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THE FUTURE AND THE EVOLUTION OF CAD

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ABSTRACT
The Computer Aided Design has constantly evolved since its appearance at the beginning of 1960s. This work summarize the history of CAD and analyze the development perspectives. Particularly have been studied the actual main topics in CAD as the data transfer problem and the debate between feature based and direct modeling. It also has been studied the impact of new available technologies as touch-screen or multi-monitor in the way of design by computer.
In the last part of this work a short comparison between CAD software has been proposed.
Keywords: CAD history, future of CAD, CAD evolution

1. COMPUTER-AIDED DESIGN EVOLUTION

1.1. CAD Chronology

Although in 1957 Dr. Patrick J, Hanratty developed PRONTO, first numerical control programming tool, the father of CAD is usually considered Ivan Sutherland that in 1963 developed Sketchpad as part of his MIT PhD Thesis. In Sketchpad the user interacted with the software through a light pen on a large CRT monitor (it was very innovative, at that time computers ran only in batch mode using punched cards and magnetic tapes).

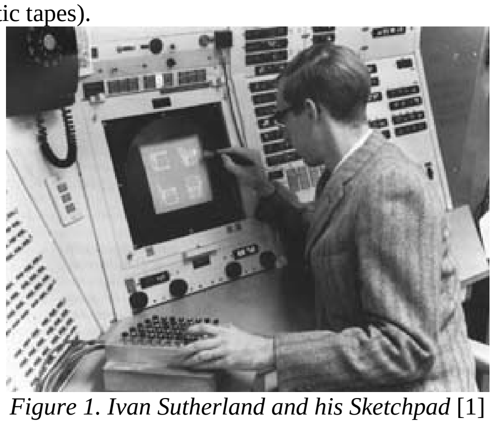

Figure 1. Ivan Sutherland and his Sketchpad [1]

First generation of CAD systems were internally developed by manufacturer in the mid of 1960s and typically concerned 2D drafting applications. General Motors produced DAC (Design Automated by Computer), McDonnel-Douglas CADD (1966), Ford PDGS (1967) and Lockheed CADAM (1967).

Figure 2. DAC-1 by GM and IBM [1]

In 1970s started the commercial use of CAD. In 1975 the first Unigraphics System (for 2D modeling and drafting) was sold by United Computing. The same year Avion Marcel Dassault acquired CADAM from Lockheed and in 1977 started the development of a 3D CAD named CATI. In 1979 Boeing, General Electric and NIST defined a new 3D data exchange format called IGES.
In 1981 Unigraphics introduced its first solid modeling system called UniSolids and Avion Marcel Dassault creates Dassault Systemes that, in the next year released CATIA V1 (first commercial version of CATI) as CADAM add-on. In the same year was released I-DEAS by SDRC.
In 1983, while Unigraphics II was introduced in the market, Autodesk (founded the year before) released AutoCAD, a CAD program for a price of about $1000 running on PC (figure 3).
In 1984 Apple presented the first Macintosh 128 and the next year was published MiniCAD the bestselling CAD for Mac. Anyway middle-1980s PCs and Macs weren’t enough performing if compared to UNIX workstation. In 1985 Dassault Systemes released CATIA V2 as a software independent from CADAM. In 1987 Varimetrix produced the first B-Rep solid modeler.
The same year a big revolution have been in CAD industry: Parametric Technology Corporation releases Pro/Engineer, the first parametric and associative solid modeler on the market, for UNIX Workstations. Pro/Engineer first release had also a very innovative and intuitive interface based on x-Window. One year later were also available CATIA and Unigraphics for UNIX Workstation.
In 1989, pushed by Pro/Engineer innovation Unigraphics retired its UniSolids and released a new program based on Parasolid: UG/Solids. In 1989 was also released ACIS kernel.

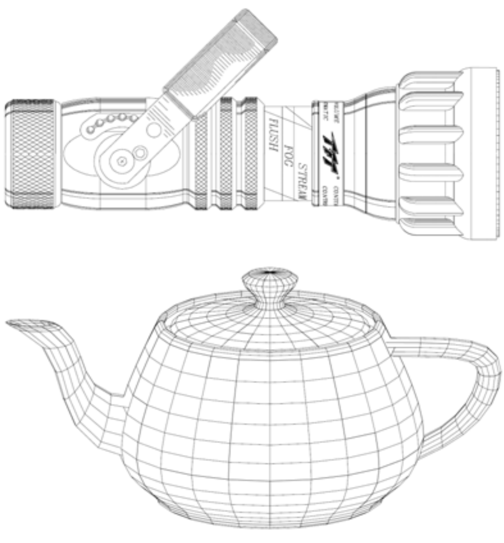

Figure 3. Autocad 2.6, with the first 3D wireframe model

In first 1990s CAD software ran on UNIX workstation and no more on mainframe and minicomputer. The CAD market was dominated by few companies: IBM-Dassault Systemes, EDS-Unigraphics, Parametric Technology and SDRC.
In 1994 Microsoft released its first 32-bit operating system and Intel its first Pentium Pro. ACIS and Parasolid were quickly available for Windows NT.
In 1995 with the first SolidWorks release 3D CAD was available for desktop pc. The advent of new economic Windows based 3D CAD system heavily modifies the market: mid-price 3D CAD category was born. In 1996 Intergraph released SolidEdge, an ACIS based CAD very similar to SolidWorks, and Autodesk, whose AutoCAD was losing market share, released Mechanical Desktop that quickly become the 1st selling CAD in the world. In 1997 Dassault Systemes (CATIA's developer) acquired SolidWorks for $320M and EDS-Unigraphics acquired SolidEdge.
In 1998 was released CATIA V5 fully supported on Windows. In 1999 Autodesk released Inventor a 3D CAD based on the ACIS kernel and not on AutoCAD (as the previous Mechanical Desktop).
In late 1990s CAD developers concentrated on improving PDM capabilities and becoming internet enabled and no revolutionary technologies appeared.
In 2000 Dassault Systemes acquired ACIS modeling kernel. In 2001 Unigraphics Solution became UGS and acquired SDRC. In 2000s CAD developers main efforts were in simplify and making more intuitive modeling and in integrating CAD in wider PLM suites. [2],[3]
In 2007 SpaceClaim, an innovative history-free direct-modeling 3D CAD, was released. In late 2000s, reacting to the SpaceClaim innovation, feature-based CAD developers start integrating direct modeling function in their product. In 2008 NX and SolidEdge integrate a new tool called Synchronous Tecnology and SolidWorks proposes Instant 3D. Also CATIA V6, released in 2008, allows direct editing. In 2009 Autodesk launched its Inventor Fusion Technology. It is the age of hybrid CAD systems.

1.2. Solid representation methods

The need to communicate in a true, complete and unambiguous way the features of a real or imaginary object drive the research of more and more powerful representation methods. Because of this in the years five generation of CAD systems have succeeded (Figure 4).

