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Implementation of computer technology for more efficient industrial design processes

Kwang-Chul Ha

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Implementation of Computer Technology for More Efficient Industrial Design Processes

by

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1. Introduction

As a design tool, Computer Aided Industrial Design (CAID) is being used in industry today more than ever. Almost everyone in the business today at least recognizes that the ever-improving power and sophistication of CAID can help compress the product development cycle, reduce the development costs, and increase designer creativity and productivity.

There are, however, numerous systems available with different principles and applications, and it can be very time-consuming and extremely costly if the designers cannot find the right CAID system for the job at once. The purpose of this paper is to guide industrial designers on the implementation of various computer technologies and techniques in order to design more effectively and efficiently.
2. New Trends and Requirements for Industrial Designers

In the 1990's, with competing products in every market segment - most produced with similar technologies, similar features and materials, and almost identical pricing - design may soon be the only element that differentiates one product from another. Industrial design is not merely a line function. Industrial design provides the essential link between engineering, manufacturing and the market place, and in essence, is the primary ingredient to present and future success.

These trends, coupled with rapid development in information technology, create a far more important role for industrial designers. It is no longer enough for industrial designers to be artists or stylists. The new generation of industrial designers will manage information, understand business, markets, materials and processes, and participate as equal partners with other organizational elements on cross-functional product development teams as well.
Being competitive as an industrial designer will require adaptability and a progressive attitude toward product development. Companies will have to reduce product development "cycle time" to quickly get a product from the drawing board to market. It will also be necessary to generate a continuous stream of new products that can target market niches for increased market penetration, market share, and company image. Designers and design firms will have to be adaptive to survive.

Business has become more complex, requiring design that will satisfy a broad range of constituents from stockholders to customers. In response, the industrial design profession has evolved in sophistication. Designers today work in integrated, multi-disciplinary teams to bridge the gaps between marketing, engineering, and manufacturing, while they strive for creative approaches that will solve real needs. The result is both long-term and short-term business success.

Industrial design is a prime example. Some design firms cling to the drafting board, rather than embrace the time and material saving capabilities of emerging computer technologies which can take new product specifications (ideas, concepts, numbers and formulas) and
translate them into images on the computer screen in hours, rather than
days or weeks.

Designers today are utilizing such techniques as surface or solid modeling,
photo-realistic rendering, and rapid prototyping to manipulate and present
designs. This greatly helps clients to see what a product looks like before
costly changes are made to the materials, dimensions, characteristics, or
functionality.

Using computers to speed the whole design process is critical to meeting
the demands of drastically shortened product development cycles. For
example, the product development cycle for new cars used to be 7 years;
today it approaches 3 years. For small, uncomplicated products,
companies used to have 2 to 4 years lead time; now they had better
introduce those products in a year or less. If companies take longer than
that, technology and marketing changes often make the product obsolete
before it is introduced. Companies, therefore, need to stay in touch with
customers - asking what they want, showing them the latest
advancements and asking for feedback. Industrial designers are trained to
question everything until the product design, production method,
marketing, financial issues, and other product information make sense and until all elements work in unison.
3. Industrial Design as a Creative Tool

Industrial designers provide visual communications and creative input for product concepts and ideas. Industrial designers help customers visualize how their businesses can grow through product development and design. They can be highly influential in establishing the use of a particular material, process, or product characteristic. Industrial designers do not limit their work to aesthetics or ergonomics of a product. They create the identity of the product, being intensely involved with the marketing analysis of the product and market. Working closely with design and application engineers, industrial designers identify the functionality of the product affecting both assembly and manufacturing.

Designers are a creative asset in the product development process. Designers contribute visual communications skills and creative input that provide visual form (two-dimensional and three-dimensional) to concepts and verbally-expressed ideas, features and benefits. Product performance definitions and objectives are refined and communicated in visual form, providing product differentiation details for market competitiveness. The
ability to share visual and technical data across disciplines via the computer encourages rapid product development.

Therefore, designers should spend a great deal of time keeping up with the world, with an eye toward developing products that fit market niches, needs, and/or demands. The design team uses this expertise throughout the development process to concurrently direct the design of new products efficiently and effectively. Much of this is performed through the aid of highly sophisticated CAID software and hardware.

