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"Worth 1,000 pictures", prototypes and rapid prototyping.

By

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Submitted to the Faculty of History of Art and Design and Complimentary Studies in candidacy for the Degree of Bachelor of Design.
1997.

ACKNOWLEDGEMENTS.

I would like to express my gratitude to everyone who helped in the research for this thesis and to my thesis tutor, Teresa Breathnach.

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LIST OF PLATES.

" If a picture is worth 1,000 words, a model is worth 1,000 pictures" (Potter, 1994, pg. 21)

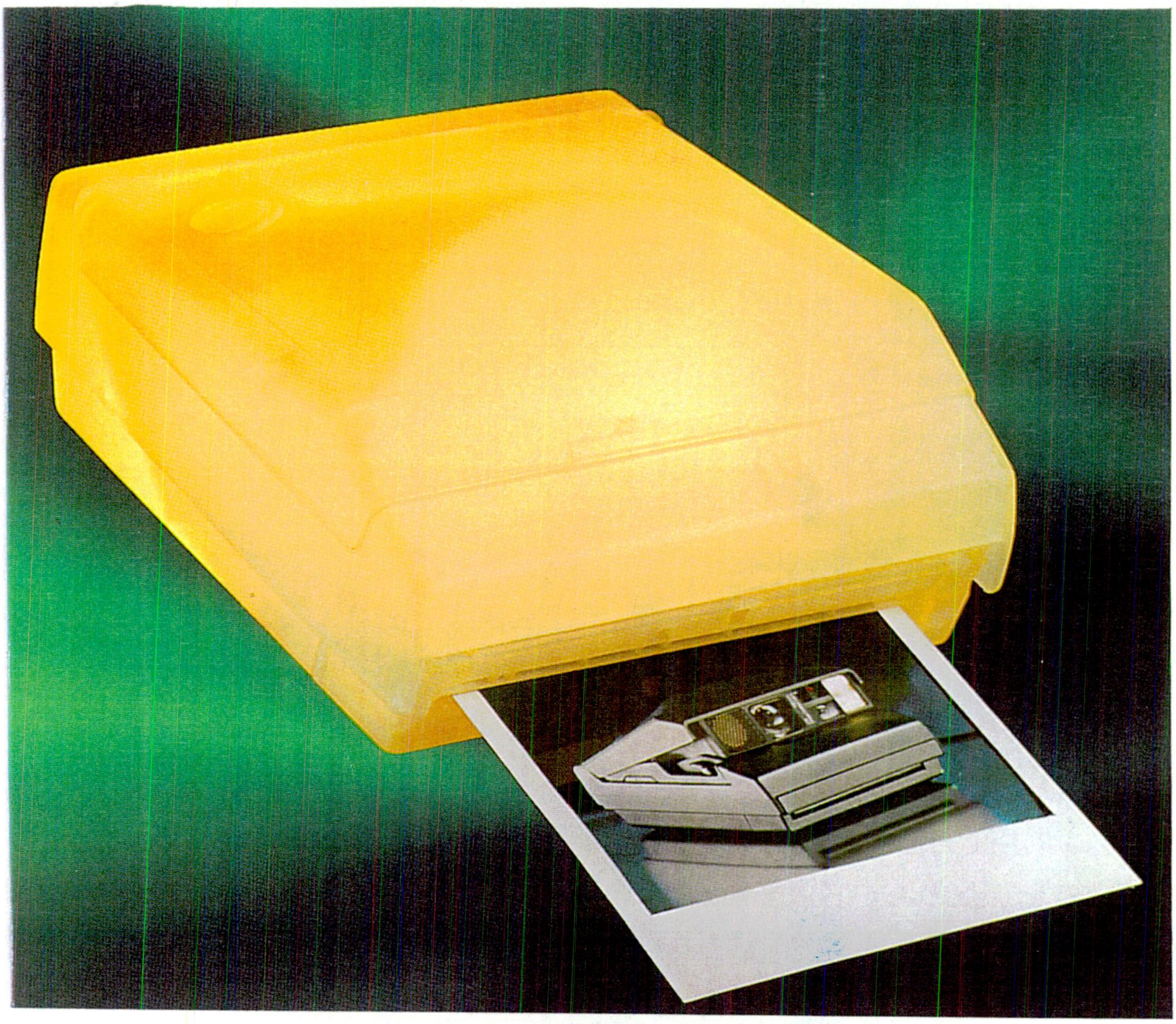


Fig. 1. Stereolithography model of a Polaroid camera.