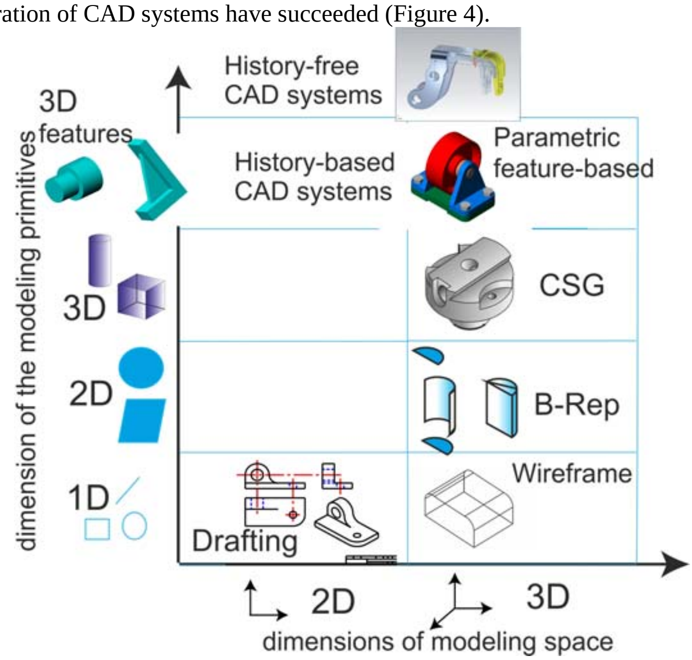

Figure 4. In the diagram are represented five generation of CAD Systems; on the horizontal axis are reported the dimensions of modeling space and in the vertical axis are reported the dimension of the modeling primitives.

First generation of CAD, Computer-Aided Drafting: the object is represented by the projection of its edges on a 2D plane.
Second generation of CAD: the object is represented by its edges in a 3D space (Wireframe representation). It is possible to generate 2D views from any point of view. The main problem of wireframe models is the ambiguity due to seeing at the same time all the edges of the model. The viewer may not be able to tell which part of the model is in front of other parts. Nonetheless, there are situations in which wireframe models can be helpful because they show front, back, top and bottom of the object simultaneously.
Third generation of CAD: the object is represented by its boundary surfaces (Boundary Representation or B-Rep). Surface elements are assembled to form an "airtight" boundary that encloses the three-dimensional space occupied by the modeled object.
It is important to understand how B-Rep differs from a traditional surface modeling. While a nonsolid CAD system may represent surfaces, a B-Rep system must also guarantee that the surfaces form a complete partition of space, even after being extensively modified. This is, in practice, a major challenge. The topology can be represented using a winged-edge data structure where the nodes are faces and the connections represent shared edges. Bottom –level nodes determine geometric definition, while connections form topological definition.
Figure 5 shows a winged-edge representation of a simple triangular pyramid where the vertices, edges, faces and the solid are explicitly represented. Topological elements are shown on different levels based on their dimensionality. Bottom-level nodes represent vertices. Above this are edges. Their downward connections point to two vertices (their endpoints). Nodes at the next-higher level represent faces. Each has connections to a loop of edges forming its boundary (three each in this case). Finally, at the top level, a single node represents the 3D solid. Its connections indicate the enclosing faces.

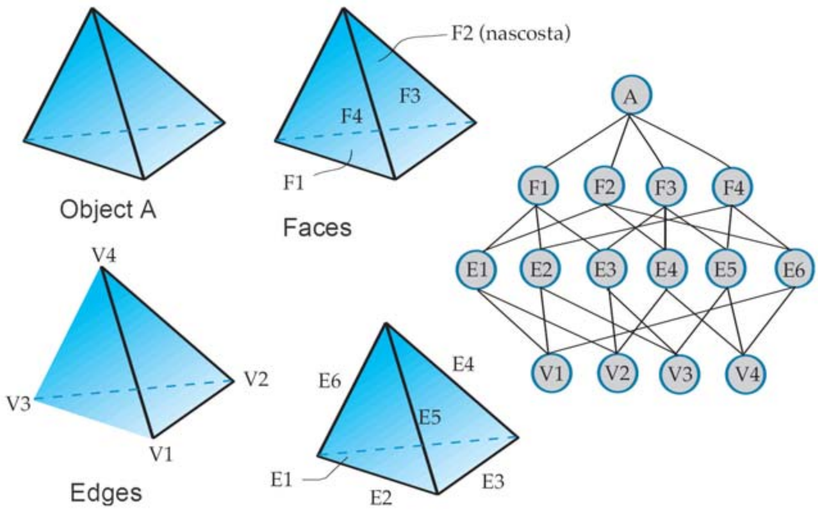

Figure 5. Winged-edge representation of a simple triangular pyramid

Faces used in B-Rep systems are adjustable: that is, they have an inside surface and an outside surface. This information is typically encoded by numbering the edges in a sequence such that the right-hand rule defines a vector that points outward from the object. Note that this is used to number the loop edges of each face of the pyramid.
By this representation method is possible to eliminate hidden edges and to get photorealistic images through a suitable choice of lights and colors. Anyway surfaces don't define a complete partitioning of the space.
Majority of the modern geometric modeling kernels are based on the boundary representation (BRep), which describes the body by listing volume-constraining planar and curvilinear faces, that cross in edges and vertices (all called boundary elements). Incidence between boundary elements defines the topology of a model, while their parametric properties define its geometry.

Fourth generation of CAD: the object is represented by the occupied 3D space (Constructive Solid Geometry, CSG). An unambiguous mathematical representation allows to determine if any point in the space is inner, boundary or external to the solid model. An object is constructed using Boolean operations (union, intersection and subtraction) to combine simple solid shapes (spheres, blocks, cylinders, etc.).
Such geometric elements are called primitive solids or simply primitives that were parameterized, for example the cylinder by diameter and height. As shown in figure 6, CSG objects are usually stored using a tree database structure. Leaf nodes represent primitives and branch nodes represent Boolean operations. Note that each sub-tree also represents a legitimate solid.

