Surface modeling in AutoCAD for architectural and structural design

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Abstract. The article considers surface modeling as the main tool for designing complex thin-walled structures, which are used in modern construction, architecture, and AutoCAD design. When constructing objects, we expanded on the formation of associative planar and network surfaces as well as extruded, lofted, rotated, and closed surfaces. We described automatic editing of associative surfaces that results from changes in forming lines. We considered the options of the command Trim on the cutting edges of other objects which can be intersecting surfaces, and also the projected geometry as applied to surfaces. We described the application of the Project geometry command in any direction as a tool for forming cutting edges, for marking curvilinear surfaces with a geometrically accurate design, and for obtaining 3D curves as the basis for other surface constructing. We considered 3D align for simultaneous moving and rotating of an object in order to align it with another object. An example of the photorealistic visualization of objects with lighting, shadow creation, and material assignment was given. The article shows civil engineering students and design engineers how surfaces can be modeled in AutoCAD, which is one of the most flexible technologies for creating 3D surface shapes.

1. Introduction

Recently, there have been active changes in design methods and construction technologies, and new concepts for shaping architectural objects have been created. Computer technologies make it possible to visualize, understand, and evaluate virtual models of future projects [1-3].

Most CAD systems imply modeling 3D bodies, surfaces, and wireframe objects. Each of these three-dimensional modeling technologies has a wide range of different functional options as well as its advantages and disadvantages. Surface modeling is considered one of the most effective technologies used to create 3D objects of complex shapes in science, engineering, motor car construction, aerospace industry, shipbuilding, medicine, construction, and architecture, i.e. - wherever the diversity of surface forms plays a decisive role [4,5].

The course of engineering computer graphics focuses on solid modeling for obtaining associative drawings [6,7].

The article aims to familiarize civil engineering students and colleagues with the techniques and possibilities of surface modeling using examples of architectural shapes.

AutoCAD implements ideas at every project stage: creating an electronic model, plotting a set of drawings, making a realistic presentation of the project, printing a 3D project using 3D printers [8,9].
A surface model is a 3D shell object with infinitely thin walls that does not have mass or volume. AutoCAD has two types of surfaces: procedural (associative and non-associative) and NURBS surfaces. Associative procedural surfaces that maintain the connection with their defining objects, and NURBS surfaces that do not maintain associative connections, but have control vertices have to be edited. Surface models are developed with the following commands: create a network or planar surface, rotate, extrude, shift, and loft. Also, procedural surfaces can be created on the basis of existing surfaces or bodies by means of conjugation and closure with the possibility to control curvilinear surfaces, changing their continuity and deflection degree. Surfaces can be trimmed, elongated, and conjugated.

AutoCAD makes it possible to simultaneously work with solid objects and with surfaces. Solid bodies can be trimmed by surfaces; surface edges can be selected as the trajectory of a solid body under shifting or lofting; a 3D body can be created by thickening or displacing the surface, and by filling the space defined by surfaces.

2. Creating a surface with the LOFT Command

One of the options of surface formation is to construct it on the basis of its sections. In the example (Figure 1), one-third part of the object was created, and the Polar array command was finally applied to it.

In order for the arc sections to be geometrically correctly constructed, the circular pattern was marked by the rays $c$ and circles $k$, displaced towards the center (see Figure 1, a).

![Figure 1](image.png)

**Figure 1.** Creating a “loft” surface.

The vertical central ray $d$ was marked by points with an interval of 10 units.

The arc $a$ (arc / start - point A, end - point B, radius - 110 units) was plotted in the UCS plane, set by the 3 points A, O, and B. The following 9 arcs were constructed similarly with a decrease in the radius by 10 units. The LOFT command was applied to all arcs (a, b, etc.) in the Cross-sections only mode. The created loft surface was multiplied by the Polar array command (see Figure 1, c).

The obtained surfaces were presented as an auto-service center. To complete it, the facade and the entrance were constructed (see Figure 1, b). The facade was created as a closed surface $P$, where the closing edges were the straight line $k$ and its projection $c$ to the lofted surface. To form the entrance, the arc $o$ was drawn which cut the lofted surface. The arch $G$ was constructed as an extruded surface of the arc $o$ along the $p$ direction.

For clear and true-to-life representation of the object, its photorealistic visualization was made [10]. A remote light source was added to the scene, shadows were created, material properties of the objects were displayed.

A surface similar to the one described above can be referred to the structures of membrane architecture. Tent structures appeared at the turn of the 20th and 21st centuries due to the introduction of new materials: from strong polymer textiles to fiberglass with the most innovative films etfe and ptfe. Membrane architecture is a very popular highly technological construction method which is used.
worldwide, it is gaining ground in Russia due to its functionality (exhibition pavilions, EXPO, airports, railway stations, sports arenas, shops, industrial and agricultural facilities, etc.) [11-14].

