Introduction to 3D modelling:

Key words: wire frame, surface and solid modelling, boolean operations, model oriented

1. Introduction.

The age of CAE (Computer Aided Engineering) started of in the 1950's, with the first attempts to automate the drafting process in design.
It wasn't after 1980, with the break through of cheaper computers, CAD/CAM took of to conquer the designing world.
In the early years the CAD-system was simply an electronic drawing board, which allowed to make technical drawings, and to easily make changes to them for new and modified designs.
Now –some 30 years later in time – the concept of CAD (Computer Aided Drafting) changed from a drawing-oriented to a model-oriented concept. CAD now stands for Computer Aided Design in which the CAD-model really is a virtual model with all its geometry and product data. In table 1, we see that next to geometry and technological data, the model now also contains organizational data about the objects, its drawings, and bigger structures it belongs to.

Product data		
Technological data	Organizational data (Object related)	Organizational data (Drawing related)
Geometry	Partnumber	Drawingnumber
Dimensions	Name	Designer
Tolerances	Weight	Scale
Material	Status of change	Drawing format
Surface finish	Origin of design	Company
Geometric tolerances	Status	Type of projection
Manufacturing process	Lot number	Revision
Inspection procedure		

Table 1: product data.

Purpose of the building of a virtual model, is to be able to make a first-time-right design, in which (expensive) prototyping and testing can be limited, or can even be unnecessary.

In this introductionary chapter we will see how these virtual models can be build in modern CAD-systems.

2. Classification of systems.

Classification of systems isn't straightforward, and has to be looked upon rather as an attempt the structure some of the most common names used in CAE, then of a rigid scheme for defining categories of systems.