Technologies like CAID, when applied to the product design development process, do not require or motivate a change of organizational structure. They do, however, enhance the flexibility of any type of organization. CAID makes any level of decentralization easier to implement, as it significantly improves the communications among contributors to the product development process. The organizations that fully implement CAID can more easily pursue alternative sources of conceptual design, engineering, and manufacturing.
4. The Benefits of Implementation of CAID

Implementation of CAID varies from application to application, but the following benefits are universal:

A. Compression of the Product Development Time Cycle

B. Reduced Product Development Costs

C. Increased Designer Productivity

A. Compressing the Product Development Cycle

Most CAID users find the benefit of speed the most visible and most rewarding. CAID can give the designers this speed by eliminating time-consuming processes and improving the quality of design by using 3D data throughout the product development cycle.

Within the corporate environment, functional departments work less independently and more interdependently. The linear process of industrial design, "passing the baton" to engineering, is superseded by simultaneous
engineering. (See Figure 1) A similar effect applies to the design consultant/client form of product development. With CAID, industrial designers can present ideas and concepts in a working session with the client, instantly making changes on screen as they together come up with different ideas or modifications. (See Figure 2)

Figure 1. Traditional design process

Figure 2. Concurrent design process
Using interactive CAID software, the design team members can play with changes to shape, surface qualities, or the way the model may work. The computer-generated model of the "Smart Reader" shows how the device works. (See Figure 3 through Figure 5) With the traditional hand rendering, it would be more time-consuming to describe how it may work as the designer would have to render each and every scene. With the help of CAID, however, the designer only has to rotate and move the desired parts of the model to achieve the same goal.

Figure 3. "The smart reader" - A scanning device for visually impaired.
Figure 4. "The smart reader"

Figure 5. "The smart reader"
Moreover, CAID can reduce unnecessary and costly prototype development with its superb visualization capability to produce photo-realistic images. By utilizing the rapid computer generation of prototypes (i.e. Stereolithography) directly from CAID data, it can also eliminate manual process of developing 3D prototypes which could take weeks and months.

Designers, furthermore, can directly pass 3D data to and from the engineering department and the model shop, eliminating the reinterpretation of design. This increased interaction within the design team in combination with the above benefits results in greater speed and improved quality of decision-making. Inovx D3, a full service product development company, is a prime example. The company's D3 group (short for digital, design and development) was formed to provide computerized product design and engineering services that help shorten the time from initial concept to manufacturing to as little as four weeks. "Not only did we save our client money in tooling and other costs, but we also saved them at least two months of rework." said Anthony Chan, the company's president. "With our computer system, we can offer clients superior products with significant time and cost savings, allowing them to bring their product to market faster and gain a competitive edge."
B. Reducing Product Development Cost

Daewoo Motors, one of Korea's leading auto manufacturers, utilized a StereoLithography apparatus (SLA) in the vehicle prototyping stage of their car development process and discovered the benefits of early design verification, shorter lead times, and effective use of budgets. Daewoo Motors reduced launch time on the new Espero sedan by 25 percent. Daewoo cut costs by employing a StereoLithography Apparatus extensively. It built over 120 SLA parts for Espero in only 2.5 months, including consoles, ashtrays, and door trim.  

In the corporate environment, much of the cost savings is quantified in terms of the elimination of expensive research and prototyping of borderline design concepts. CAID can reduce design flaws early in the product development stage with its realistic and accurate 3D models. Its models and photo-realistic images can be used in implementing market research early in the product development process. The increased human communication facilitated by CAID often results in lower costs and better design.
C. Increasing Designer Productivity

Garden Way, Inc., a leading producer of outdoor power equipment based in Troy, NY, implemented CAID in 1991 as it recognized the need for a CAID system to streamline product development.

The most difficult task for the design and engineering team at Garden Way, Inc. was the Chipper/Vac's plastic housing. Curvaceous, cavernous, and highly asymmetrical, the housing anchors the unit's battery, rotor, fan, engine, wheels, transmission, and collection bag, all of which must fit into specially designed compartments. Using the CAID system, Garden Way designed the housing with 3D clarity, and exported files to ANSYS for finite element analysis and mold-filling analysis. Garden Way then sent the finalized CAD files to vendors, whose tooling was expedited by the accuracy of the file's geometry. The firm began prototyping, followed by endurance field testing and production in record time. "We saved more than a year in development and production time using CAID system" said Peter Sawchuk, the company's vice president of engineering.³

Companies implementing CAID are positioned to respond to market demands for more and better designs with the added productivity.
Particularly in industries like jewelry, eyewear, and accessories, where new products are released every few months, CAID helps the companies manage the tremendous workload. Furthermore, in instances, when the designers are located in one spot whereas engineering and manufacturing facilities are located in other less expensive regions, CAID as a communication tool between them can pay out in a single season. Overall, working in three dimensions helps designers communicate design information more effectively and can ultimately be more productive as 3D data is passed from CAID to CAD and back again during redesign.

