CAD/CAM and the Exchange of Product Data

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Abstract

A 3D model defined in a CAD-system is used as a basis for design and product development. The concept of Computer Integrated Manufacturing (CIM) consists of sharing information between different applications used for design and manufacturing of a product so that the requirements of the manufacturing processes are taken into account already at the design stage, allowing shortened product development cycles. Later on in the product's life-cycle, the same product data could be used to support e.g. maintenance processes. This process requires that different CAx applications can share the same product model. Thus CIM puts stringent demands on the abilities of CAx tools to exchange product data and the methodology used in the design process. The emerging ISO STandard for the Exchange of Product Data (ISO 10303 STEP) addresses some of these needs, while use of existing *de-facto* standards require a pragmatic approach and careful selection of CAD-tools and planning of design methodology.

Keywords: CAD/CAM, Shape Geometry, Product Data, STEP, Engineering, Manufacturing

1 Introduction, CAD-data exchange is often the bottleneck

A Computer Aided Design (CAD)-system used to be a computerized drawing automation tool. Nowadays CAD/CAM systems are 3D solid modelling tool which allow for complete definitions of product geometry in an electronic form. This data can be used as a basis for numerous other applications. Typically the geometry of the CAD model is shared with applications for strength analysis such as FEM programs, rapid prototyping systems, or used to make up the instructions to guide NC-machine tools for the manufacturing process. The CAD-geometry can also be used as a basis for simulation processes, or is simply exported to visualisation applications to generate e.g. a film showing the future product in its environment.

Smooth and reliable exchange of product data between different CAx applications is therefore of utmost importance to ensure coherent product definitions and avoid duplication of design work.

However, progress is the area has been hindered by:

- Proprietary solutions (E.g. CAD-systems without interfaces to other vendor's products.)
- Different system concepts and architecures
- lack of proper standards
- Wrong methodologies due to difficulties in understanding new CAE tools and the needs for data exchange.

This paper intends to explain some of the underlying problems through a brief look at CAD-geometry and solid modelling concepts (CSG, B-rep) as well as current CAx exchange formats (STEP, IGES, DXF, SET). Special attention is devoted to STEP; the ISO STandard for the Exchange of Product data (ISO-10303) which addresses industry needs for data sharing between CAx applications and storage of product data.

2 CAD/CAM and solid modelling concepts

A key to the understanding of Product Data Exchange is some knowledge of the way geometry is represented in the involved CAD-systems. CAD-systems using a similar internal geometry representation can exchange geometry without much difficulty provided that some neutral file interface exists [3]. On the other hand if the target application of the transfer uses a different representation from the sending system one must try to compromise on the design metodology and export information in a way which can be understood by the target system.

2.1 Wireframe representation

A wireframe model is represented by defining edges and points. An edge may be a line or a curve. This representation is natural for a designer who is familiar with mechanical drawings, since it is the lines and curves in a drawing which define 3D shape. A wireframe model is simple to deal with in a computer with small storage space and quick access time.

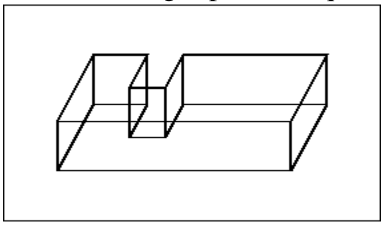

Figure 1: Wireframe representation

Pure wireframe representation is has a number of drawbacks as a basis for modelling 3D solids, notably the possibility of creating ambiguous models and the lack of graphic or visual coherence.

2.2 Surface representation

A surface model is represented by edges and points, as is a wireframe model, but with additional *faces* which fills the space between the edges and points. Each face is described by a surface, which can be elements of quadrics like cone, cylinder, sphere, or a set of splines. One of the most common is the B-Spline representation [1]. B-Spline (Basis-Spline) is one category of surfaces employing parametric polynomials using parameters.

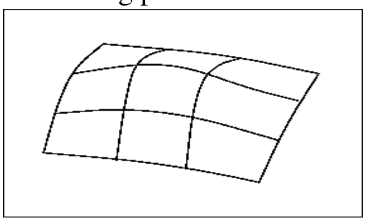

Figure 2: A simple surface model

In CAD systems for design using free-form surfaces sculptured surfaces, surface models are commonly used for the internal representation. However, a surface model does not contain topological information, and can therefore be ambiguous when determining the volume of an object. Surface models play an important role in industry, because they give an accurate description of the surface of an object which can be used e.g. to guide NC-milling machines or other manufacturing-oriented applications. Another area where free-form surfaces are in extensive use is for styling of e.g. car-bodies and other consumer products where the shape and design plays and important role.

2.3 Constructive Solid Geometry (CSG)

With CSG, solids are described as combinations of simple primitives or other solids in a series of Boolean operations, i.e. a CSG model is constructed using a so called building block approach. A user operates on parameterised instances of solid primitives with Boolean operators.