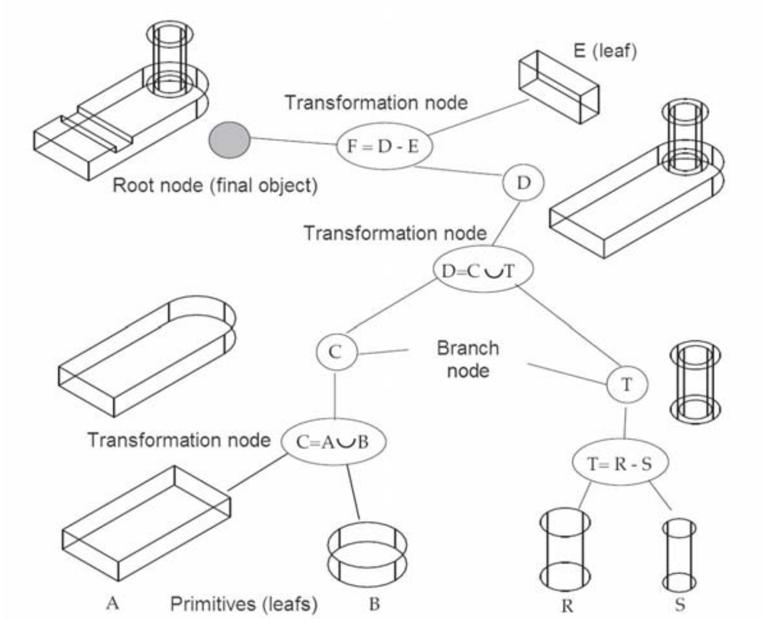

Figure 6. Tree database structure

This "classical" CSG tree can be extended by the use of transformation nodes. They can be used to change the location and orientation of an object or some part of an object represented by a sub-tree. This provides for the independent design of a part and its later incorporation into a larger object or assembly (as a sub-tree). Rather than using separate nodes, often geometric transformations are simply incorporated into each node. Auxiliary information such as material type or previously computed mass-properties data can also be attached to nodes.
It is possible to model complex solid shapes by using geometric operations such as revolution, extrusion, loft and sweep.
A CSG representation is severely limited in most solid modeling situations, however, because it is unevaluated. An object's face, edges and vertices are not available because CSG representation models and manipulates high level primitives. For this reason the latest CAD systems use a boundary evaluation operation that generates a B-Rep (a method that defines and stores a solid as a set of vertices, edges, faces (points, lines, curves and surfaces) which completely enclose its volume) from a CSG solid.
However, the real innovation of CAD systems is in 1990s with the arrival of Parametric Technology's Pro/Engineer (ProE) CAD system. ProE started as another Brep system but the innovation was a sketch-based graphical user interface (GUI) that allowed constraint and dimensional annotations to the sketches (figure 7). Sketches were then automatically instantiated by solving geometric constraints. Furthermore, the traditional CSG operations (union, intersection, difference) were replaced by operations such as extrude, revolve, protrude, and cut, using the sketches to define profiles with which to carry out these operations. Extrude and revolve are easily recognized as creating primitive shapes,

but protrude and cut are not immediately seen as CSG operations. This is the fifth generation of CAD: the object is represented through its features (Feature based systems). The flexibility of this kind of systems is improved by parametrical and variational technologies. Moreover is possible to assembly different components through complex mating relations. In fact much of the information needed in the life cycle of a product, particularly its design and manufacturing process, evolves around the geometry shapes of the product. Historically this led to the interest on geometric modeling and the current generation of CAD systems based on geometric modeling techniques that provide useful functionality for geometry drafting, detailing, visualization and analysis. In the larger context of the overall design and manufacturing process, geometric models (CSG and B-Rep models) are not so attractive because they don't consider the varying roles that geometry has during the design process.

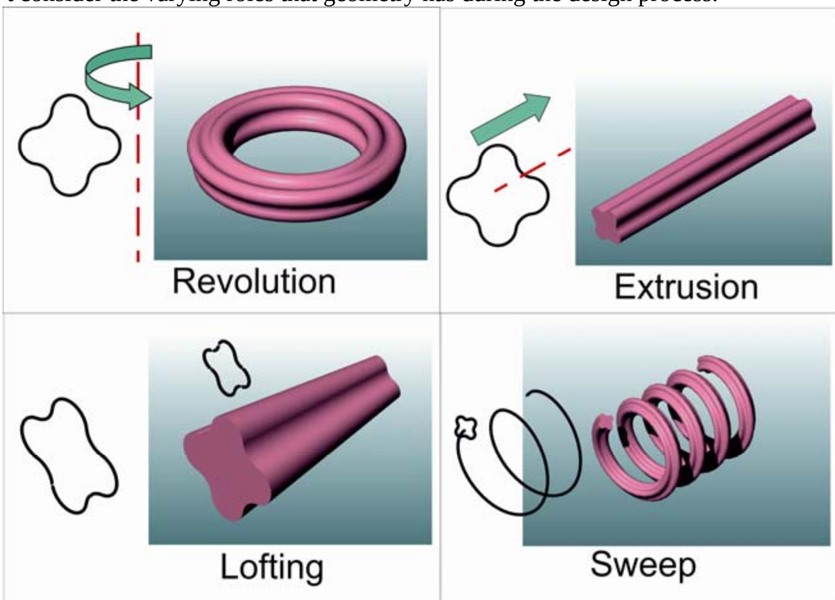

Figure 7. The user can sketch a profile with constraint and dimensional annotations to carry out operations such as extrude, revolve, lofting and sweep

In the field of mechanical design software, where new products with hundreds of innovative features are introduced every year, the development of parametric, feature-based, fully associative, solid modeling technology has played such a role.

This modeling system using features and parameters is a method of linking dimensions and variables to geometry in such a way that when the parameter values change, the geometry updates accordingly. With this innovation, many design concepts could be explored and changes could be made remarkably quickly compared with the redrawing required by traditional CAD. For example if you model a solid with a through hole, the hole doesn't change if you change the thickness of the model

In this modeling system high-level modeling entities named "features" are used to provide all the improvements to ordinary geometric modeling techniques. *Form features* can also be modeled by boundary representation. From the designer's prospective, a form feature is a geometric image of an elementary operation of a metal-cutter, such as drilling, turning, milling. Pro/ENGINEER, released in 1987, became the first commercial feature-based CAD system

All features are based on parameters (dimensions, for example). These parameters control the various geometric properties of the entity, such as the length, width and height of a rectangular prism, or the radius of a fillet. They also control the locations of these entities within the model. The parameter may be modified later, and the model will update to reflect the modification.

A parametric model is fully associative to the drawings and assemblies that reference it. Changes to the model are automatically reflected in the associated drawings and assemblies. Likewise, you can make changes in the context of the drawing or assembly and know that those changes will be reflected back in the model.

The CAD systems of the fifth generation are called also **history-based CAD system** is able to capture an original user's design intent because the software remembers and enforces relationships between objects build by the designer. As a user works, the software builds a feature history tree (figure 8), which tracks all relationships and parameters and stores the order in which users create features. The tree effectively serves as a part "recipe." Changing a step and replaying the recipe forces associations in the history tree to ripple through the model and " regenerate" the new part. Once a part is built, users need only type in variables to change a preprogrammed model.

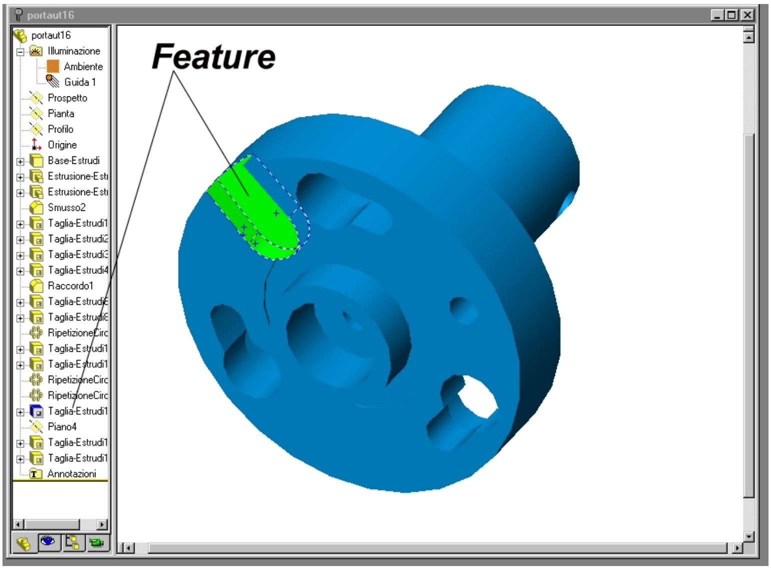

Figure 8. Parametric feature-based approach: the designer create a recipe of embedded engineering constraints and relationships that automates an optimize the design. As a user works, the software builds a feature history tree, which tracks all relationships and parameters and stores the order in which users create features

2. DIRECT MODELING

One of the major limits of parametric 3D CAD is the need of well trained and heavily specialized personnel. In fact "although the parametric approach is powerful, it does require expert knowledge about how best to embed engineering constraints and relationships within a model" [4].

