

# A STUDY OF AN ALGORITHM FOR THE CONSTRUCTION OF SURFACES DEFINED GRAPHICALLY BY CURVES APPLIED IN THE ARCHITECTURAL ENVIRONMENT

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## ABSTRACT

The aim of the present research is the construction of graphic surfaces defined by sections with parallel planes or by the points coordinates of the network nodes. To achieve the set goal, an algorithm for constructing 2 and 3 images of graphical surfaces, defined by curves, has been investigated. An approbation of the algorithm is also presented along with its application in an architectural environment.

**Key words:** algorithm, nodes, Geometric modeling, Graphical surface, Topographic surface, sections.

## INTRODUCTION

In a design process, the form of a building can be explored as a designer's goal in the architectural environment. The design tool is of great importance among the factors influencing the development of a form such as geometry, performance, beauty, stability, and safety issues.

An incomplete classification of surfaces with inherent and multiple subordination has been made, aiming only to pragmatically specify some general concepts. The present work does not take into consideration the properties and the methods of obtaining of common surfaces such as: helical surfaces, rotational surfaces of the second degree, conoids, cylindroids, etc.

A surface that can be defined by an equation of the type  $F(x,y,z)=0$  is called mathematical. Any mathematical surface can be considered formed by the movement of a straight or a curved line (constant or changing according to some law). Such a representation of mathematical surfaces is called kinematic and is particularly convenient for their graphical interpretation.

The moving line (curved or straight, spatial or planar) which defines the surface is called generator. Mathematical, graphic, and pseudo-graphic surfaces are curvilinear or rectilinear depending on the type of the surface generator (curved or straight).

Rectilinear surfaces are cylindrical surfaces, conical surfaces, rectilinear spiral surfaces, cylindroids, conoids, and hyperbolic paraboloids (Mamieva, 2019).

Rectilinear surfaces are:

- developable (a cylinder – straight and inclined; a cone – straight and inclined) and
- non-developable (cylindroids, conoids, hyperbolic paraboloids, helical surfaces, toroidal and spherical surfaces).

A surface (a cylinder, a cone, or a hyperbolic paraboloid) can be represented as obtained by the movement in a certain way of one or more different generators, i.e., can be defined differently, depending on the task being solved (Figure 1a).

