simple road profiling tools, applied on the clouds of points scattered over the terrain surface.

So, as we tried to be as innovative and effective as possible on this particular airport location study, we stopped here, ending up with the triangulated models of the obstacle limitation surfaces, the application of the isopachytes for the terrain penetration analyses and with the use of the clouds of points for the creation of shadow profiles.

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