Plastic light and flexible shells make it possible to easily model complex unique surfaces of mostly non-linear forms, including those borrowed from nature [15].

3. Object created by planar surfaces

Surfaces in real structures are often represented just by their simplest forms, i.e. flat surfaces, but in their original design. The object described in the example (Figure 2) was constructed by moving and rotating planar horizontal circular strips. The object markup is similar to the previous one. A planar surface-strip ABCD was obtained from a closed polyline formed by two arcs DA and CB, and segments AB and CD (see Figure 2, a).

![Figure 2. Plotting a composition of planar surfaces.](image-url)

The surface-strip takes up a vertical position when the 3D align command is applied. The points A, B, and C on the object were marked as the base points, the points A, B, and N served as the target points (see Figure 2, a). As a result, a cutout was formed in the horizontal circle, and the planar circular strip turned and moved to the vertical plane.

All subsequent 19 strip surfaces were made with a 10-unit shift to the center and a 9 shift to the left, similarly to the above considered one. Twenty Aligned strip surfaces were rotated 90 ° clockwise as copies (see Figure 2, b and c).

Figure 2, d shows a photorealistic representation of originally arranged planar surfaces as a summer cafe pavilion.

4. Plotting of a hyperbolic paraboloid as a network surface

Ruled surfaces have been extensively applied in engineering and design of buildings, architectural structures, and roads due to such qualities as beauty, reliability, and manufacturability [1,16,17].

In AutoCAD, the surface of a hyperbolic paraboloid was plotted with the Network Surface command. The segments a and d were indicated as the first direction edges, and b and c – as the second direction ones (Figure 3, a).

The created surface was used to exemplify the formation of the shell cover of the cylindrical building of a creativity center. The surface of the hyperbolic paraboloid was trimmed by the shape of the circle o with the commands Project geometry and Trim by the edge o (see Figure 3, a).

The cylindrical shell of the building was plotted by Extruding the circle to a given height or by Rotating the generatrix around the axis. The shell surface was Trimmed by the surface of the hyperbolic paraboloid (see Figure 3, b).

Domes and shells have always attracted engineers and architects’ attention due to their functional correspondence and architectural and artistic qualities [18-23]. One of the most important operations of architectural design is optimal layout of surfaces into constituent elements [24]. To construct windows and a door, the cylinder surface had meridian-circular marking a’ and b’ with horizontal
segments \( a \) and radial segments \( b \) created with the \textit{Project geometry} command along the axes OX and OZ.

![Diagram of segments a and b with Project geometry](image)

\textbf{Figure 3.} Plotting building elements and editing windows.

The window frame, i.e. the contours \( b' \) and \( c' \) which had cylinder curvature, was created on the basis of the contours \( b \) and \( c \) with the \textit{Project geometry} command along the OX axis (Fig. 3, c). Before constructing the window surface, the Surface \textit{Associativity} function was enabled, so that they maintained connection with the objects on the basis of which they were created.

The frame was constructed as a set of \textit{Extruded} surfaces (vertical lines of the contours \( b' \) and \( c' \)), \textit{Lofted} surfaces (3d arcs of the contours \( b' \) and \( c' \)) and a \textit{Closed} surface of the contour lines \( b' \). Also, the frame can be created by subtracting 3D bodies obtained by \textit{Displacing} the closed surfaces of the contour lines \( b \) and contour lines \( c' \). Glass is a \textit{Closed} surface of 3d lines of the contour \( c' \) (see Figure 3, b).

To edit the window representation easily and quickly, which becomes most relevant at the stage of assigning materials or making changes to the shape and dimensions, a \textit{block} has to be created of the frame and glass (see Figure 3, d).

Associativity makes it possible to automatically change the shape of all the window surfaces when making adjustments to the objects that form them. So Figure 3, e shows the changed window blocks created by the displacement of arcs and segments of the contour \( c' \), based on which the surfaces were constructed. When changing the surface itself, the associativity is lost.

The doors were constructed in a similar way basing on the contour lines \( n \) and \( m \) (see Figure 3, f). Before multiplying windows by \textit{Polar arrays} and \textit{Copying} them on the floors, it is necessary to make openings in the cylindrical wall by subtracting Boxes, to which the same commands were applied.

The floor slab surfaces were constructed, and, like the wall cylinder surface, were \textit{Trimmed} by the covering surface. Covering, building walls, and slabs can be converted into a solid object by \textit{Thickening} or \textit{Displacing}.

Figure 4 shows a photorealistic image of the created 3D graphic object that makes a presence effect in the projected space.
5. Conclusion

Computer surface modeling makes it possible to create any surface shapes and operate with them. Joint application of different modeling types contributes to rational and qualitative development of a three-dimensional model and depends on the designer’s expertise.

Acknowledgement

“The article was supported by the Government of the Russian Federation (Resolution No. 211 of 16 March 2013), agreement No. 02.A03.21.0011.”

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