At the present time CAD is not a suitable tool for engineers. In fact a long training and a fulltime commitment are necessary to be proficient with the parametric history-based modeling technology. Engineers need an easy-to-use 3D tool tailored for conceptual design but usually they communicate concepts through 2D sketching or presentation tools and then a CAD operator has to interpret their wishes in a specific modeling tool. This way is easy to commit errors and lose time often resulting in not achieving what engineer effectively wanted [5].

A more user-friendly approach to 3D CAD comes from 3D direct modeling. By this technology designers can perform quick and immediate models editing without knowing anything about their modeling history but simply translating and rotating faces, edges and nodes. Moreover through a direct 3D modeling system a designer can easily continue a design where others left off resulting very performing for CAD model exchange on extended design teams.

With this approach designer can create quickly and easily 3D models which can be modified through direct on-the-fly interaction with the geometry (figure 9). This methodology is called explicit modeling, and is flexible and easy to use. This approach is also called history-free and it can be more effective in the early stages of design where the designers can create highly customized products without the extra effort of up-front planning the process of modeling. 3D direct modeling can be learned in very short time and, because its approach is very similar to 2D, is quite easy for a 2D designer transfer its skill on the new technology.

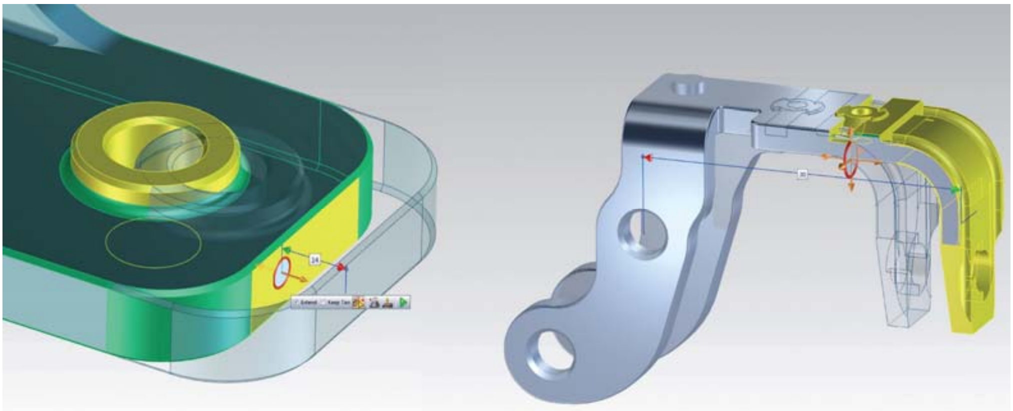

Figure 9. With the history free approach the designer can create quickly and easily 3D models which can be modified through direct on-the-fly interaction with the geometry

On the other hand, leaving to many degrees of freedom to the user “practically any editing operation unrecognizably changes the original model, “alienating” it from the design intent. A table is no more a table; a bearing is no more a bearing, etc.” [6]
In the history free CAD systems it is possible to builds all components, parts, and assemblies in one common workspace. Multiple parts and assemblies can be loaded at the same time and a single command lets users arrange parts in a subassembly or move subassemblies within a top-level assembly.
All things considered, direct modelers seem to be great for preparing models for FEA and CFD, for quick 3D conceptual models and dumb models editing while feature-based CAD are still the best for “families” of mechanical design and highly configurable models [7].
Another indisputable advantage of direct (or explicit) modeling is the solving of the feature exchange problem. In fact there are no more features to transfer and traditional “dumb” file format are enough to perform an effective data transfer between different CAD platforms. Moreover direct modeling could be useful to modify and simplify geometry to perform FEA without caring about what software the model is made with.
History-free modelers are useful at the manufacturing stage, where often it is not important to get the design history but need to leverage designs from many different CAD systems with the flexibility to work with supply-chain mold, die, and designer shops.
In conclusion, history-based systems usually target products involving large families of similar parts; moreover in many cases 70, 80, or even 90% of a new product is simply reused components. For companies committing a design, a system with built-in design intent that has logic about how modifications are propagated makes subsequent reuse fast, efficient, and reliable.
History-free systems are very useful in R&D environments and conceptual and manufacturing stages of design.
Some CAD vendors offer today an hybrid approach, which combine parametric and explicit modeling. The actual trend in CAD software development is to integrate direct editing tools in traditional history-based software to preserve the control and automation of parametric technology gaining the flexibility and direct interaction of direct modelers [8].
The table 1 shows a comparison between different explicit modeling strategies of main CAD vendors.
History based and history free are available in the same UI of Siemens NX 7.5 but are not effectively combined. Synchronous Technology is the name of this functionality which allows the manipulation of geometry without the burden of a history tree. Faces can simply be grabbed, pushed, pulled and rotated into place, offering a much more freeform method of modeling (figure 10). By combining a set of direct modelling operations with dynamic rules and filters, it allows modifications to be made directly to the geometry without having to rollback or edit the feature history. There’s no recalculation

and no regeneration and it works with both native NX and imported geometry. Acknowledging that users like to work in different ways, history can also be switched on and off at will inside NX. Users can chose to work entirely with history, entirely with Sync Tech, or a combination of the two.

Table 1. Comparison between different direct editing technologies [9][10]

Technology	Product	Main features
Synchronous Technology	Siemens NX and SolidEdge	Hybrid technology: the direct modeler automate and control the history tree
Inventor Fusion Technology	Autodesk Inventor	Hybrid technology: is possible to switch between parametric and direct mode
CoCreate	PTC CoCreate	Direct modeling with the possibility to add constraint to the model
SolidWorks	Dassault Systemes SolidWorks	Hybrid technology: direct modeling features have been gradually added in SolidWorks
V6 direct editing	Dassault Systemes CATIA	Hybrid technology
SpaceClaim	SpaceClaim	Direct modeling
Iron CAD	Iron CAD	Hybrid technology