Another advantage of CAID in increasing productivity is that designers can create more design alternatives because CAID tools reflect the designer's changes to form or surface qualities instantly. Also, designers can be more productive by building on previous designs using a library of shared, reusable 3D models, textures, colors, and 2D graphics.
5. What to Buy and How to Buy

With today's fast changing technologies, comparing the performance of the many software and hardware platforms, especially those made by different vendors, can be a tough assignment. Individual machines perform some tasks better and others worse, so it is hard to tell how all the various factors (CPU, I/O, graphics, caching, etc.) play together when running today's complex CAID applications. Some applications require more RAM, others demand better and faster graphics capabilities. In general, computer technologies are advancing at such a fast rate that it is almost insignificant to mention what system to buy now since today's best and fastest machine will soon become obsolete.

The price and performance gaps between UNIX workstations and personal computers (including IBM-PC compatibles and Macs) has narrowed in recent years. Many CAID software packages are designed to run on less expensive PCs and to achieve almost the same goals. However, most of the serious CAID applications run only on UNIX platforms made by such companies as Silicon Graphics, SUN, Hewlett-Packard and IBM. Generally, these systems cost tens of thousands of
dollars depending on configurations - most of today's applications require 128 MB of RAM and at least 1 GB of hard disk space as their standard configuration. The software costs are comparable to hardware costs, and in some cases are more. Thus, designers and organizations have to take a very careful approach to make a wise investment.

A. Systematic Approach for Hardware

The best way to avoid chaos in this situation is use a systematic approach. A little preparation and effort will pay enormous dividends and will eliminate the possibility of losing time and money. A checklist of required and optional workstation characteristics is needed as the basis for the evaluation. A list of commonly used peripherals should be maintained in an up-to-date manner. If available, the set of benchmark documents from each vendor should be obtained. The following guidelines are an example:

a.1. With Budget.

When budget becomes available, ask these simple questions:

1. Will the purchase be compatible with the systems that currently exist
in-house?

2. Have you defined a set of mandatory requirements that must be addressed by all competing proposals before they can qualify for the remainder of the benchmark?

3. Is the goal of this acquisition a smaller number of high-end workstations, or is it a larger number of mid-range or low-end workstations? Which is more desirable?

a.2. Type of Processors.

The importance of workstation performance is undeniable. Depending on how a system will be used, the performance measurements can be broken down to the following categories.

1. I/O performance, which is the rate of the system can move data into and out of the system, typically from disk, is important. This can be expanded to include rates at which the system can access networked data.
2. Graphics performance is particularly important in a modeling and rendering system. Performance can be affected by a number of display pixels and color maps. With very complex renderings, it could mean a difference between a few minutes and a few hours.

3. Floating point performance is crucial to a modeling system. Floating point and graphics performance of a workstation are the best indicators of overall performance in most of the CAID system's modeling environment.

a.3. Testing

Making a decision based only on paper study can lead to faulty conclusions. There is no substitute for hands-on testing and recording of actual results with files of typical complexity. Suggested testing is:

- Record elapsed times for retrieving, storing, regenerating, and rendering a test suite of drawings, parts and models.
a.4. Sample Checklist

The following is a list of suggested check points:

1. Describe and demonstrate the user interface, built-in editor and screen dump capability.

2. Describe the ability to customize the user interface.

3. Demonstrate the ease of use of extensions to the interface, cut and paste between windows and the use of the various shells available.

4. Describe the ability to monitor system configuration, usage and events such as:

   - Disk space availability, with alarms when a given limit is reached.

   - Tools to distribute files across the network.

   - Methods to add peripherals.

   Management of print queues.

   - Configuration of serial ports.

   - Administration tools for system usage by departments or groups.
5. Evaluate the ease of use and completeness of the written manuals/documentation.

6. Evaluate the support of the network system.

7. Look at utilities for disk partitioning.

8. Evaluate the vendor's policies for the maintenance and support of the hardware and software.

9. Evaluate policies for maintenance response times and reimbursement for excessive downtime.

10. Evaluate the training classes.

11. Examine the upgrade path for the CPU and graphics engine.

12. Examine the local data backup methods.

13. Consider the options for the presentation methods.

14. Provide a complete list of third party software supported on the workstations.

15. Consider access of peripherals (tapes, disks, scanners, etc.).
16. Consider PC and Mac support and interface issues.

17. Evaluate the different types of input devices such as the mouse, the tablet, the dial control unit or the SpaceBall™.