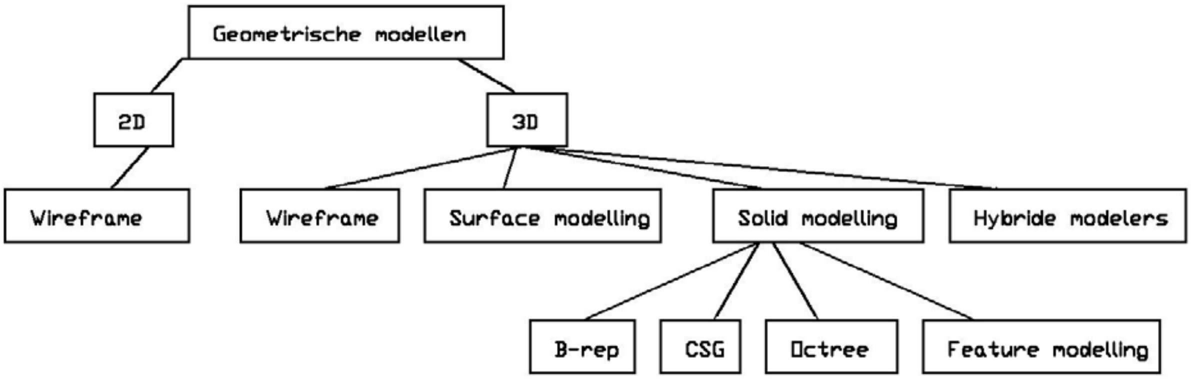


Figure 1. Classification of CAD-modellers

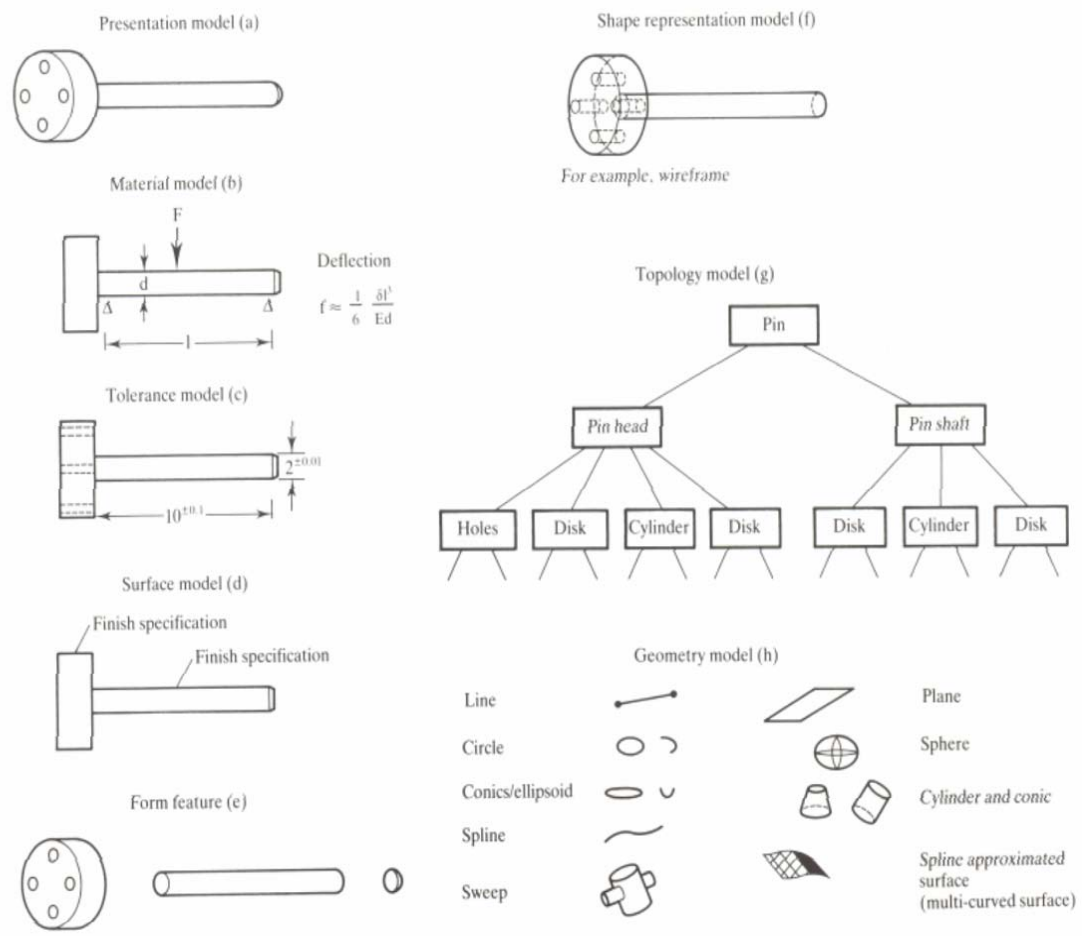


Figure 2. Classification of an object in different approaches.

3. 2D- modelling.

2D-modelling was the first method of CAD-modelling. In this concept an object is represented as it is on a technical drawing. Primitive entities (lines, circles, arcs..) describe a geometry, which has to be interpreted by the reader to reconstruct it as a model.
Most important – and nearly only remaining software – is without doubt Autocad® from Autodesk®.
This kind of software replaces the drawing board by an electronic drawing board, with extra features such as copying parts, redesign, edit and modify which used to be very tough on paper drawings.
2D-modelling still is very popular with SME (Small and Medium sized Enterprises) because of its low cost, and easy manipulation). Also for diagrams and schematic drawings it’s very useful.
Because of the nature of the field of study and practice, in architecture and civil construction, most of the design work still is done on 2D-sytems.

4. 3D-modelling.

3D-modelling offers a lot more to the designer. It represents the object/structure as it is in reality. An object is represented by a spatial structure in which the object is described either by primitive entities, surfaces or blocks of massive solid material.
Arguments to move up from 2D to 3D include:

- Better visualisation: the model looks like the real live object
- Lesser risk for mistakes: a 3D-system will only accept spatial structures that can (geometrically) exist in space.
- Faster dataflow in between steps in the design process: as all information (geometry, administrative and technological features) is part of the object, all this information will pass automatically to the next step in design or manufacturing.
- Automated drawing extraction: spatial objects are the basis for projection views, sectioning and hidden line removal.
- Faster design: editing possibilities lead to the recycling of former designs.

