REPRESENTATION AND MODELLING OF 3D OBJECTS IN DIFFERENT CAD SYSTEMS

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Abstract. This paper deals with problems that are related to representation and modelling of 3D objects in different engineering areas. Surface-based and volume-based models are commonly used in CAD systems, but another types of models are also important in nowadays engineering because they provide new possibilities for solving engineering problems.

Key Words: 3D modelling, 3D model representation, CAD

1. Introduction

Visualisation of 3D objects allows humans to better perceive and understand the world that surrounds us. We live in a three dimensional (3D) world, thus simulation of either real objects or real situations in a computer environment are used more and more often. This is the reason why representation and modelling of three dimensional objects is so important nowadays.

A model in 3D computer graphics is the word used to describe the method or way in which we represent the 3D shape of an object within a certain program. How do we arrive at a specific method for creating an individual virtual model? The answer is that it depends on the nature of the object, on a particular computer technique that we are going to use to bring the object to life and on its application. All these factors are interrelated. We can represent some 3D objects exactly using a mathematical formulation – for example, a cylinder or a sphere; for others we use an approximate representation. Usually there is a compromise between the accuracy of the model's representation and the bulk of information used.

2. Classification of 3D models

Different methods of representation have their advantages and disadvantages but there is no universal solution to many problems that still are to be solved [1]. In particular, some specific modelling methods have evolved for particular contexts. A good example of this tendency is the development of constructive solid geometry (CSG) methods popular in interactive CAD (Computer Aided Design) because they facilitate an intuitive interface for the interactive design of complex objects as well as a representation. CSG is a constrained representation while we can only use it to modelling the shapes that are made of certain combinations of so called primitive shapes or elements that are pre-defined and included in the system.

Different authors use different classification of spatial models' representation and modelling. A. Watt & F. Pollicarpo [1] defines five categories of model representation: polygonal, bicubic parametric patches, CSG, spatial subdivision technique and implicit representation. D. Breen et al. [4] clasify 3D models into two groups – exact (wireframe, parametric surface, solid model) and approximate (mesh, voxel) models. T. Funghouser [2] defines four groups: raw data (point cloud, etc), surfaces (mesh, subdivision, para-

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metric), solids (voxels, etc) and high – level structures (CSG, sweep, constrained blocks etc). In general it can be said that there are two main groups, which are most important in CAD systems: surface-based and volume-based models.

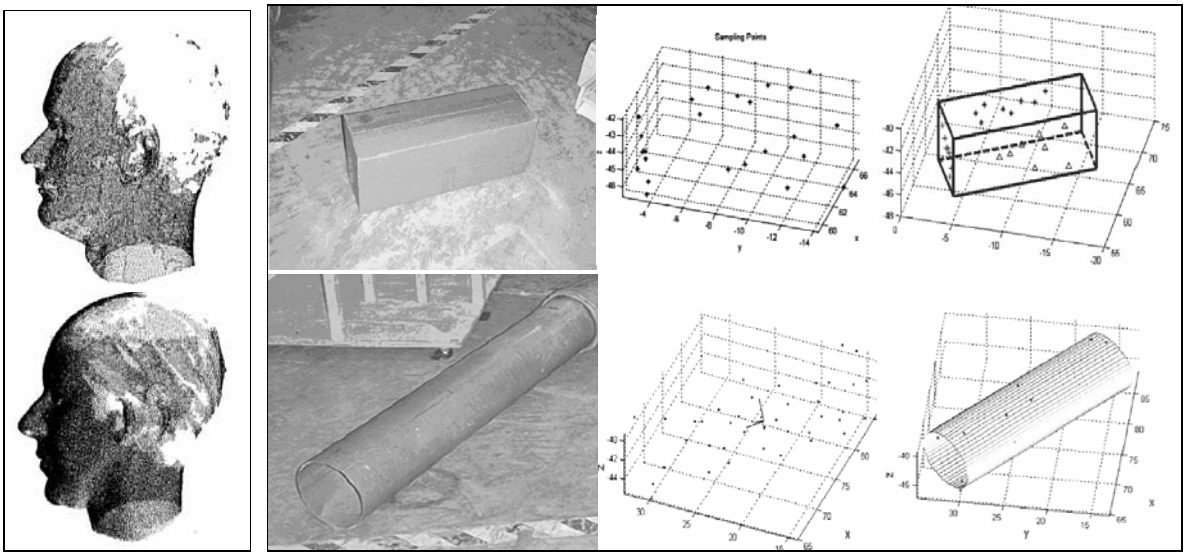

Figure 1: (Left) Point cloud representation (head models by Won-Ki Jeong et al.).
(Right) Graphical workspace modeling by using point cloud representation [5].