18. Evaluate erase-on-delete features of disk.

19. Examine support of peripheral devices such as:

   - Paper/Transparency

   - Film/Microfiche

   - Magnetic Media

   - SLA

   - Virtual Reality

   - Monitors

20. Support of standards

   - Communication

   - Graphics

   - Text
- Database

- Operating Systems

The last two items should be significantly refined to accommodate the requirements for each site. Each site should have its own substantial list of other necessary features.

a.5. Hidden Costs

A factor commonly overlooked is the hardware, software and operating system maintenance fees. Most vendors introduce new versions of their software and operating system once or twice a year. In order to keep current with the latest version of software, it is a good idea to purchase maintenance agreements provided by the vendors. This is a less expensive way to do that, as they charge a lot more later if you do not have the valid maintenance contract.

Since these costs can skyrocket, however, they must be included in the quote and factored into the price points and negotiations. Most workstations come with a full one-year warranty. The second-year maintenance costs can cause your department to drop support. It is a good idea to get the maintenance fees in writing and budget accordingly.
B. Systematic Approach for Modeling Software

Unfortunately, it is impossible to find a perfect software solution for a CAID system. A system with excellent drafting capabilities might not have good modeling capabilities. An excellent modeling software might lack a photo-realistic rendering capability that many designers hope to have for their presentations. Another problem is that CAID systems are not very well integrated with the software that performs downstream processes, such as drafting, finite element analysis, and numerical control tool path generation.

The best way to solve this problem is to integrate a CAD system that has good modeling and drafting capability with a visualization system. The following categories are a guide for evaluating a modeling system:

b.1. Wire-frame system

This is the simplest way to build a 3D computer model. In the construction of the wire-frame model, the edges of the objects are shown as lines. Figure 6 illustrates this form of representation. For objects in which there
are curved surfaces, contour lines can be added to indicate the contour. The image assumes the appearance of a frame constructed out of wire - hence the name "wire-frame" model.

Figure 6. Wireframe representation of a refrigerator.

There are limitations to the models which use the wire-frame approach to form the image. These limitations are especially pronounced in the case of three-dimensional objects because all of the lines that define the edges (and contoured surfaces) of the model are shown in the image. The lines that indicate the edges at the rear of the model show right through the foreground surfaces. This can cause the image to be somewhat confusing to the viewer, and in some cases the image might be interpreted in several different ways. This problem can be solved with the hidden line removal process.
There are also limitations with the wire-frame models in the way different CAD systems define the model in their own databases. For example, there might be ambiguity in the case of a surface definition as to which side of the surface is solid. This type of limitation prevents the CAD system from achieving a comprehensive and unambiguous definition of the object. 4

b.2. Solid Modeling system

An improvement over wire-frame models, both in terms of realism to the user and definition to the computer, is the solid modeling approach. A solid model can be defined as a geometric representation of a bounded volume. In this approach, the models are displayed as solid objects to the viewer, with very little risk of misinterpretation. Unlike wire-frame models, designers can actually treat the solid models in the same way they would with clay or foam models. They can cut, bend, drill a hole or perform any other manipulation to the model on the screen. This feature in solid modeling systems lets industrial designers easily build a complete model with material thickness (see figure 7) when required. This process would be very tedious and time-consuming with a wire-frame modeling system since designers would have to create each and every entity manually.
Moreover, since the solid models contain material information, it is easy to check all kinds of material properties such as volume, center of gravity, interference checks, etc. These characteristics of solid modeling allow third party vendors to develop more highly sophisticated and automated downstream applications which makes the transition between designers and engineers more effective.

Figure 7. Exploded view of solid-model parts.

However, solid models require a great deal of computational power, in terms of both speed and memory, in order to operate. The advent of powerful workstations and the latest generation PCs have supplied some
of the needed capacity to meet this requirement. Thus, we can expect to see more and more applications of this type in the future.

b.3. Surface Modeling system

Surface modelers are widely being used in the automotive and aerospace industries. A major difference between solid modelers and surface modelers is the absence of topological information connecting the surfaces. Surface modeling systems also lack the capability to describe the interior of the part. The surfaces that are generated by surface modelers have zero thickness. However, surface modelers are capable of describing very complex surfaces where many solid-based systems have trouble.