3D-modelling makes it possible to construct virtual models, with the incorporation of properties (material, weights, material properties, colour and appearance) of the real live object in the CAD-model.
Through an integration of applications (FEM, CAM and kinematical simulation) the virtual model can be used to test the object, even before making expensive prototypes.

5. Wireframe modelling:

Wire frames were the first types of geometrical descriptions for computer aided designs. Objects are represented by primitive entities (lines, circles, arcs..) as in a traditional technical drawing. We only draw the boundary entities en fill in the object by reasoning.
Wire frame modelling is primarily used in 2D-systems. In 3D CAD systems it is also useful in drawing extraction and visualisation of solids.

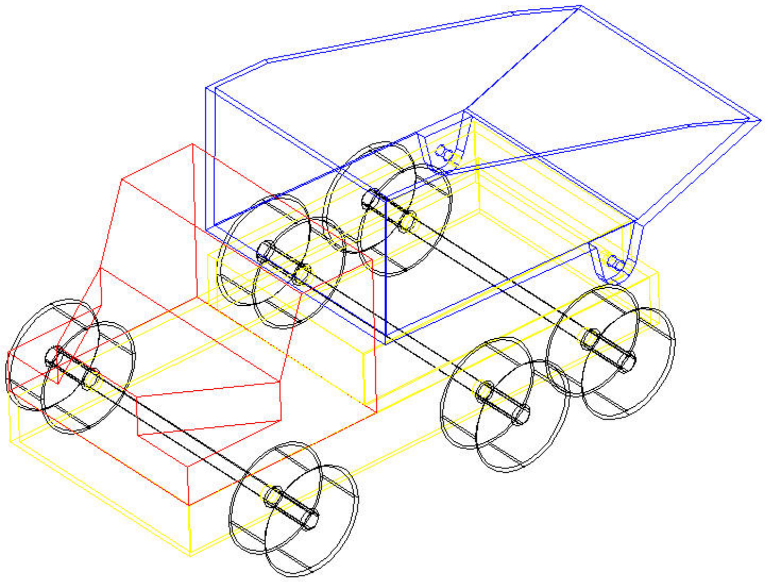
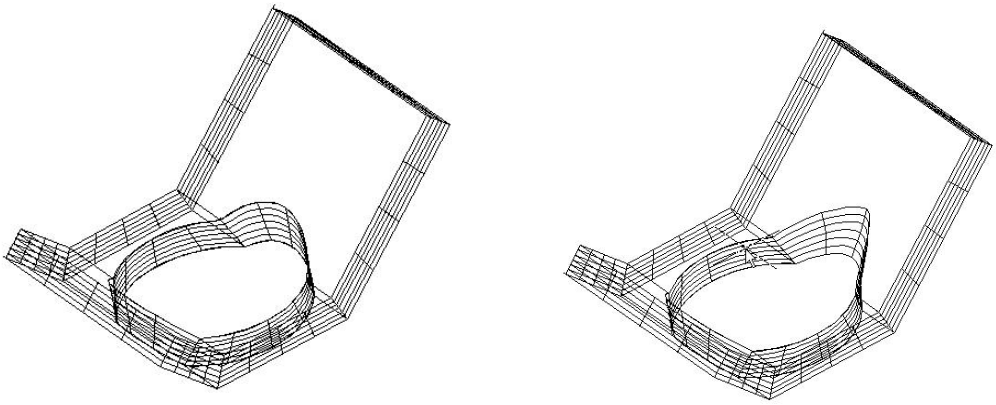


Figure 3: 3D wire frame of toy-truck.

For measuring distances in a design, simulations in 2D-planes and diagrams, wire frame is by far the easiest and fastest way of modelling.

6. Surface modelling

Surfaces describe an infinitively thin layer shape in space. By combining surfaces a closed volume of material can be defined in space, and thus object can be described.
Next to the boundaries of object they also contain the faces of an object. It gives a visual and mathematical definition of the object and is as such a further step towards a real virtual model. As such it solves several problems which arise with wire frames: dimensional information of complex shapes is now also available, and there is a real division in space between object and emptiness.
These complex shapes are defined with curves and surface (Bézier, B-Spline and NURBS technology).