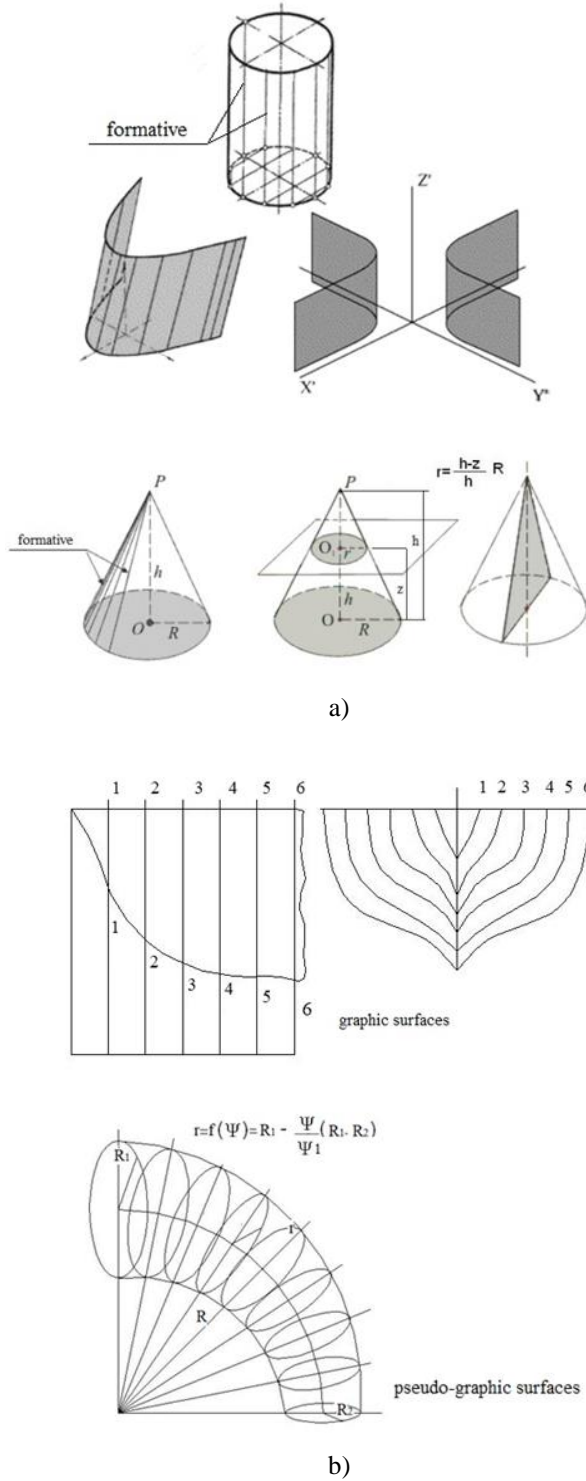


Figure 1: Types of surfaces depending on the moving line: a-rectilinear surfaces b-graphic and pseudo-graphic surfaces.

The creation of graphic surfaces is provoked by the kinematic interpretation of mathematical surfaces with a variable generator (Figure 1b). When the change of the generator cannot be described by some mathematical function, it is set graphically, by plane curves in certain planes, assuming that there will be a smooth transition between them. Examples of such surfaces are the boat and ship hulls (Figure 2a), airplane wings (Figure 2b), public buildings awnings, tent domes on circus grounds, exhibition pavilions, etc. In many cases, even surfaces that can be accurately described mathematically are defined graphically.

In the design process, the form of a building can be explored as a designer's goal in the architectural environment. The design tool is of great importance among the factors influencing the development of a form such as geometry, performance, beauty, stability and safety issues (Khalili et al, 2007).

Graphic surfaces are widely used in engineering, geodesy, road engineering (when determining the routes and the excavation works volume, as well as the volume of the embankments), building interiors and exteriors (when determining ceilings and non-traditional roofs and facades), and in many other cases (Todorova et al, 2023).

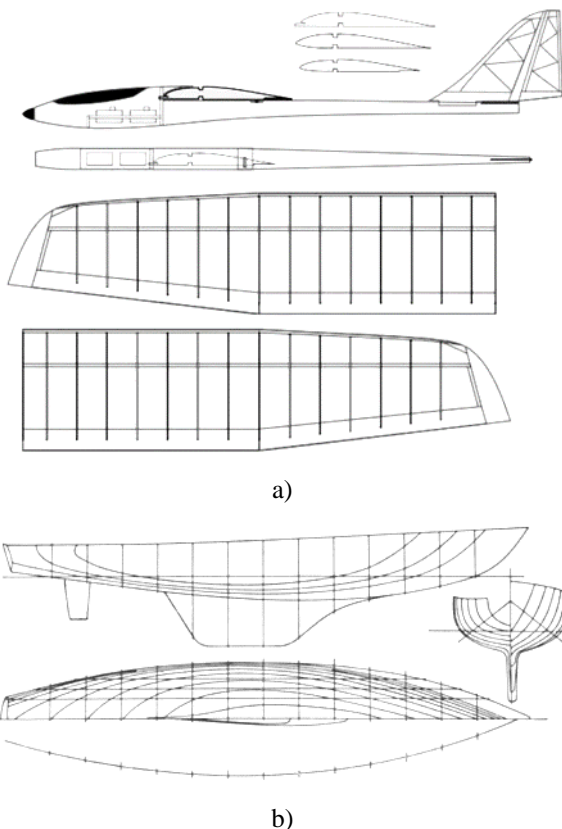


Figure 2: Application of graphic surfaces defined graphically by plane curves a- wings of airplanes, ([www.blog.tadroberts.ca](http://www.blog.tadroberts.ca)), b- hulls of boats and ships, (<https://pin.it/3DfanTH>).