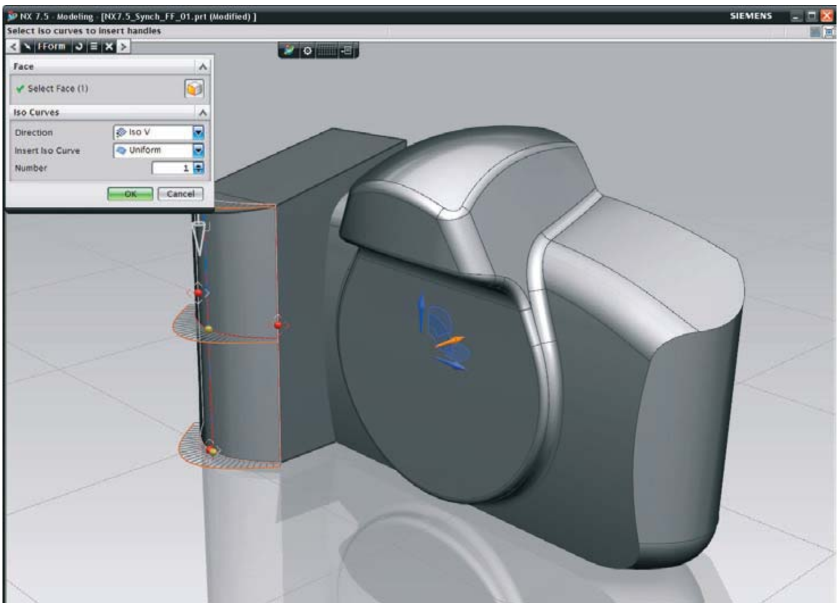

Figure 10. The new Freeform tools of Siemens NX7.5 with Synchronous Technology allow users to manipulate not only prismatic geometry, but to also work freely with complex freeform, geometry

Autodesk Joins the Hybrid CAD with Inventor Fusion which represents company's offering of parametric and direct modeling in a single product. Inventor Fusion Combines history based and history free through a function named Change Manager that allows to perform direct editing on parametric models and then decide if convert those edits into parametric features (figure 11). The changes in the model are shown superimposing the modified model on the original one. If changes

are accepted the history tree is updated changing interested features or adding direct editing features. This way of altering history tree must be used carefully because design intents can be automatically changed or deleted.
SolidWorks uses the direct editing allowing to modify the history tree without directly acting on it by Instant 3D. This tool permits to change parameters values directly editing quotes on 3D models without opening sketches and features. The main SolidWorks direct editing tool is the "move face" feature that allows to translate and rotate any face of the model. Modifies made by this feature are stored in the history tree as any other one (figure 12).
SpaceClaim Engineer is an innovative 3D direct modeler which enables engineers to easily create concepts and prepare 3D designs for digital prototyping, analysis, and manufacturing without the complexity of traditional feature-based CAD (figure 13).
IronCAD Next Generation incorporates history-based modeling and direct modeling (figure 14). Both use the same dynamic feature editing tools, allowing the drag, drop, snap and positioning of geometry. IronCAD uses of both ACIS and Parasolid within a single application. This can bring benefits in problem modeling situation.
Cocreate was acquired by PTC in 2007. His explicit approach is flexible and easy to use, so it's ideal for companies that create one-off or highly customized products. The designer can quickly and easily create 3D designs through direct, real-time on-the-fly interactions with model geometry (see figure 9).

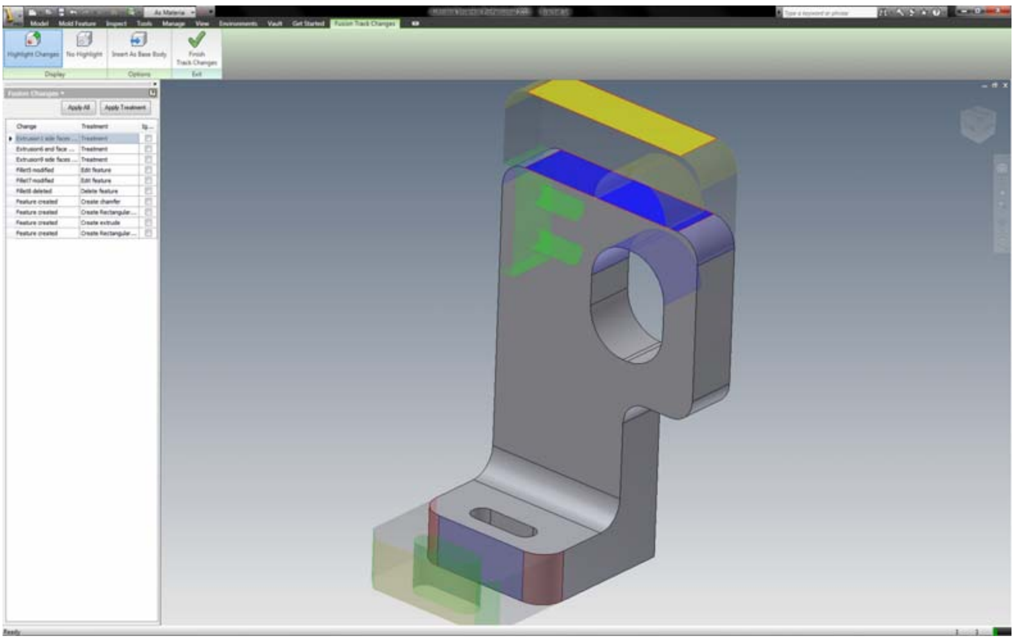

Figure 11. Though Inventor Fusion the designer can create geometry through push-and-pull operations

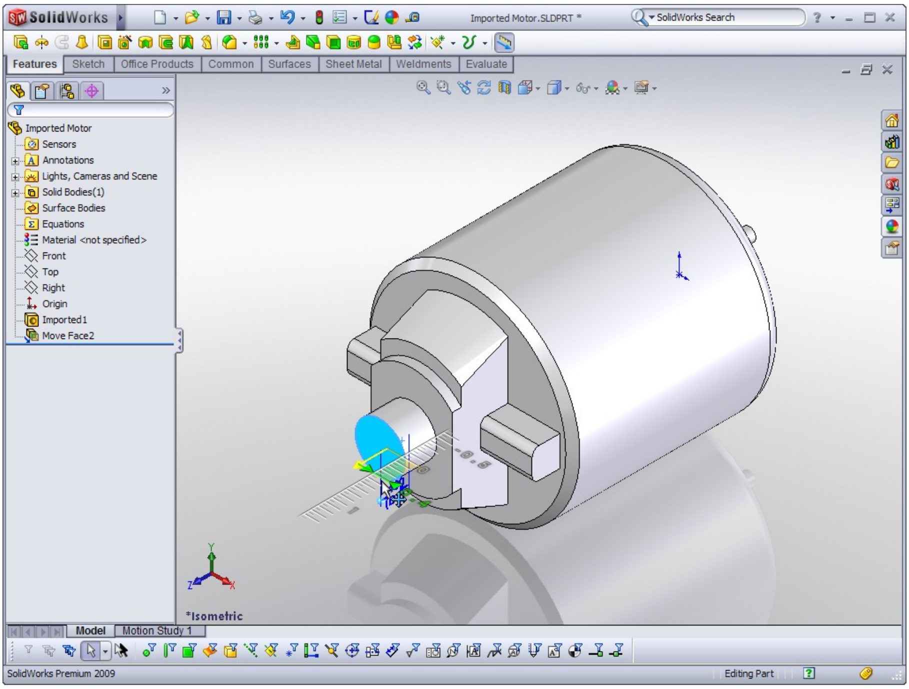

Figure 12. The main SolidWorks direct editing tool is the "move face" feature that allows to translate and rotate any face of the model.