Unlike solid modeling systems where an ambiguous description of geometry is not allowed, non-ambiguity is not a requirement for a surface modeling. Individual surfaces are assembled to form the desired shapes. Although the entire surfaces may appear correctly on the screen, there could be the existence of unclosed surfaces in the model, especially where one surface meets the other. This can present a problem if and when the data is sent to rapid prototype systems which require closed surfaces.
b.4. Parametric modeling system: The Ultimate in Modeling Systems?

The "parametric" or "variational" modeling technique brings a new level of intelligence to design automation. With other methods of modeling, small design changes often mean starting all over. However, the parametric, dimension-driven, models allow designers to assign "special" dimensions that control the geometry as they model (see figure 8). These dimensions can be fixed values, formulas that reference other features of the model, or can reference control dimensions set at the design management level. If a design change is required, designers simply assign a different set of dimension values which cause the model to automatically adjust its shape accordingly.

Figure 8. Parametric model of a portable gas cooker.
This parametric feature has a great potential for industrial designers because they do not have to be concerned about the final shape when they start a model. Industrial designers can begin with a very generic shape with no exact dimensions, then refine the geometry at a later stage of the design process by changing a numerical value or a geometrical relationship. This also means that industrial designers will easily be able to develop variations of a design without having to model each time.

Another advantage of a parametric system is that it captures the design intent. Design intent is built into the model by specifying the rules and objectives that govern the creation of the design. This process involves dimensioning the model in a way that describes the interdependencies rather than putting in fixed values. This can automate many tasks that with other systems must be done manually. Such tasks include modifying a design and its manufacturing instructions to meet new design requirements, generating families of parts or assemblies, substituting one part in an assembly for another, and assembling components that are created separately.

Another important feature of the parametric system is associativity. Since the users of parametric systems assign all the necessary dimensions to
the models, they can automatically generate fully dimensioned two
dimensional drawings from the solid models at any time during the design
process. All drawings associated with the models reference the solid
model rather than it being copied into the drawing. This means that any
modifications designers may make to the solid model, 2D drawings will
automatically be updated or vice versa. This unique characteristic of the
parametric system allows industrial designers to spend more time creating,
not drafting. Furthermore, this single database ensures that everyone
working on the project has the most current revision and that the effects of
these changes are not overlooked.

Today, most advanced CAID systems are striving for the ultimate system
by combining solid and surface generation with parametric features into
one homogeneous system.
6. Computer Presentation Techniques with 3D Models

Seeing, they say, is believing, and in most businesses it is necessary for people to believe with all their hearts before they will invest money and time in a project. This is one of the biggest tasks for industrial designers. However, how do you see something that does not exist? Answer: render.

Rendering is the process of adding color, texture, the illusion of transparency or reflectivity, and other visual effects to 3D models. Some designers prefer to use computer rendering instead of traditional methods because they want a high-tech look. Others use it because of the efficiencies realized.

A. Scene Description

Once 3D objects have been defined, the next step is to organizing them to describe a scene. This involves placing lights to illuminate the objects' surfaces and determining the view by selecting a camera position and lens type. The main purpose of scene description is to set the stage for the next step, which is rendering.
a.1. Camera

The camera in rendering software is designed to mimic a real-world camera, with a lens through which light rays converge at a focal point and focus onto an image plane. Users can change the field of view by either imitating different cine lenses or changing the field of view by degrees.5 By and large designers can position the camera anywhere in the scene.

a.2. Light Sources

The light sources in rendering packages also imitate actual lighting situations. The three most common lighting types are ambient, directional, and radial. Ambient light is non-directional, distributing light uniformly like sunlight on an overcast day. Directional light sources mimic the effect of spotlights, with their cone-shaped spread, or direct sunlight, which has a distinct, parallel look. Radial lights illuminate from one spot but not in a specific direction, like a light bulb.6

a.3. Colors
The colors of objects are normally determined by assigning combinations of colored lights, not by painting. Users have the options to set multiple colored lights that can be positioned relative to the objects.

B. Rendering

Generally speaking, there are three categories of image rendering techniques used in CAID systems: shading, ray tracing, and texture mapping. Industrial designers often use these methods in combination to create a desired look in the most economical way.

b.1. Shading

There are two types of shading: Gouraud shading and Phong shading. All rendering software and many CAD programs offer these techniques. These shading methods are all illumination models which mean that they describe only the relationship between the surface shape of an object and the color and direction of its lighting. Thus, for example, objects rendered using these shading methods have shading, but cast no shadows.
Gouraud Shading

With Gouraud shading, which is sometimes called flat shading, each facet of an object has the same color at all points. It shows gradation of color across a surface and some cases a rough approximation of transparency. This technique is normally used for quick visualization during the modeling process because it is the simplest and fastest (see figure 9 & 10 for example).