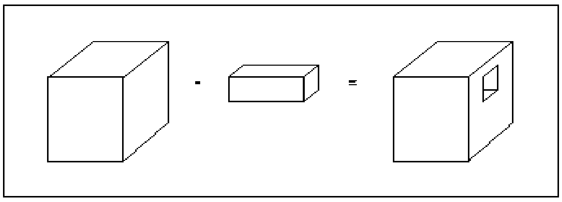

Figure 3: CSG: An object is constructed by means of subtracting one element from the other

2.4 Boundary representation (B-rep)

B-Rep models represent a solid indirectly by a representation of its bounding surface. A B-Rep solid is represented as a volume contained in a set of faces together with topological information which defines the relationships between the faces. Because B-Rep include such topological information, a solid is represented as a closed space in 3D space. The boundary of a solid separates points inside from points outside of the solid. B-rep models can represent a wide class of objects but the data structure is complex, and it requires a large memory space. A very simple B-rep model constructed using 6 faces is shown in Figure 4

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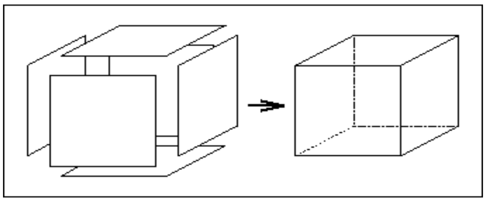

Figure 4: Simple B-rep solid formed of 6 faces

Boundary representation can be divided in three classes: facetted, elementary, and advanced B-Rep. In facetted B-Rep, a solid is bounded by planar surfaces. Only points, planes and planar polygons are required and are implicitly represented by their vertex points. The surfaces included in elementary B-Rep are planar, quadric, and toroidal surfaces. The bounding curves of the faces are lines, conics, or 4th order curves. In advanced B-Rep, the surfaces includes also spline surfaces (B-Spline, Bézier, NURBS, etc.) in addition to elementary B-Rep. The bounding curves are spline curves.

2.5 Hybrid representation

Modern CAD-systems almost always use some hybrid form of representation which is a combination of the basic variations described in the previous text. This is because different representations have their advantages and drawbacks for different application areas. Typically CAD-systems use either CSG- or B-rep and an internal primary representation, while approximated facetted B-rep is used as a secondary representation for display purposes.

Two major approaches exist. In the first approach, the modeller has CSG as the primary representation. From CSG, B-Rep models are created using boundary evaluation. The user has no direct access to the secondary representation. (Examples of this type of modellers are EUCLID[1] and Bravo3[2].) In the second approach, the modeller has B-Rep as the primary representation. Such modellers often use CSG as a way to let the user describe basic shapes and do operations on them via the user interface. However, such systems typically allow additional modification methods which directly modify boundary data structures and thus the CSG representation can not be updated. (Examples are ACIS[3], Parasolid[4] and Pro/ENGINEER[5].)

One should note that conversions from *CSG to B-rep. is possible* by evaluating the CSG tree, while conversion of a *B-rep. model to CSG is not possible* by conventional methods and is still subject for research.

3 Product data exchange standards & methods

CAD-vendors traditionally tend to protect their share of the marked by sticking to proprietary formats and not put serious efforts into the implementation of neutral interfaces. Typically the vendors try to push their customer to buy their particular analysis module or say, NC-machining preparation software. Market pressure and use of various computer platforms for CAD-packages has broken this trend, although a number of vendors stick to their old habits. Nevertheless quite some exchange can be done via existing formats if a good methodology is used.

3.1 Current exchange formats and *de-facto* standards

CAD-exchange formats (Table 1) should be used for exchange of CAD models when there is a need to access the exact geometry. When a model is needed for visualisation and verification purposes, a Graphics format (Table 2) may be more useful and easier to handle. This is especially the case for 2D Drawings, which often are exchanged only to be visually checked. A format like HPGL is then more appropriate than a CAD-exchange format like IGES or DXF.

Table 1: CAD-exchange formats currently in use

Format:	Full name, explanation	Used to exchange:
IGES	Initial Graphics Exchange Specification	Wireframe, Surfaces, and drawings
DXF	Drawing Exchange Format from Autodesk	Drawings and Wireframe
SET	Standart d'Exchange et Transfert	Wireframe, Surfaces, drawings, solids
ACIS SAT	ACIS Solid Exchange Format	ACIS models (Autocad, Microstation etc.)
VDA-FS	VDA, Flachen Schnittstelle	Surface geometry
STEP AP203	ISO 10303-203 Configuration Controlled Design	3D CAD models and product data

Table 2: Graphics exchange formats

Format	Comment
VRML(Virtual Reality Modeling Language)	Standard for viewing 3D objects via the Web rapidly gaining popularity.
Wavefront, Inventor, 3DS, Flight	3D graphics *de-facto* standard formats for Facetted B-rep models
SLA Stereolithography format	Triangular facets used for Rapid Prototyping applications
HPGL, Postscript	Image files used for plotters. Good for visualising drawings.