*Graphic surfaces can be set according to three methods:***1. First:**

**1.1.** By a certain number of curves lying in parallel planes at the same distance from each other – in this case, the curves represent intersections of the parallel planes with the graphic surfaces. It is possible that the intersections with the planes pass through the axis of the body if it is symmetrical (for example, a helical surface of a ramp). There is also a possibility that the distances between the intersecting planes are unequal; curves are set graphically; the parallel planes are in two mutually perpendicular directions so that two or more orthogonal projections of the graphic surface, or its three-dimensional image, can be constructed.

**1.2.** Through a certain number of curves lying in parallel horizontal planes (horizontal) at equal distances from each other above and/or below the horizontal projection plane (in the positive or negative half-space – a projection method of the quoted projection, which is widely used in the depiction of the earth's surface and in solving relative engineering tasks, such as: design of roads and hydrotechnical facilities, urban planning, mining, etc. These surfaces are called topographic).

**2. Second:**

Tabular format – through the points coordinates in the nodes of the network where the two systems of the parallel planes intersect. These systems are mutually perpendicular to each other.

**3. Third:**

Combined – part of the curves are set according to the first method – through the projection of curves (the sections of the two mutually perpendicular systems of mutually parallel planes with the graphic surface), and another part is set according to the second method – through the points coordinates in the nodes of the network where the two systems of the parallel planes intersect and the systems are mutually perpendicular to each other.

There is also another possible case – when one of the curves (sections) is set by its equation.

When the geometric object (the graphic surface) is set according to the first method – by means of a certain number of curves lying in parallel planes at an equal distance from each other in two mutually perpendicular planes – the construction of the missing third projection and the three-dimensional image of the graphic surface is done by constructing the points from the network nodes. The points coordinates of the graphic surface, necessary for the construction of the missing third projection and the three-dimensional image, are taken from the given two projections of the surface. The points of the graphic surface are the intersection points of the planes sections of the two mutually perpendicular systems, parallel auxiliary planes of the graphic surface and lie on the grid projections.

The problem-solving algorithm is similar to the other two methods of graphical surface setting, but the point identification in the absent projection and the three-dimensional image is obtained by the coordinates from the table (in the second method) or in a combined method, using graphical, tabular or analytical data. Surface points identification can be streamlined by being located first in one plane, which is for example parallel to the frontal one, and then in the subsequent parallel planes of the same system. Further, in an analogous way, the points lying in the other mutually perpendicular systems of parallel planes can be identified.

The algorithm is not restricted to any particular subset of developable surfaces (RoseAlla at. all, 2007). The proposed algorithm is demonstrated by creating a surface model of various curved meshes (Park at. all, 2015).

**MATERIALS AND METHODS**

The problem-solving algorithm of this type can be described as follows:

1 – the known data of the geometrical object is depicted – a graphic surface is set in one of the above-mentioned ways – for example, in the considered case, this is achieved graphically through the projections in the frontal  $f(\pi_1, v)$  and the horizontal  $h(\pi_2, \mu)$  projection planes (Figure 3). This can also be done by applying three-dimensional graphic CAD systems, for example, based on the AutoCAD platform and the Solid WORKS, or others, such as: NURBS Development Of Quadratic Surfaces For 3D Graphics Systems, Open GLSCOP, Inroads, Auto Desk Civil Engineering, etc. (Lazarova, 2007, Maldzhanski, 2000, Buss, 2003, Milev, 2013) manually, semi-automatically or automatically. Geometric modelling can be modelling of surfaces or solid objects depending on the task. Modelling can be achieved in several different methods depending on their suitability for the given specific case. In the presented case, it is appropriate the graphical surface to be modelled with B-splines, while for the topographical surfaces this can be achieved with, for example, the Auto Desk Civil Engineering.