Figuur 4: surface model of a bracket.

Surface models can describe every form of complex geometry. This makes surface models the primery tool for free-form modelling. Free form modelling is used in industrial sectors as plastics, thin walled structured, car bodies but also topographic measuring and modelling.

7. Solid modelling

Solid models (Solids) describe the model as it is, as one chunk of material. Mathematical as well as visually, solids define one solid object. This is the most advanced description of objects, and it offers the closest resemblance an analytical model can offer to reality at this moment in time.
High end modellers offer means to not only describe geometry but also to include material properties and other organizational data – so called product data – in the model.

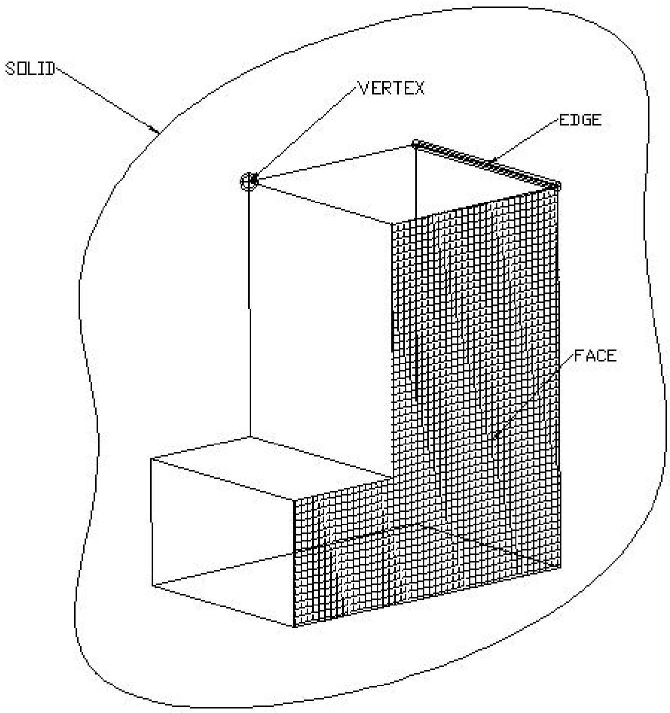


Figure 6: defining terms in solids

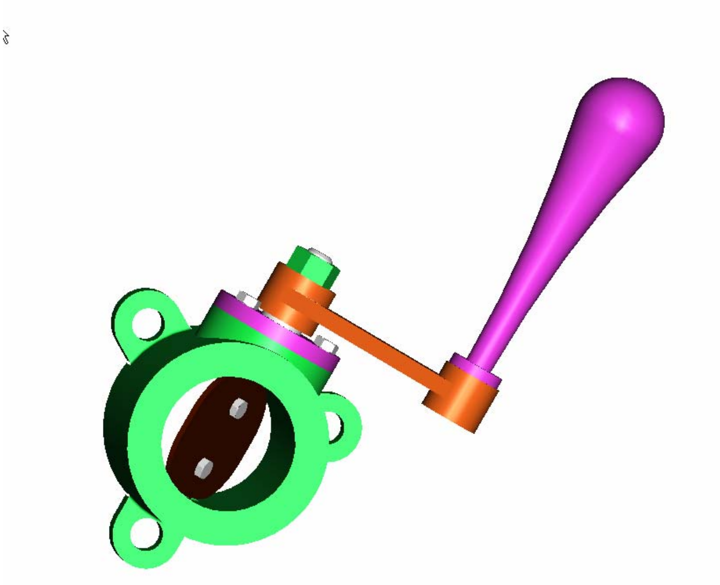


Figure 5: object made by solid modelling

There are three mean methods to describe solid models are in the computer database.

7.1 B-rep: (Boundary Representation)

A B-rep solid is a solid which is completely described by its wire frame components. Two or more vertices define an edge. Any closed loop of edges will form a face. A closed set of faces defines a Boundary representation solid.