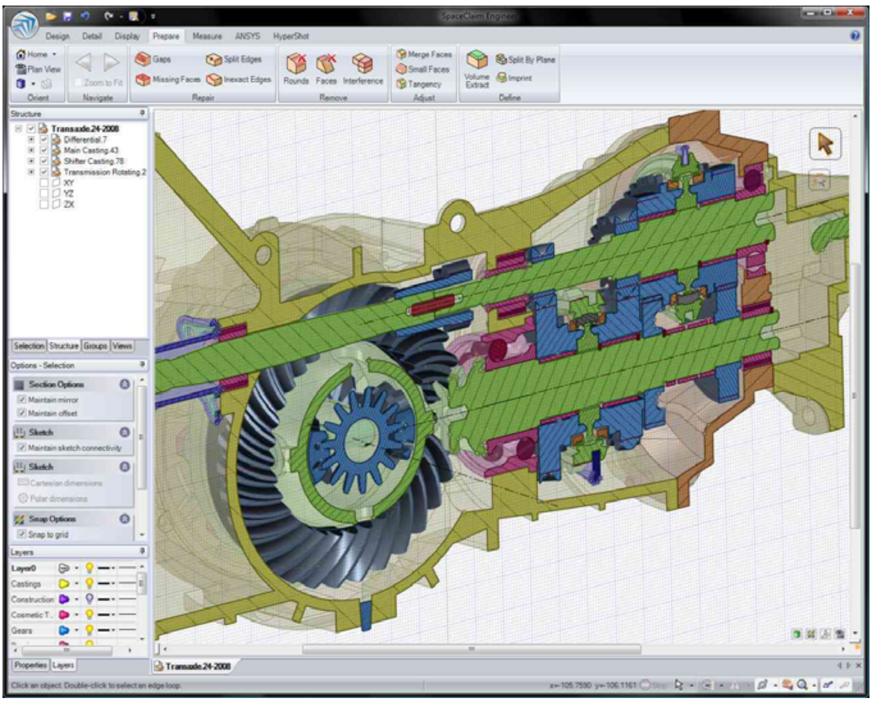

Figure 13. SpaceClaim is a direct 3D modeler with powerful capabilities to clean up imported geometry and simplify models for analysis.

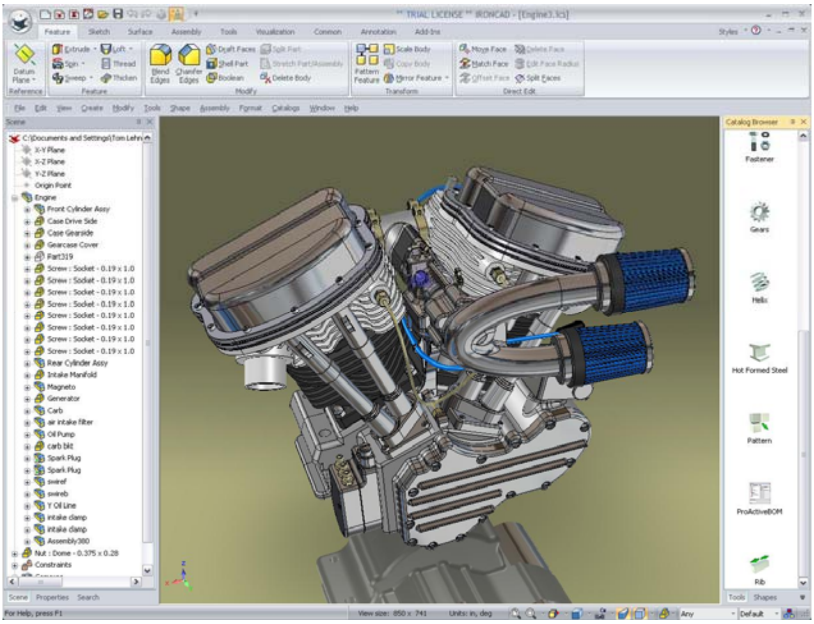

Figure 14. The power of IronCAD is in the freedom it gives the user to choose when and where to apply a traditional parametric approach.

3. THE INTEROPERABILITY ISSUE

One of the hottest topics in CAD is the data-exchange problem or interoperability issue. In fact designers have everyday more the need to interact each other sharing models in extended design teams or with other companies designers. There are two main obstacles that prevent en effective interoperability among different CAD system. The first one is due to the lack of CAD vendors to solve the problem. In fact each one try to defend its market share locking its customers on the proprietary CAD formats. The second one is due to technical problem. In fact, because every CAD system has its own way to store and manage data, the exchange between different systems (and sometimes between different releases of the same) is done by standard like IGES or STEP containing only shape data losing a wide set of information including the design intents [11],[12]. Moreover shape data are often misinterpreted when transferred by a neutral format. In fact different internal mathematical representation schemes and accuracy often lead to have gaps or overlaps between joined surfaces, disjointed vertices and edges and so on.

A lot of exporting errors can be avoided simply following several modeling rules. In fact sometimes a different modeling sequence will help getting a better part quality. As an example are to be avoided features children of fillet and chamfers. Most of CAD software offers tools to check models (both pre and post-transfer) and eventually repair errors. This kind of tools usually search for thin sliver faces, cracks, internal voids, self intersecting curves and surfaces, degenerated entities, overlapped edges and so on.

A more effective transfer is possible if the different CAD systems share the same geometric kernel. In fact, although some CADs use proprietary kernels, lot of them use commercial ones like ACIS® and Parasolid®. In this case the better way to perform data transfer is to use the native kernel format (.x_t or .x_b for Parasolid® and .sat for ACIS®). To give more chance to obtain an effective data transfer between CAD with different kernel is, in several CADs, possible to export the model in the kernel native format of the destination CAD [13].

Anyway, although the use of proper translation techniques coupled with an accurate and wise modeling allows to transfer correct geometries, a large set of information is missed.

Particularly lost information, using neutral file format, are [14]:

- Construction history
- Parameters
- Constraints
- Features

Moreover neutral file formats don't guarantee the validity of exchanged geometry and usually have a huge size resulting inappropriate in online data exchange [15].

Lot of studies have been performed on the interoperability problem resulting that about 87% of OEMs outsource some portion of their engineering [16] creating extended teams separated by geography, time zones and language. In this kind of environment interoperability is fundamental the ability to share product data between a wide range of software systems. In fact practically 100% of OEMs exchange 3D CAD data with outsourced engineers or suppliers and only 34% of the times companies receive data in their preferred CAD format [17]. It's very hard to quantify the cost of the lack of interoperability and it has been estimated, in the US automotive supply chain, to be about $1B per year[18]. The high cost of interoperability can be associated to time and money spent in the possible solution to the problem of data exchange [11],[17]:

- Investing in specific CAD System, enforcing it in the extended enterprise.
- Investing in data exchange processes to transfer product information from one design system to another.
- Investing time to remodel product in case of ineffective data exchange, due to not working, dumb or lean models.

To transfer design intent and features from different CAD system are usually proposed two different ways: feature recognition and direct conversion.

3.1. Feature recognition

Practically all CAD system embed feature recognition tools suitable both to reconstruct modeling history of dumb models but also to recognize feature in RE models.