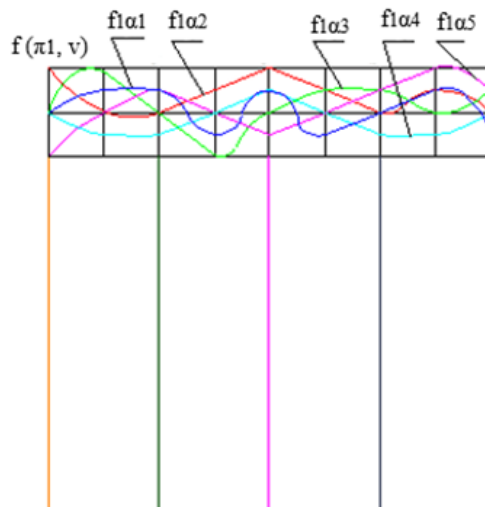


Figure 3: Set graphics surface.

2 – the system of parallel secant planes is depicted and denoted by their traces in the frontal  $f(\pi_1, v)$  and horizontal  $h(\pi_2, \mu)$  projection planes –  $f1\alpha_1, f1\alpha_2, \dots, f1\alpha_5, h2\alpha_1, h2\alpha_2, \dots, h2\alpha_5, h2\sigma_1, h2\sigma_2, \dots, h2\sigma_5$  (Figure 3 and Figure 4).

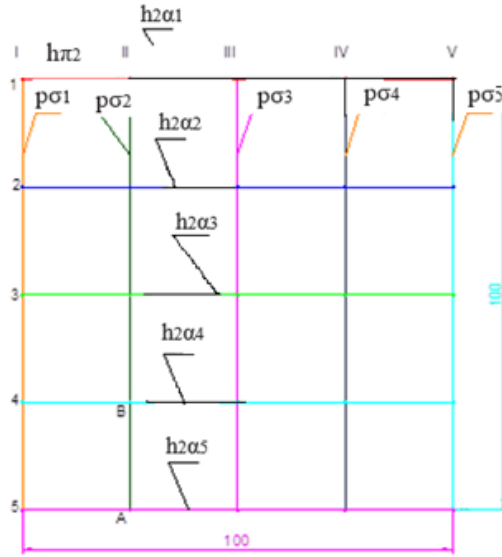


Figure 4: Define a system of parallel secant planes.

3 – the missing orthogonal (in this case profile) projection of the graphic surface is constructed. Its points are determined by the coordinates in the frontal  $f(\pi_1, v)$  and horizontal  $h(\pi_2, \mu)$  projection planes. The points lie on the profile traces of the system of parallel to each other planes and on the main frontal projection plane  $f(\pi_1, v) - p\sigma_1, p\sigma_2, \dots, p\sigma_5$  (Figure 5).

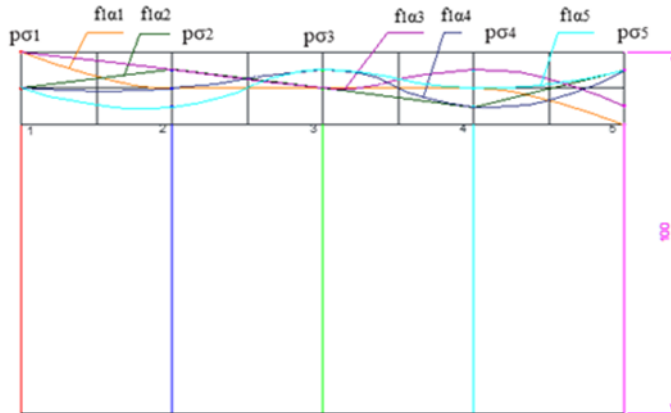


Figure 5: Constructing an orthogonal projection.