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3 ACIS is a trademark of Spatial Technology Inc.
4 Parasolid is a trademark of Electronic Data Systems Corp. Copyright ©1996 EDS
5 Pro/ENGINEER is a trademark of Parametric Technology Corporation

3.2 STEP

STEP, Standard for the Exchange of Product Model Data, provides a representation of product information along with the necessary mechanisms and definitions to enable product data to be exchanged between different applications and processes.

The overall objective of STEP is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent from any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product data bases and archiving. The ultimate goal is an integrated product information database that is accessible and useful to all the processes necessary to support a product over its lifecycle.

STEP addresses different computer applications associated with the complete product lifecycle including design, manufacture, utilization, maintenance, and disposal. STEP is thus not only targeting CAD/CAM applications, but includes processes related to the organisation of the product data such as definition of materials, formal contracts and specifications which are valid across organisations.

Conformance to STEP is therefore very important when one implements an Engineering Data Management System, (EDMS or PDM-system) which describes Engineering processes and the organisation of Product Data. STEP provides standard templates and mechanisms for how to describe organisational data related to engineering products without company-specific flavours.

3.2.1 STEP Architecture

STEP is organized as a series of parts, grouped into different series: *description methods*, *integrated resources*, *application protocols*, *abstract test suites*, *implementation methods*, and *conformance testing*.

STEP uses a formal specification language, EXPRESS (Part 11), to specify the product information to be represented. The use of a computerised Data Definition language enables precision and consistency of representation and facilitates development of implementations.

The *Integrated Resources* is a library of general purpose information models for things like geometry, topology, product identification, dates, times etc. (The 40-series parts.)

Among the *Implementation Methods* are a Physical File format (Part 21) and a group of standard application programming interfaces (Part 22-26)

By means of the EXPRESS language and common definitions from the STEP integrated resources, so called *Application Protocols* (APs) are used to specify the representation of product information for one or more industry-specific application area.

Examples of STEP APs are:

- AP203 : Configuration controlled 3D designs of mechanical parts and assemblies
- AP212 : Electrotechnical Plants
- AP214 : Core Data for Automotive Design Processes.
- AP221 : Process Plant Functional Data and Schematic Representation.
- AP 223 :Exchange of Design & Manufacturing Product Information for Cast Parts

4 Conclusion

Exchange of product data is at the core of the computing application environment in Engineering and Manufacturing organisations. It is very important to get an understanding of the bottlenecks which are present in the exchange of data between dissimilar computer systems. One issue is Geometry Representations, another one is the use of common conventions to describe different aspects of Product Data.

The ISO STEP standard addresses many of the needs for Product Data Exchange and is becoming the reference for implementations of engineering applications in industry.

4.1 Recommendations

- Purchase of CAD/CAM packages: Prefer CAD-systems with a common geometry engine like *ACIS* or *Parasolid* to more odd systems if there is no clear-cut business advantage with the odd system. Insist on proven support of STEP and commitment to further STEP development.
- Understand the needs of your particular business process, know why you want to exchange product data and for which purpose.
- Be pragmatic and use alternative formats for exchange with other systems when necessary.
- Dedicated tools for adaptation of geometry representations can help to overcome specific problems. Examples are conversion between different surface representations (Bézier->NURBS) or between different types of splines in IGES files. (An example is the CADDFAS [6] application at CERN.)
- Understand the importance of STEP, use STEP methods and mechanisms. Even if you are not within a well defined part of the standard, you may use EXPRESS and the Generic STEP-resources when implementing Computer Applications to handle Product Data. (One example using this approach is the GEANT4[7] Simulation package currently under development in the High Energy Physics community.)

References

1 Mortenson, Ernst G. *Geometric Modelling* (Wiley & Sons, 1989)

2 LaCourse, Donald E. *Handbook of Solid Modelling* (McGraw-Hill 1995)

3 Helpenstein, Helmut J. *CAD geometry data exchange using STEP.* (Springer 1993.)

4 ISO 10303 *Industrial automation systems and integration -- Product data representation and exchange* Parts 1, 11, 21,22,31,32,41,42,43,44,45,45,47,49,201,203,CD212, CD 214 + more.

Pointers to STEP information: http://cadd.cern.ch/cadd_step.html

US-Product Data Association: http://www.scra.org/uspro/

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[6] CADDFAS is an application which let you convert an IGES file from the dialect of one CAD-system to that of another system. CADDFAS is based on the NFAS package from BMW and has been adopted for use in the High Energy Physics Community.

[7] GEANT4 is a toolkit framework for tracking particles and to simulate the response of a detector to an event. The GEANT4 application is developed using Object-Oriented Methods and has a geometry engine based on STEP Part42 geometry. More information on the URL: http://wwwcn.cern.ch/pl/geant/geant4.html