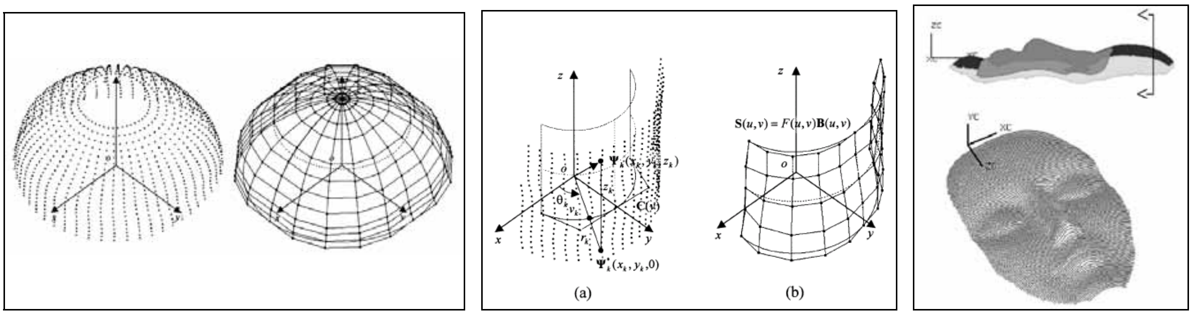

Figure 2: (Left & midle) From point cloud to NURBS [7]
(Right) Modelling cloud data for prototype manufacturing [6]

Point cloud presentation (Fig. 1 left) is unstructured set of 3D point samples. It is acquired from range finder, computer vision, etc. This kind of model representation is also important in nowadays engineering, for example in graphical workspace modeling [5] (Fig. 1 right). Techniques to rapidly model local spaces, using 3D range data, can enable implementation of: (1) real-time obstacle avoidance for improved safety, (2) advanced automated equipment control modes, and (3) as-built data acquisition for improved quantity tracking, engineering, and project control systems. Point cloud representation of 3D model can also be used in prototype manufacturing [6] (Fig. 2), also when a CAD model has to be constructed from a physical model in some rapid product development processes [7] (Fig. 2), or reliably reconstruct the geometric shape of a physically existing object based on unorganized point cloud sampled from its boundary surface [8].

3. Surface-based models

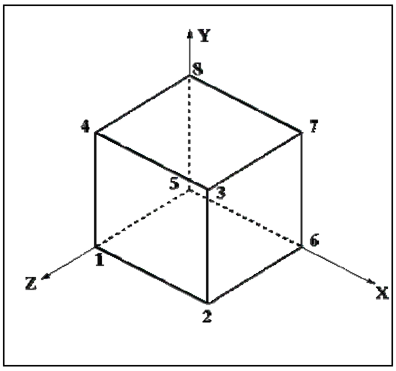

Figure 3: B-rep model

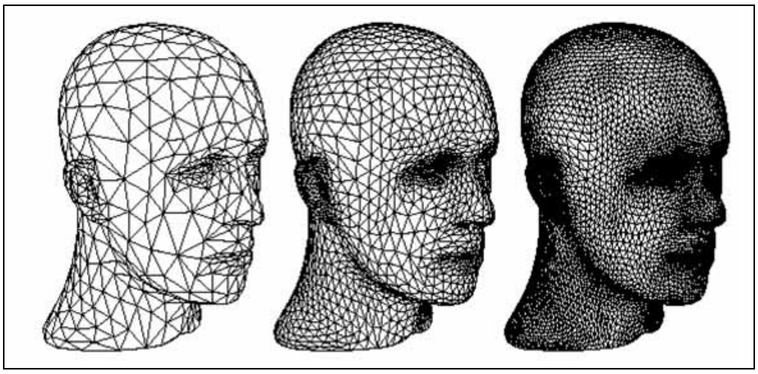

Figure 4: Polygonal mesh representation (by Zorin & Schroeder)

Using a **polygonal representation**, objects are approximated by a net or mesh of planar polygonal faces. With this form an object with any shape can be represented to a chosen accuracy. Representation methods such as this are also called Boundary Representations or B-reps (Fig. 3). This type of representation may also be used to represent an approximation to a curved surface, where the curved surface is approximated by planar polygonal patches (Fig 4). There are two main disadvantages using this method: (i) an accuracy is arbitrary, when polygons are very small and (ii) that polygon objects are more or less fixed – given an object it is difficult to change its shapes.