4 – the intersection points of the sections (curved lines)  $a\sigma_1, a\sigma_2, \dots, a\sigma_5$  with the sections (curved lines)  $p\alpha_1, p\alpha_2, \dots, p\alpha_5$  are determined, which are located in the network nodes. When they are joined, the appearance of the three-dimensional image of the graphic surface is obtained (Figure 6).

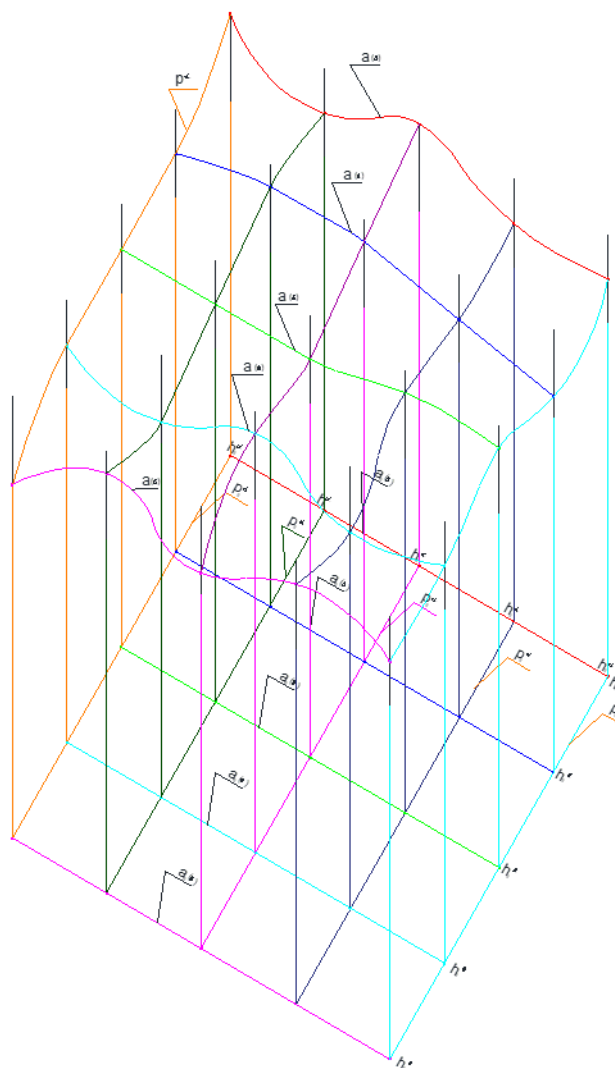


Figure 6: Finding intersection points of section.

5 – a more precise determination of the graphic surface separate parts (in this case between the planes  $\sigma_4$  and  $\sigma_5$  of one of the systems of parallel planes and the planes  $\alpha_1$  and  $\alpha_2$  of the other system of parallel planes perpendicular to the first) is achieved analogously to the description in item 4 – by constructing additional planes from the two systems at equal distances between them. The newly obtained points and lines of intersection determine the graphic surface even more precisely and this allows for the solution of various tasks (for example, if we assume that this is some topographical surface, the trajectory of a linear object, in this case a horizontal one, (e.g. a road section) can be determined (Figure 7).

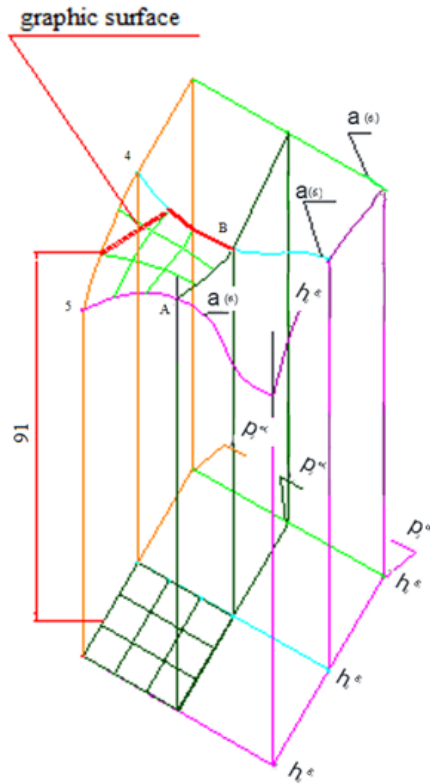


Figure 7: Precise definition of the graphic surface.