Figure 9. "The smart reader" - An example of Gouraud shading.
Figure 10. A Gouraud shaded image of a PC with transparency.

- **Phong Shading**

In addition to color gradation, phong shading adds highlights, smooth transparency, shadow mapping, bump mapping, and pattern mapping to the model. It interpolates the flat polygons so that edges are smoothed and shades progress from light to dark without shifts.\(^7\) However, the shape of an object has to be fairly smooth without radical changes in surface contour, otherwise phong shading may smooth the transition inappropriately. Because phong shading generally produces good results and it is relatively fast, this is the most often used technique.
b.2. Ray Tracing

Ray tracing is the most time-consuming and computationally expensive process of the rendering algorithms, meaning it requires more RAM, hard disk space, a faster CPU and graphics engine. However, it also gives the most photo-realistic images (see figure 11). As computers get faster and cheaper, more designers will use this method for image creation.

Ray tracing captures shadows, highlights, refraction, and reflections. For every pixel, a single imaginary ray of light is projected from the center of the camera into the scene and back. The ray tracer calculates the effects of all light sources as they interact with surfaces. These calculations take into account user-determined settings for reflectivity, refraction, and transparency.8

Figure 11. A ray-traced image. (Image courtesy of Alias.)
b.3. Texture Mapping

In the real world, most objects are textured. Textures give visual interest to shapes - the grain in a piece of wood, the irregular patterns in the marble floor or the brick wall. Texture mapping is extremely important to industrial designers because it can specify which of several materials were used to build a surface. A texture is a description of a surface that can tell everything about it except its basic shape (see figure 12).

Figure 12. Texture mapping on a bag. (Image courtesy of Alias.)
However, it would be difficult to model these details onto a surface. The process of texture mapping involves taking a source texture and applying it to a surface to make that surface more realistic. There are a few different types of mapping techniques although the terminology may vary.

First, flat mapping is one of the easiest and most popular methods. It paints a picture directly onto a surface, like applying a decal on a surface. This technique is used only for objects with relatively little surface curvature in the model. The second type of mapping is normally called wrapping. This process is like covering the object with plastic wrap. No attempt can be made in this method to correct distortions. In the third type, the program controls distortion by wrapping a pre-defined geometric model. Designers have to tell the computer what the shape of the object is - sphere, cylinder, cone, etc.

In addition to the three methods described above, it is worthwhile to explore the other type of mapping technique: displacement mapping. The other three mapping techniques do not actually change the surface itself. It is basically a trick, an illusion. To actually distort a surface, designers may use the technique called displacement mapping. A displacement map
specifies that the bit of surface that is being shaded should be moved before it is drawn. The movement is performed in the direction of the surface normal, and the amount is given by the displacement map. Thus, the silhouette changes, and shadows cast by and upon this surface show the change. A point designers should note is that displacement mapping only works in systems that are designed especially to do this task; many systems are not. Another drawback to this technique is that it becomes difficult to tell which surfaces are in front of others since displacement maps move surfaces around. 9

By using different types of mapping, industrial designers can simulate most of the visual attributes of a ray traced image. Although creating texture mapping requires some effort, it is still less time-consuming than ray tracing because designers have the control of placing reflections only where they want them, adding only those needed to produce the desired level of realism. Today, many third party software packages are available on CD ROM formats with many different textures available that designers can use. Also, many plastics vendors are beginning to supply libraries of their standard textures for mapping process.
C. Animation

Arguably the most dynamic way to present a design is computer generated animation. However, until super fast and yet affordable computers are available, computer generated animation is very expensive novelty for most industrial designers. A computer animation is a series of rendered images shown in sequence, like a cartoon. Therefore, it is possible to simulate how the design works on the screen without having to make a physical working model.