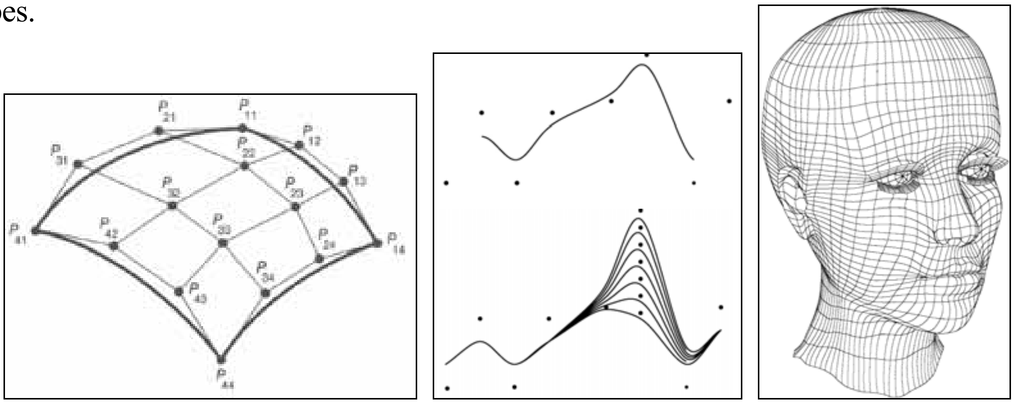

Figure 6: NURBS effects of moving control points (head model by J. Birn;)

Bicubic parametric patches are so called curved quadrilaterals. Representation of those models is similar to polygonal mesh except that the individual polygons are curved surfaces (Fig. 5). Each patch is specified by a mathematical formula that gives the position of the patch in 3D space and its shape. The shape or curvature of the patch can be changed by editing the mathematical specification. NURBS (Non-Uniform Rational B-Splines) (Fig.6) based representa-tions of 3-D geometry can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic freeform surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process from illustration and animation to manufacturing.

4. Volume-based models

Spatial subdivision techniques simply means dividing the object space into elementary cubes known as voxels and labelling each voxel as empty or as containing part of an object (Fig. 7). It is a 3D analogue of representing a 2D object as the collection of pixels onto which the object projects.

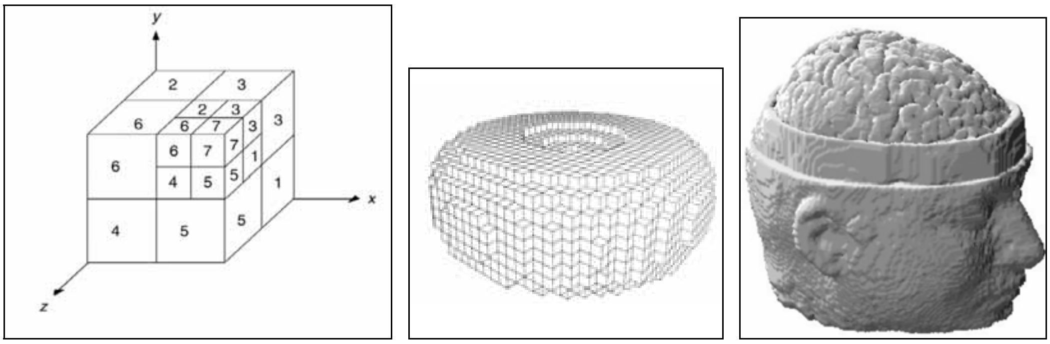

Figure 7: Spatial subdivision techniques: octrees and voxels. (head model by B. Rigaud)