6 – the actual sizes (lengths) of the curves can be determined by their projections on the main projection planes – frontal  $f(\pi_1)$  and profile  $\pi_3$ . The example of determining the actual sizes (lengths) of the curves shown is for field 4-5-A-B (Figure 8).

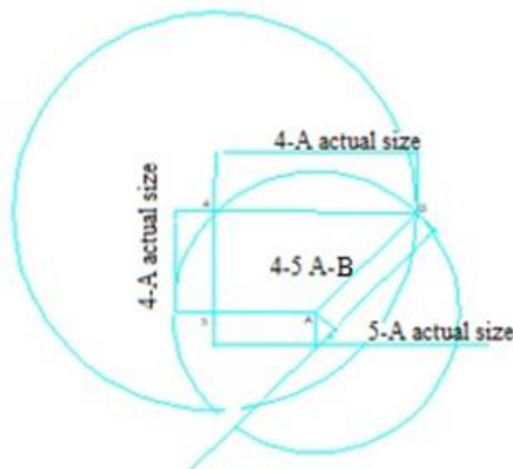


Figure 8: Determining the actual dimensions (lengths) of the curves shown is for field 4-5-A-B.

An application of a graphics surface in architecture is presented in Figure 9a and 9b. – pavilion in Seville (Kenneth et all, 2007). It is depicted using parallel planes in 2D and 3D view.

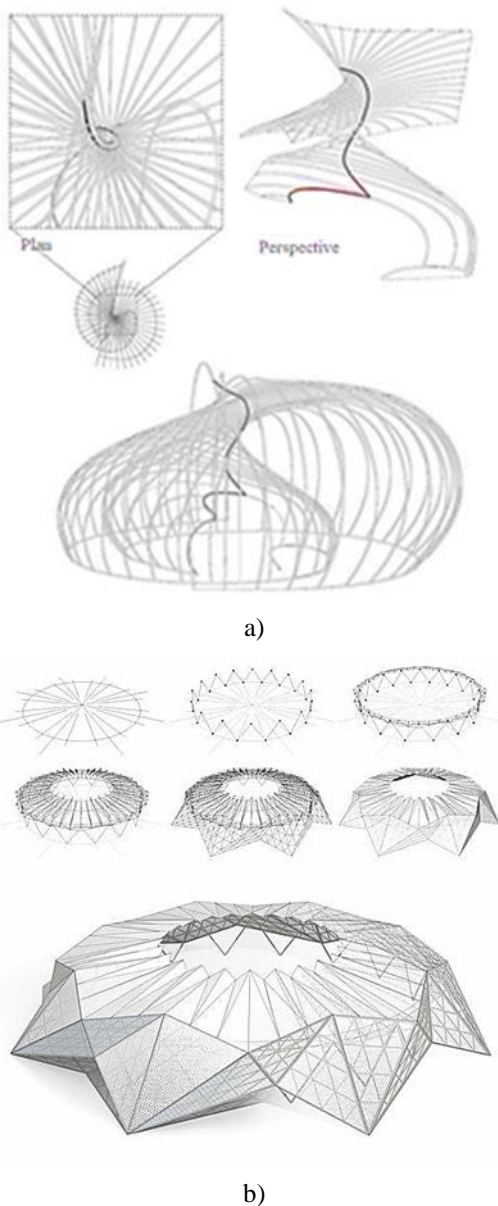
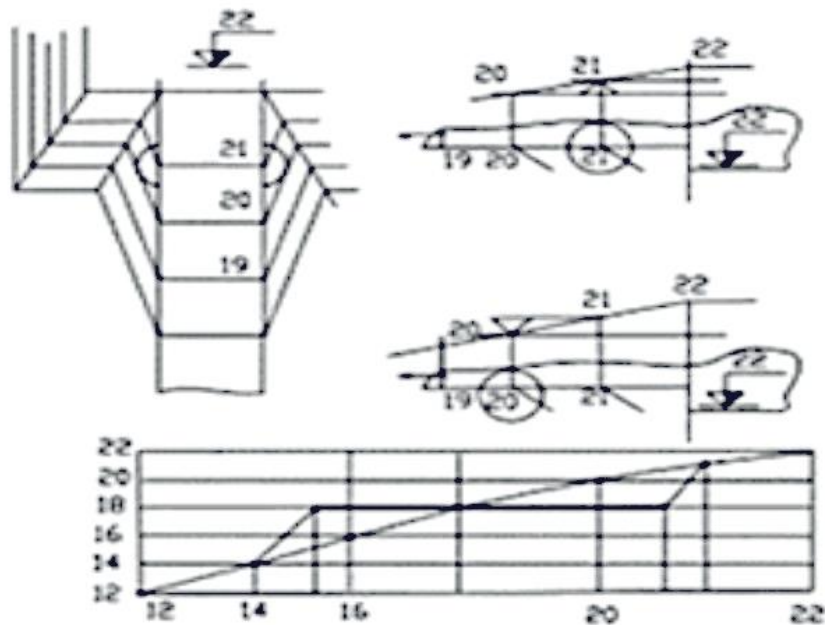