Feature recognition tools exploit different methods usually following logic rules or graph based approaches [19].

The main problem in feature recognition is the ambiguity of the modeling process. In fact every part can be modeled in lot of different ways achieving the same geometrical result and there is any chance to understand which of the manifold choices has been followed. As a consequence of this parameterization and design intents are lost. Moreover complicated operations of lofts and sweeps are rarely recognized by software.

The problem of feature recognition is faced by different works particularly concerning the feature identification from approximated geometries (STL) [20] or the implementation of innovative techniques [21][22].

3.2. Direct conversion

An alternative to feature recognition is the direct conversion of model between different CADs. This can be done by converter embedded in the CAD suite or by third party software. Usually this kind of conversion is done by replicating the model performing all the operations from the source CAD history tree in the target one. This kind of conversion is often performed through macros and takes the name of "macro conversion". Using the macro conversion method the model isn't actually exchanged and the only information transmitted is the command list. If effectively implemented this method allows to share complete models across different CAD system without losing design intent and the possibility to perform parametric editing on it.

Although this method can solve or at least alleviate the data exchange problem nowadays doesn't exist a feature based CAD data exchange standard. Anyway some solution, often based on XML technology, are proposed [15][23],[24][25],[26].

4. INTERNET & CAD

4.1. Collaborative design

While product life is rapidly decreasing and product structure is frequently changing and becoming more customer-oriented, manufacturing systems have become today complex and globalized. For this reason manufacturers have reduced the development and the manufacturing production time, and have adopted an outsourcing approach. In fact, product development and production do not occur within a single manufacturing plant, but have become a joint venture between suppliers, manufacturers, distributors, and customers. So, it becomes very important to manage the workflow harmoniously and to share information efficiently among geographically dispersed users. Starting from these needs, the new concept of collaboration focuses its attention on tools for sharing information and knowledge in various divisions and for executing tasks cooperatively in order to improve product quality. In the era of collaborative engineering are everyday more necessary tools that allows a real-time co-operation between geographically distributed engineers and web is the natural media to share information between engineering teams.

The collaborative CAD systems can be divided in two categories off-line and on-line. In off-line collaborative CAD systems are simply shared the results of the design process. The target of on-line collaborative CAD systems is to share data instantly exalting the human-human interactions. This can be obtained by two different architectures: centralized or replicated.

The major obstacles to the collaborative engineering are connected to the previously examined data exchange problem. Several solutions are proposed involving, as an example, the exchange of features avoiding the transfer of the whole model [27],[28][29].

4.2. Hosted computing

In the last years a lot of applications are available on internet hosted on remote servers. As an example a lot of people read and write emails or manage bank account directly by internet browser. Since February 2007 is offered by Google Inc. a new online application called Google Docs that allows to write and edit documents (word processor, spreadsheet, presentation) online collaborating with others users. Other examples of hosted computing are Gliffy, an online diagramming software, and, in the field of CAD, Drawings Now, a SolidWorks® online tool that allows to view and print SolidWorks® created drawings (DXF, DWG, and SLDDRW file formats). Hosted computing gives several advantages to end users. In fact allows to work with always update software (the software update is performed by the developer on its server, when the user connects to the server simply find the last version software ready to work) and the system requirements are usually less restrictive. For these reasons is possible to foresee a development of web CAD instruments, in the beginning probably only for low-performances systems and in a more far future also for high level system.

5. HARDWARE EVOLUTION

5.1. Input devices

Mouse and keyboard are general purpose human interface device and often are the only devices designers use to interact with CAD software. Dedicated input devices can help designers to improve their work by concentrating on modeling and non on computer interaction. Those input devices are useful particularly for manipulating (by translations and rotations) the model or for 3D snapping. Examples of those devices are pantographs like SensAble PHANTOM® (that is position sensing: the input device moves without resistance, figure 15) or 3D mouses like 3Dconnexion SpacePilot™ (force sensing: the input device doesn’t move and user actually controls the moving speed) [30].

Figure 15. SensAble PHANTOM® (on the left) and 3Dconnexion SpacePilot™ (on the right)

In last year a new input device is becoming very popular because is intuitive and easy-to-use: the touch screen. The main applications of this technology are on mobile phones, PDAs and recently on personal computers. Taking into account that for its first CAD prototype (in 1963) Ivan Sutherland used a light-pen to give inputs interacting directly on the screen is possible to imagine that the implementation of this technology on personal computers will modify the way of interact with CAD systems. Anyway touching the screen forces the user to perform wide arms movement while with several centimeters of mouse movement allows to completely control a full HD widescreen desktop and it is impossible to think that a designers can work for several hours with arms lifted to interact with the screen.
Another evolution that has been studied for input interfaces is the possibility to give commands to a CAD software by voice. The designer use mouse to select entities on the screen and the voice to call features. As an example saying “Give me a circle” the circle command will be activated. Anyway this kind of features are not enough developed to perform effective improvements in complicated environments but in future will help designers in speeding-up their work reducing the time spent in navigating menus [31].
CAVE (Cave Automatic Virtual Environment) solutions combine the most sophisticated design software, computing systems and 3D display technology to build an immersive 3D virtual reality environment in which designers and engineers can conceive, experience, collaborate and modify their creations in real-time. A CAVE is a small room in which several walls and sometimes the floor and ceiling are large rear-projection screens; using interactive 3D glasses and motion tracking systems, those in “the cave” can view, interact and navigate around prototypes almost as if they were the real thing (figure 16)

5.2. Multiple monitor

The actual decreasing of the price of LCD monitors and the contemporaneous availability of graphic cards with dual monitor support are inducing a lot of companies in equipping their employees with this new technology. In fact is everyday experience that the excessive number of window simultaneously opened on the desktop and the continuous “jumping” between two or more of them inevitably slows the work. The possibility to have more space to put, and simultaneously control, the more used windows can speed up work and increase productivity. Until yesterday graphic cards supported at most two monitors and connecting more than two monitors at the same workstation needed more graphic cards (and not always is possible to install more than one on the same computer) and a lot of time spent in pc configuration. Now with new technologies like ATI® Eyefinity™ (that allows to use up to six monitors with only one graphic card) or NVIDIA® nView™ is everyday easier and quicker to effectively connect multiple monitors to a single workstation [32].

Figure 16. CAVE is a 3D display technology to build an immersive 3D virtual reality environment in which designers and engineers can collaborate and modify their creations in real-time.

6. CAD SYSTEM COMPARISON

3D CAD software is today dominated by 4 vendors, Dassault, Autodesk, PTC and Siemens. Their 3D CAD software products are very similar and the functionalities comparable. The vendors, in order to avoid competing on 3D CAD functionality, seek to focus exclusively on their PLM capabilities and "business process innovation".

Almost all commercial packages has delivered integrated and easy-to-use design validation tools, rendering, animation, and data management to allow users to gain more downstream value out of their designs. The designers can create a single digital model with the possibility to design, visualize, and simulate their products (figure 17). The digital prototype permits to reduce reliance on costly physical prototypes and get more innovative designs to market faster. Traditionally, the validation of a design before was built usually by expensive specialists. But with the actually CAD systems don't need to be a simulation expert to effectively simulate and optimize designs digitally since the product line includes easy-to-use and tightly integrated part and assembly-level motion simulation and stress analysis functionality. By simulating stress, deflection, and motion, it is possible to optimize and validate your design under real-world conditions, before the product or part is ever built.