One way to describe the motion of objects is using the so-called "key-frame" in which the position of the objects is defined at specific frames of the animation sequence. Then, the program determines intermediate positions by interpolation. Another popular method allows the user to draw a path along which the object is to travel, and create a graph describing the position of the object on the path at any given time. Yet another technique combines both of the above methods and provides a means of choreographing all of the individual motions relative to one another.10

However, computer animation can take a long time to produce. For NTSC video format, 30 frames are needed for one second of animation. This
adds up to 1,800 rendered images to create one minute's worth of animation. Most industrial design companies do not usually have the luxury of that much time to create so many computer renderings and animations. We can just hope that animation will become an essential medium for the visualization and communication of industrial designs in the near future.
7. Rapid Prototyping

One of the biggest advantages of using CAID systems is ‘rapid prototyping’ technology. These new prototyping methods have also been described as Desktop Manufacturing, Solid Imaging or Automated Fabrication. Once the model is finished, designers send files directly to the rapid prototyping system for a physical 3D model, just like having a printer or plotter for 2D drawings. Since theses technologies produce prototype parts or models in a matter of hours, it saves a great deal of time and money. It also eliminates the possible misinterpretation between designers and model makers or clients. No matter how experienced one may be at reading blueprints or CAD images of a complex object, there is no substitute for having the actual part available. The reduction of errors through accurate 3D parts can be substantial. Blind holes, complex interiors, compound curved surfaces, etc. can often lead to interpretation difficulties.

As an example, a 2.4 liter car engine block was modeled using a CAD system at Chrysler Corporation. Initially, all the CAD model views appeared correctly. When the first prototype was built on a SL machine, it was discovered that a flange intended to be positioned only in the space
between cylinders 2 and 3 had also been inadvertently positioned between cylinders 1 and 2. Prior to the prototype, this error was never detected in numerous reviews. 11

Rapid prototype parts can also serve as the pattern for an investment or lost wax type metal casting operation (processes which can be used for the production of cast metal cavity and core inserts).

The rapid prototype processes use a variety of different technologies for part production, however, each of these processes have several fundamental concepts in common:

- Defining the part geometry on a CAD system

- Slicing the geometry into discrete 2D slices

- Production of a physical 3D model, layer by layer
A. StereOLithography

The most popular rapid prototyping technique is the stereolithography system developed by 3D Systems, Inc. of Valencia, California. It is presently the worldwide leader in this field by a very considerable margin.

The first step involves the generation of the 3D object (preferably solid model). It then goes through a translator which converts the boundary surfaces of the object into numerous tiny triangles. This process is sometimes called 'tessellation'. The next step involves generating supports in a separate CAD file. Designers and engineers can accomplish this task manually or with a third-party software such as "Bridgeworks" which builds the support automatically. Then the slicing program takes over, slicing the model into layers having thicknesses in the 0.005 - 0.020 inch range. The finer the increments, the finer the finished model but the more time required for construction. The finished file with sliced layers can then be sent to the SL (stereolithography) machine which is a vat of liquid photopolymer, an ultraviolet laser and a elevator. A platform in the vat raises to just under the surface of the polymer and the laser fabricates (hardens in this case) each layer one at a time, starting from the bottom layer, producing a solid, three dimensional part. Figure 13 illustrates how the stereolithography system works.
Figure 13. Basic schematic of the StereoLithography system.

Once laser fabrication is finished in the machine, the part then has to be drained of excess resin, cleaned, and postcured for final finish. With the laser process, the part is only partially polymerized. Using a postcuring
apparatus, the part can essentially be completed and obtain the final mechanical strength of the prototype. Figure 14 is a stereolithography model of a fax machine.

![Figure 14: SLA model of a fax machine.](image)

Since the part is generated layer by layer, however, the surface of the part will have "steps" on the surfaces, and must be smoothed. Most of resins that are being used today for SL machines are easy to sand to achieve the smooth final appearance. With the development of new resin materials, designers are able to use less than 0.005 inch for the thickness of each layer which results in a smoother surface quality directly from the SLA vat.
Those industrial design firms fortunate enough to own and utilize this very expensive cutting-edge technology report that it saves time over traditional model making methods primarily because they no longer have to produce detail drawings for the model makers. As more and more service bureaus are becoming available, many other industrial designers will have access to this state of the art prototyping technology.

B. Selective Laser Sintering

This is another fast emerging technology in the rapid prototyping area. Selective laser sintering is somewhat similar to the stereolithography process, as it uses a laser to form a plastic part. Instead of using photosensitive liquid polymer, the selective laser sintering process uses powdered thermoplastic material. Thus, this technique has a potential to produce complex prototype parts directly out of the production material (or similar material) in a relatively short period of time directly from computer models. Selective laser sintering can also produce parts from metal powders, clearing the way for the direct fabrication of tooling.
Here is how selective laser sintering process works (see figure 15). The model is built and sliced in the same fashion as stereolithography. Then the model is built up layer by layer in a bin of powdered thermoplastic material where a laser traces each cross section of the part. The preheated thermoplastic powder is momentarily heated and softened by the laser to a point where sintering of the particles takes place. Robert A. Malloy describes the 'sintering' as a process where the viscosity of the heated powdered polymer drops to the point where surface tension overcomes viscosity and fusion between neighboring particles occurs. Then the platform lowers by another layer of thickness while the powder reservoir is raised. A new layer of powder is laid down with a leveling roller, and the machine repeats the process until the part is complete.