Figure 9: Determining the graphic surface of an architectural object (a, b) – (textiletabernacle.wordpress.com, <https://www.behance.net>, <https://www.archdaily.com/179243/grand-stade>).

Another type of tasks with pre-defined graphic surfaces (in this case a topographic surface – Figure 10 is to determine the boundaries of the embankment and the trench on a construction site, a railway, or a roadway (Danchenko et all, 2012).



**Figure 10: Determining the boundaries of the embankment and trench on a construction site with given graphic surfaces.**

Normally, the slope angles of the trench are taken as 1:1, and of the embankment as 1:1.5. The line of zero will pass along the horizontal at elevation 22. The excavated part of the site will be to the north, while the embankment – to the south. In the area of the excavation, the site is widened to form channels for the purpose of drainage. The required boundaries of the earthworks are determined by the intersection points of the topographic surface horizontals with the slopes of the excavation and the embankment, respectively. In order to construct these lines, the horizontal slopes of the trench and the embankment are to be constructed. In this example, it is assumed that the distance between the horizontals of the trench equals to 1m, and that of the embankment – to 1.5m. In case the work is performed in the AutoCAD environment, this can be achieved very easily using the offset command.

## RESULTS AND DISCUSSION

As a result, of the construction of the exterior of architectural objects, whose graphic surfaces have a variable character, it is acceptable to render them by plane curves based on certain planes, with a smooth transition.

As a result, the surface of the trench and the embankment slopes is depicted with its horizontals. The lines of intersection of these surfaces with the ground and with each other are then constructed. The lines to be determined are identified by the intersection points of the horizontal lines of the considered surfaces. The method proved to be time-saving and able to provide accurate estimation data, in comparison to the manual methods (Atanasov et al, 2022).

## CONCLUSIONS

1. Graphical surfaces with a variable generator, where no mathematical function is applicable, must be graphically set on the basis of plane curves in determined planes with a smooth transition.
2. The created algorithm for constructing 2 and 3 graphic surface images, graphically set by curves, is applicable both in architecture and exterior design, as well as for determining the boundaries of a construction site embankment and trenches.
3. Graphic surfaces are widely used in buildings interior – e.g. ceilings, and exterior – non-conventional roofs and facades. In addition, it was established that they are completely applicable in geodesy, e.g. in road construction when determining the routes, the volume of excavations, and the volume of embankments.
4. On the basis of the conducted research and approbation, it can be concluded that the algorithm is completely applicable for solving problems of this class.

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