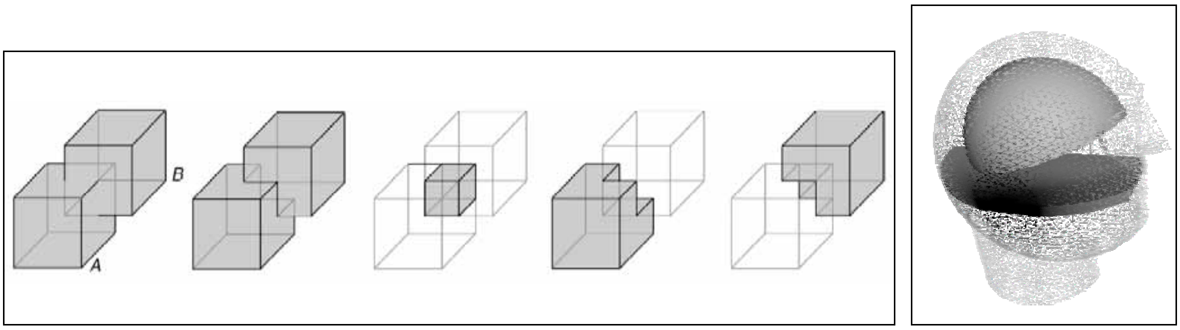

Figure 8: Boolean operations for solid models (by Foley/Van Dam); CSG head model by B. Sawicki, J. Starzynski

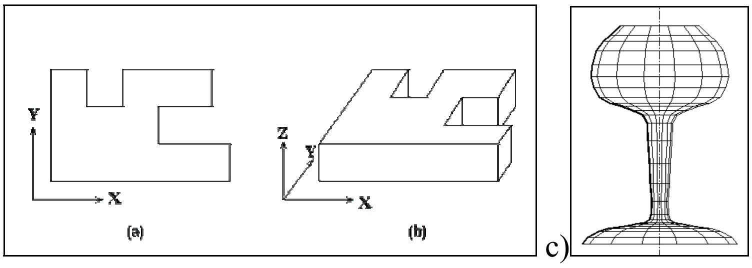

Figure 9: Sweep representation: a, b – by extrusion; c – by revolution.

CSG is an exact representation within certain rigid shape limits. The method has been developed by taking into account the fact that a great number of manu-factured objects can be repre-sen-ted by combina-tions of elemen-tary shapes or geometric primi-tives (Fig. 8). This method is a volumetric repre-sentation – a combined shape is represented by a set of elementary volumes or primitives. This contrasts with the previous two methods which represent shape using surfaces. The simplest form of **sweep** is that produced by sweeping a two-dimensional area along an axis perpendicular to its plane. This form of sweep is most useful in representing objects which are extruded with constant cross section or for objects which are machined to a given profile. Fig. 9 (a) shows a two-dimen-sional profile in the XY-plane which is swept along the Z-axis to produce the three-dimen-sional object pictured in (b). Another common form of sweep is to rotate a two-dimensional profile around an axis. In constructing a planar faceted model the profile will be defined at a finite number of points and will be rotated in finite steps to produce points on the surface hence defining a polygon mesh. This is illustrated below where the highlighted

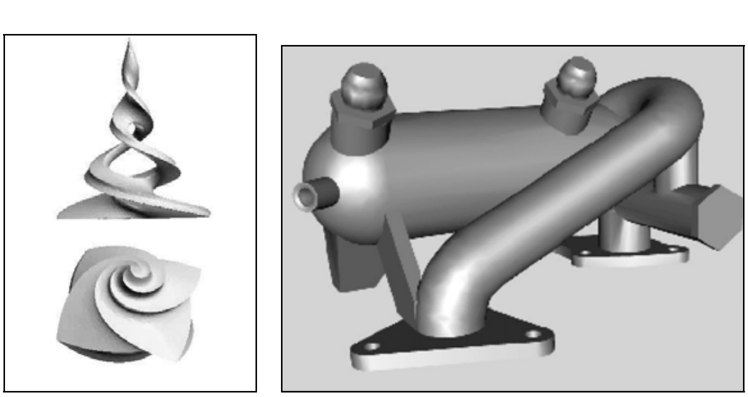

Figure 10: (Left) Implicit models (Y.Ohtak), (Right) Implicit surface model (B. Lorensen)

profile on the left has been rotated about the vertical axis to produce the mesh of points on the model of a wineglass (Fig. 9 c).