The database representation of this structure is a net-structure. In this structure we can see that some modifications to the solid are easy to implement: geometrical changes where coordinates of vertices are moved in space are possible. Modifications that result in the numbers of faces, edges and vertices are in most cases impossible.

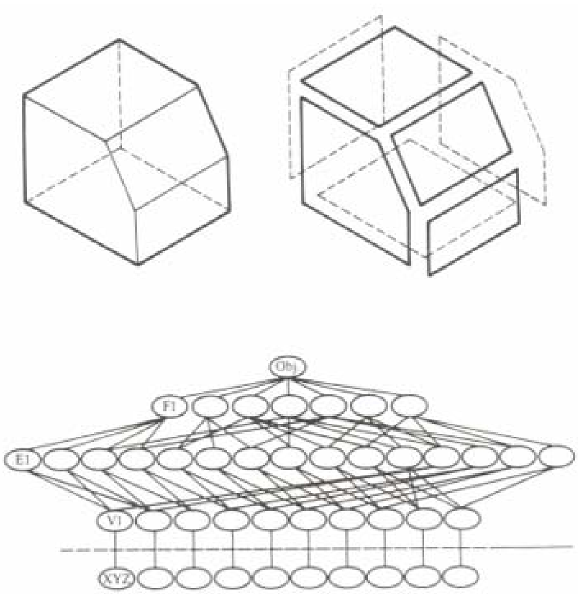


Figure 7: B-rep netstructure.

STL (Stereo Lithography models or Standard Triangular Language models) are B-rep solids, as well as early solid modellers like standard Autocad® 3D-solids.

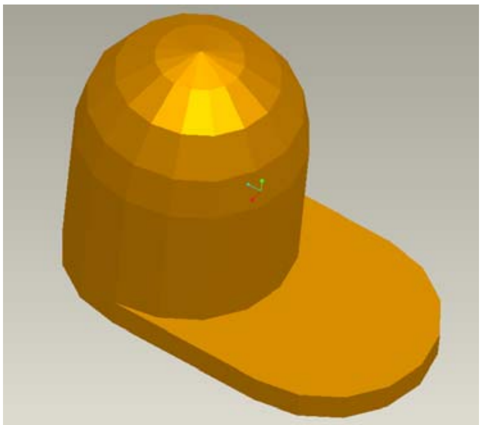


Figure: STL-model (faceted)

7.2 CSG: (Constructive Solid Geometry)

A CSG-solid is build and stored in the database as a combination of (primitive) forms. The combining instructions are boolean operations: union, subtract and intersect. In the case of solid modelling we combine chunks of material to form an object.

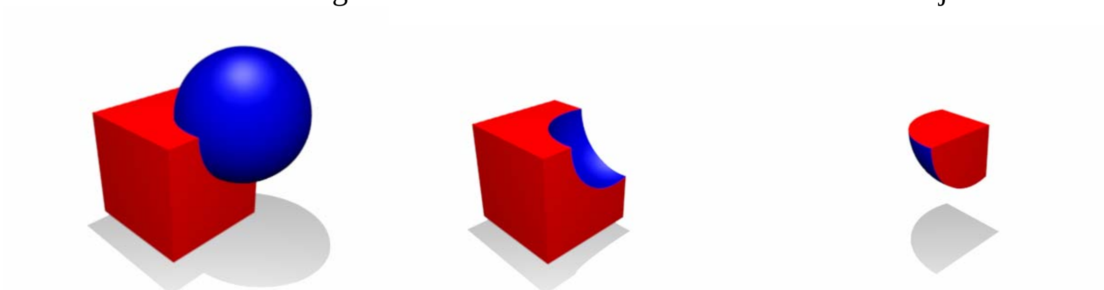


Figure 8. Boolean operations: union, difference, intersect, performed of a cube and a sphere.

The building process or part history is stored in a model tree which describes forms and chronology of the part building.
All of today’s modellers use some kind of CSG-solids, mostly in combination with feature modelling (cfr infra).