In Table 2 is proposed a short comparison of most widespread 3D CAD system. Of every system are shown geometric kernel, operating system and class. Another useful information would be price but for every CAD are available many packages with different options, features and tools and is impossible to perform an objective analysis. Moreover price are different in different countries and even by different resellers. Because of this instead of price it has simply indicated class. Usually high-range CAD offer a better control of features particularly for complex geometries (but are less user-friendly and require a longer training) and are integrated in complete PLM solutions.

Table 2. Comparison of most widespread CAD system

Company	Product	Geometric Kernel	Operating System	Class
Autodesk	Inventor 2010	Autodesk ShapeManager®	Windows	Mid-range
Dassault Systemes	CATIA V6	V6	Windows	High-range
Dassault Systemes	SolidWorks 2010	Parasolid®	Windows	Mid-range
PTC	Pro/ENGINEER Wildfire 5.0	GRANITE®	Windows, Unix	Mid-range/High-range
SIEMENS	NX 7	Parasolid®	Linux, Mac OS, Unix, Windows	High-range
SIEMENS	Solid Edge with Synchronous Tecnology 2	Parasolid®	Windows	Mid-range

Figure 17. With the actual CAD systems the designers can create a single digital model with the possibility to design, visualize, and simulate their products.

7. REFERENCES

[1] Carlson W.: A Critical History of Computer Graphics and Animation, design.osu.edu, 2003 (http://design.osu.edu/carlson/history/lessons.html)
[2] Bozdoc M.: The history of CAD, mbdesign.net, 2003 (http://www.mbdesign.net/mbinfo/CAD-History.htm)
[3] CAD software history, cadazz.com, 2004 (http://www.cadazz.com/cad-software-history.htm)
[4] Explicit 3D Modeling: An Alluring Alternative for 2D Holdouts, White Paper, Parametric Technology Corporation (PTC), 2008.
[5] Jenkins B.: 3D Engineering: How 3D Direct Modeling Empowers Conceptual Engineering and Enables Simulation-Driven Product Development, White Paper, Ora Research LLC, 2009.
[6] Ushakov D.: Variational Direct Modeling: How to Keep Design Intent in History-Free CAD, White Paper, LEDAS Ltd., 2008.
[7] Gordon L.: Direct or history-based modeling?, machinedesign.com, 2009, (http://machinedesign.com/article/direct-or-history-based-modeling-0331).
[8] Stackpole B.: 3-D Modeling Debate Spurs New Generation of CAD Tools, designnews.com, 2009, (http://www.designnews.com/article/189793-3_D_Modeling_Debate_Spurs_New_Generation_of_CAD_Tools.php).

[9] Stackpole B.: All Aboard The Direct Modeling Train - Here's how the new hybrids and direct modeling options stack up, designnews.com, 2009, (http://www.designnews.com/article/189805-All_Aboard_The_Direct_Modeling_Train.php).
[10] Wong K.: Direct Modeling versus Parametric Modeling: The Historical Debate Continues, Desktop Engineering, 2009, (http://www.deskeng.com/articles/aaarfa.htm).
[11] Lichtenberg J.: A New Approach to Eliminating Barriers to Collaboration in Multi-CAD Environments, White Paper, SpaceClaim Corporation.
[12] Gordon L.: Comparing 3D CAD modelers, machinedesign.com, 2006, (http://machinedesign.com/article/comparing-3d-cad-modelers-1122).
[13] Gerbino S.: Tools for interoperability among CAD systems, International Conference on Tools and Methods Evolution in Engineering Design, 2003.
[14] Kim J., Pratt M.J., Iyer R.G., Sriram R.D., "Standardized data exchange of CAD models with design intent", Computer-Aided Design 40 (7), 760-777, 2008.
[15] Chen L., Peng W., Ye X., "Heterogeneous CAD Hybrid Data Exchange Based on Feature Semantics and Geometry Representation", Proceedings of the 10th International Conference on Computer Supported Cooperative Work in Design, 2006.
[16] CADCAMNet and Longview Advisors 2007 Interoperability Survey
[17] Markson H.: Achieving CAD Interoperability in Global Product Design Environments, White Paper, SpaceClaim Corporation.
[18] Brunnermeier S.B., Martin S.A.: Interoperability Cost Analysis of the U.S. Automotive Supply Chain, prepared for NIST, 1999
[19] Babic B., Nesic N., Miljkovic Z.: A review of automated feature recognition with rule-based pattern recognition, Computers in Industry 59 (4), 321-337, 2008.
[20] Sunil V.B., Pande S.S.: Automatic recognition of features from freeform surface CAD models, Computer-Aided Design 40 (4), 502-517, 2008.
[21] Sunil V.B., Agarwal R., Pande S.S.: An approach to recognize interacting features from B-Rep CAD models of prismatic machined parts using a hybrid (graph and rule based) technique, Computers in Industry (in press), 2010.
[22] Li M., Langbein F.C., Martin R.R.: Detecting design intent in approximate CAD models using symmetry, Computer-Aided Design 42 (3), 183-201, 2010.
[23] Yang J., Han S., Cho J., Kim B., Lee H.Y., "An XML-Based Macro Data Representation for a Parametric CAD Model Exchange", Computer-Aided Design and Applications 1 (1-4), 153-162, 2004.
[24] Sun W., Ma T., Li T.: Constraint conversion method in feature-based heterogeneous CAD model exchange, Information Technology Journal 7 (5), 783-789, 2008.
[25] Li X., He F., Cai X., Chen Y., Liu H.: Using Procedure Recovery Approach to Exchange Feature-based Data among Heterogeneous CAD Systems, Proceedings of the 2009 13th International Conference on Computer Supported Cooperative Work in Design, 2009.
[26] Zhang Y., Luo X.: Design Intent Information Exchange of Feature-based CAD Models, 2009 World Congress on Computer Science and Information Engineering, 11-15, 2009.
[27] Shen W., Hao Q., Li W.: Computer supported collaborative design Retrospective and perspective, Computers in Industry 59 (9), 855-862, 2008.
[28] Ma Y., Tang S., Au C.K., Chen J.: Collaborative feature-based design via operations with a fine-grain product database, Computers in Industry 60 (6), 381-391, 2009.
[29] Jing S., He F., Han S., Cai X., Liu H.: A method for topological entity correspondence in a replicated collaborative CAD system, Computers in Industry 60 (7), 467-475, 2009.
[30] Fiorentino M., Uva A.E., Dellisanti Fabiano M., Monno G.: Improving bi-manual 3D input in CAD modeling by part rotation optimisation, Computer-Aided Design 42 (5), 462-470, 2010.
[31] Kou X.Y., Xue S.K., Tan S.T.: Knowledge-guided inference for voice-enabled CAD, Computer-Aided Design 42 (6), 545-557, 2010.
[32] Mainelli T.: Driving Productivity with Multiple Monitors, White Paper, International Data Corporation (IDC), 2010.