Figure 15. Basic schematic of the selective laser sintering system.
C. Automated Filament Extrusion Prototyping

Another new and yet less expensive rapid prototyping technology is Automated Filament Extrusion Prototyping. This process is sometimes called *Fused Deposition Modeling*. It too starts with a 3D model which is sliced into layers, then thermoplastic filament (approximately 0.05 inch in diameter) is fed through an electrically heated extruder head. The hot filament melt spreads over the previously formed layer, fuses to the surface, and resolidifies (see figure 16).

![Diagram](image)

Figure 16. Basic schematic of the automated filament extrusion system.
8. Reality Check

One problem that industrial designers face in using computer technologies is that each system is not integrated perfectly, though some are better than others. Some of the modeling and rendering packages that are being marketed specifically for industrial designers do not have drafting capabilities. Therefore, 3D data must be translated into a standard file format such as DXF or IGES recognizable by other systems. Since most of these so called 'industrial designer packages' use NURBS (Non-Uniform Rational B-Splines) to provide designers greater flexibility in generating free-form curves and surfaces, they are very difficult to dimension. Since we live in a world where a very few manufacturing companies bypass the detail drawing stage of the process and use the 3D data directly in the manufacturing process, designers are often forced to use a system that utilizes more regular geometry. Because of these issues, it looks like the best system for industrial designers is a combination of a CAD package and a rendering program. However, using standard file formats such as IGES and DXF exclusively to transfer files back and forth between the two does not always guarantee a perfect result, especially with trimmed surfaces. Therefore, designers should carefully study the availability of
third-party translators that generally work better than those standard file formats.

Even though one may be able to pass the geometric information through IGES translation, the difference between the systems often requires a great deal of rework, sometimes almost rebuilding the model from scratch. For example, when a non-parametric model is sent to a parametric system, although the geometry should be transferred correctly, all the dimensional information is lost. In that case, one may have to use the imported geometry as a base reference to build a new parametric model.

Industrial designers should note that the files they generate are not necessarily what the engineering and manufacturing departments want or require. When analysis engineers perform FEA (Finite Element Analysis), for instance, they prefer not to use details that would not affect the result such as small fillets, decorative bumps and recesses which are very important to designers. Until we have an intelligent computer system that can automatically filter out the excess some day, it is very important for designers and engineers to be aware of these differences and find an acceptable means of work-around.
9. Conclusion

People are generally fascinated by innovation, especially if the end result provides real benefits. All these computer technologies that were discussed in this paper have proven their value for industrial designers. There is no doubt that they can help designers generate, define, visualize and communicate design ideas faster and more effectively than traditional methods.

One should not expect to find a perfect system. The key is implementation. As discussed in this paper, each system has different characteristics, strengths and weaknesses. Designers and design companies should study their individual needs and explore all options available. Obviously, an automotive designer needs a different system than a product designer. It is certain that more choices in both hardware and software will be available in the future. As computer hardware becomes faster and more powerful, designers will have more advanced and feature-rich software able to do things that are impossible to do today. When virtual-reality becomes readily available, for instance, designers will be able to design, evaluate, and modify in real-time without leaving their
workstations. Furthermore, we can expect to see better integration between systems in the future. One can purchase a modeling software from one vendor, a rendering package from another, an FEA system from yet another, and they will all work flawlessly in harmony.

There is no doubt that these advancements in computer technologies will greatly change the way industrial designers think and work. Most importantly, it will make true concurrent design process possible. Without it, the advantages of an integrated product development process will remain permanently out of reach. The sooner you jump into the game, the better chance you have to build the best system for you and your company. It is no longer a mere luxury for industrial designers. The industrial design industry is already using these technologies in numerous design applications. The earlier that designers make a commitment to adopt CAID technology, the more certain one can guarantee the advancement of the industrial design profession.
Notes


6. Ibid., p. 140.

7 Ibid.

8. Ibid.


13. Ibid., p. 295.
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Jacobs, Paul F.  *Rapid Prototyping and Manufacturing*. Michigan : Society of Manufacturing Engineers, 1992,