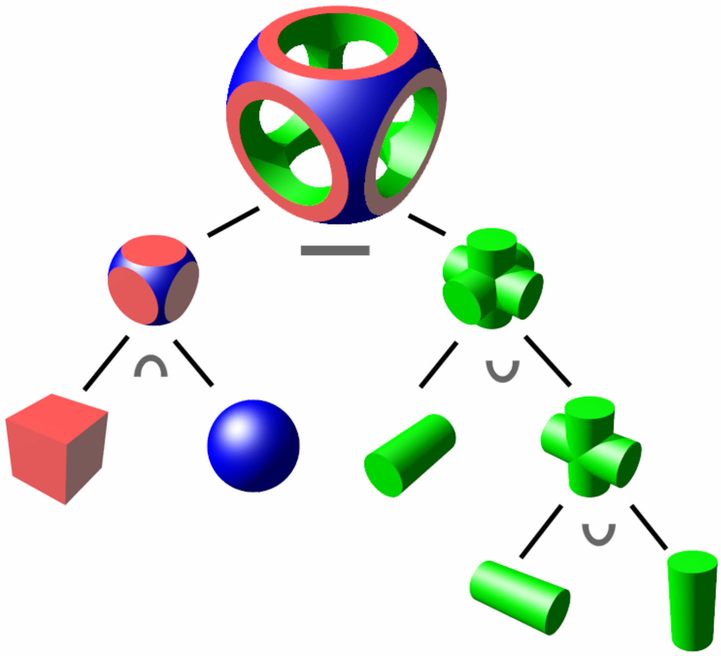


Figure 9: construction of a solid by use of Boolean operations.

7.3 *Spacial enumeration/occupancy/octree:*

Spatial occupancy divides space in small uniform compartments. This division can be stored in a 3 dimensional matrix. Every part of space occupied by material in the object fills up one cell in the matrix.
By combination of (lots of) these compartments or blocks, any form can be described. Because boundaries of the objects are always jagged – due to the basic form of the compartments – and because of the large amounts of compartments necessary to accurately describe complex geometry, special enumeration isn't used (anymore) to define CAD-models.
An alternative form of special enumeration is often used though in FEM-software, for the automated generation of a FEM-mesh. Difference with the initial definition is that FEM-compartments have the same topology, but can have different dimensions. Most used form of building blocks is a hexahedron, a volume with 4 corners and bounded by 4 triangular faces.

8. Feature-based modellers

Feature based modellers always generate CSG-solids. Instead of using blocks, cylinders, spheres and other primitives, feature based modellers use jargon which is used in production: extrusions, holes, rounds, chamfers...
As such they are an extended form of CSG, and not as much a form of solid.
The first commercially available and successful modeller of this kind was ProEngineer® from PTC® (Parametric Technology Corporation) in the late 1980's. This approach was later incorporated in every modeller which is now available.

9. Hybrid modellers.

Hybrid modellers are modellers which seamlessly combine surface models and solids. It offers the easy of working with solids and the free-form design power of surfaces.
Pro Engineer Wildfire is such a hybrid modeller, in which every face of a solid is a surface, and where every surface can be used to construct a solid.

10. Parametric modellers.

A parametric CAD-model can be changed (geometrically and dimensionally) on any moment in time. Through the use of the model tree and the CSG definition of the object the model will update to the changed dimensions.
As such a designer can rework his design without having to restart every time.