In two-dimensions a curve can be defined by an equation which relates its x and y coordinates. Such an equation can be explicit or implicit. In the explicit case one variable (usually y) is defined as a function of the other (usually x). In the implicit case an equation relating the two variables is given which cannot usually be solved to directly give one variable as a function of another. **Implicit representation** is not so often used in 3D objects representation, because there are not so many objects which can be described by implicit functions, for example spheres or some examples in Figure 10 (left). But the implicit methods can be used in implicit surface model creation (Figure 10 right) the implicit surfaces are natural objects to use for the description of surfaces via skeletons. (The skeleton of a surface being a simplification, it might be substantially easier to compare skeletons.). It also allows for nice warping between objects of different topologies [2].

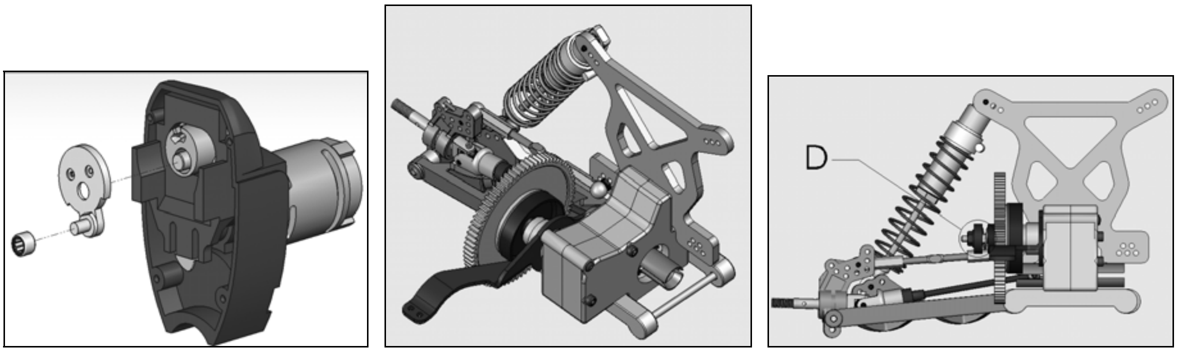

Figure 11: Drawings by SolidWorks

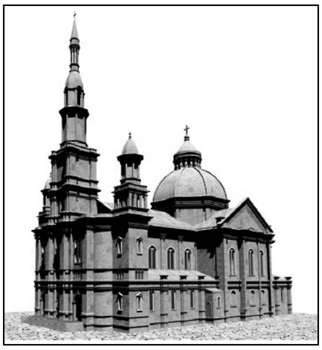

Figure 12: NURBS bicycle model by Ch. Lizra, Citroen model Autodesk 3ds max, Church Autodesk Revit analysis of aircraft using MSC.Software tool MSC.DYTRAN [12]

In nowadays engineering is not enough to create perfect spatial geometrical model (Figure.11, 12). Various methods of model analysis is needed. For model structural analysis finite-element methods are often used (Fig.13).

6. Conclusions

The rapid development of computing in engineering erodes the boundaries between using of different types of 3D objects representation and modelling. Though current CAD systems are generally based on CSG and bicubic parametric patches technologies, the other technologies for representation and modelling 3D objects are also used in contemporary engineering. These methods provide new possibilities for solving various engineering problems.

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REPREZENTACJA I MODELOWANIE OBIEKTÓW TRÓJWYMIAROWYCH (3D) W RÓŻNORODNYCH PROGRAMACH CAD

Praca dotyczy różnorodnych metod modelowania obiektów trójwymiarowych (3D) w przestrzeni wirtualnej środowiska komputerowego. Opisano metody modelowania: CSG (Constructive Solid Geometry), które wykorzystywane w programach CAD ułatwiają intuicyjne tworzenie modeli złożonych, modelowanie z zastosowaniem płatów powierzchniowych stopnia 2-go, uogólnione równania powierzchni, równania parametryczne powierzchni, modele drucikowe (wireframe models). Rozpatruje się również siatki powierzchniowe, czyli powierzchnie bikubiczne NURBS (Non-Uniform Rational B-Splines). Autorka za pomocą zdjęć ilustruje tworzone przez uczonych z całego świata, modele z wykorzystaniem wymienionych powyżej metod,. Praca zawiera rzetelną klasyfikację modeli 3D tworzonych w środowisku wirtualnym komputera. W podsumowaniu podkreśla się fakt, iż najczęściej stosowanymi metodami tworzenia modeli 3D w programach CAD są: CSG oraz powierzchnie parametryczne z wykorzystaniem siatek NURBS.

Reviewer: Renata GÓRSKA, PhD, MSc

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