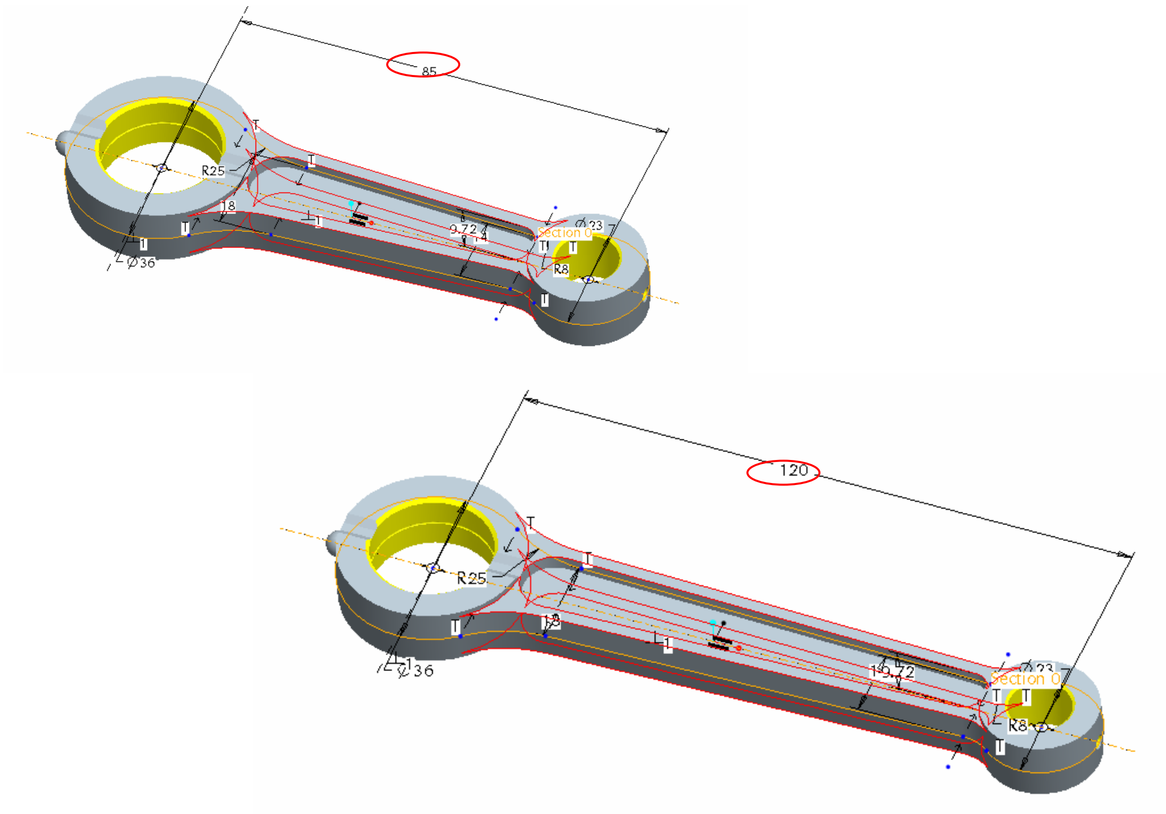


Figure 10: in a parametric modeller a change of dimension leads to a change in geometry.

11. Wildfire®: a parametric hybrid feature modeller

Wildfire, when classified in the above definitions, is described as a parametric hybrid history based feature modeller:

- Parametric: every dimension and property put in the CAD model, will have its influence on shape and properties of the object.
- Hybrid: every solid face is a NURBS-surface, and every surface can be used to construct solids.
- History based: Wildfire captures the chronology of the design in the model tree.

- Feature based: a design is constructed through the use of features (extrusion, hole, thread, round…), and not with primitives (sphere, block, wedge, cylinders).

Wildfire is a so-called "high end" solution: it offers integration with all kinds of tools to control the complete trajectory of the design. From sketch up to drawing, from object to production, calculation, simulation and quality control, the whole lot is integrated in one software line. (CAD/CAM/CAE/PDM…..).
Besides PTC (with ProEngineer Wildfire) there 2 more high end solution suppliers: Siemens (Unigraphics NX®) and Dassault Systems (CATIA®).

Midrange software solutions include Autodesk Inventor®, Solidworks®, Solid Edge®, One Space Designer®. They mostly just offer solutions for modelling. Integration with other designtools and complex designing is rarely incorporated at the same level. As such for complex designs and large industries, these products lead to unacceptable compromises. Many of these products are stripped versions, or basic products which can be upgraded in a later stadium to there bigger brothers (Solidworks, Solid Edge..).

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