INTRODUCTION.

Today's society is demanding more from design. Designers must be constantly aware of the individual needs of customers and try to facilitate them. Because of this increase in demand and awareness companies must be able to react quickly in order to stay in competition. An area which takes up a lot of time and expense for companies is the development of new products. This development involves every aspect of the process from choosing the initial concept to the testing, marketing and final manufacture of the product. This thesis will discuss a new technology, rapid prototyping, which benefits this area in the design process.

This thesis will discuss the introduction of rapid prototyping, also known as RP, and the importance of it's appearance in the design process and the manufacturing industry. Even though rapid prototyping is only in existence ten years, RP made it's debut with the introduction of Stereolithography in 1986, it's applications have gone beyond the area of manufacture. It has found uses in the areas of the automotive and medical industry as well as becoming a very reliable manufacturing tool. Examples will be given in Chapter 4 on different applications of RP.

Of all the methods of rapid prototyping Stereolithography has emerged as the foremost method of prototyping in the manufacturing industry. This thesis aims to examine this success and attempts to establish how and why Stereolithography has been such a success. After the first patients for Stereolithography were received in 1986 there was a flood of other methods of rapid prototyping onto the market. Alot of these methods were based on ideas similar to that of Stereolithography, while other methods utilised different ideas on producing parts.

Firstly, it aims to examine the importance for designers and engineers to examine three-dimensional models at an early stage in the design process, as two-dimensional drawings do not give enough information about the product. Errors, no matter how small, made at an early stage will cost a company money and valuable time on the market. On today's market products only have shelf lives of six to twelve months and then the product becomes outdated by improved products and new technology. It is therefore vital that errors are detected as early as possible. The most efficient way that this can be done successfully is through the testing and analysing of three-dimensional models and prototypes.

To examine the success of Stereolithography a comparison between the different types of rapid prototyping must be made. In the research for this thesis I found that there had been little published concerning this subject of comparison. The only literature that was available was the CARP project. So in order to achieve my objectives I decided to give an outline of the success of Stereolithography against other rapid prototyping methods, as well as comparing the advantages and disadvantages of each.

The information that was used to write this thesis came from reading various articles and books written by people directly involved with rapid prototyping and it's development. Interviews were carried out with Gavin Gilmour of the Product Design and Development Centre and Michael McAulife of Pace Technology. These are the only two companies in Ireland that provide rapid prototyping services. Information from the CARP Project report was also used. The CARP Project (Computer Aided Rapid Prototyping) consortium was comprised of a range of partners, each of whom wanted some specific need from rapid prototyping. The CARP Project took place over three years and it's objective was to establish the potential of rapid prototyping. It is important to remember that there is still ongoing research and development in the area of rapid prototyping and that information in this thesis is as accurate as possible for the time it was written.

CHAPTER 1.

The changing design process.

Caldecote (1979) defines design as “the process of converting an idea into information from which a new product can be made”.(Walsh 1992, pg.18) From this definition we see that design is an activity in which ideas and concepts take a physical form. In product design it is very seldom that a design stays on paper as a sketch or technical drawing. In order for a company to stay competitive in the market place it must be quick to react to other companies' strategies and also get their product out on the market before their rivals. More and more is being demanded of designers and their licence for error has long since disappeared. Designers must take every aspect of the design into account, from the initial concept to the manufacture and packaging of the final product. Only a few problems can be solved from two-dimensional drawings. Because of these limitations new technologies have been developed to help designers to get the best from their work. A good analysis for the need for changes in the design process is presented by J. Christopher Jones (Cross 1986, pg.44). Jones suggests that many of the changes in the design process have developed from problems that have occurred in the conventional design-by-drawing process. He suggests that now drawings do not give enough information about the product. The model will give a three-dimensional visualisation of the product. The designer, engineer and customer will be able to pick up the part and examine it at a more detailed level than drawings. From the three-dimensional model the relation between surfaces can be seen and examined. The product can be tested for ergonomics. None of which can be done by looking at drawings.

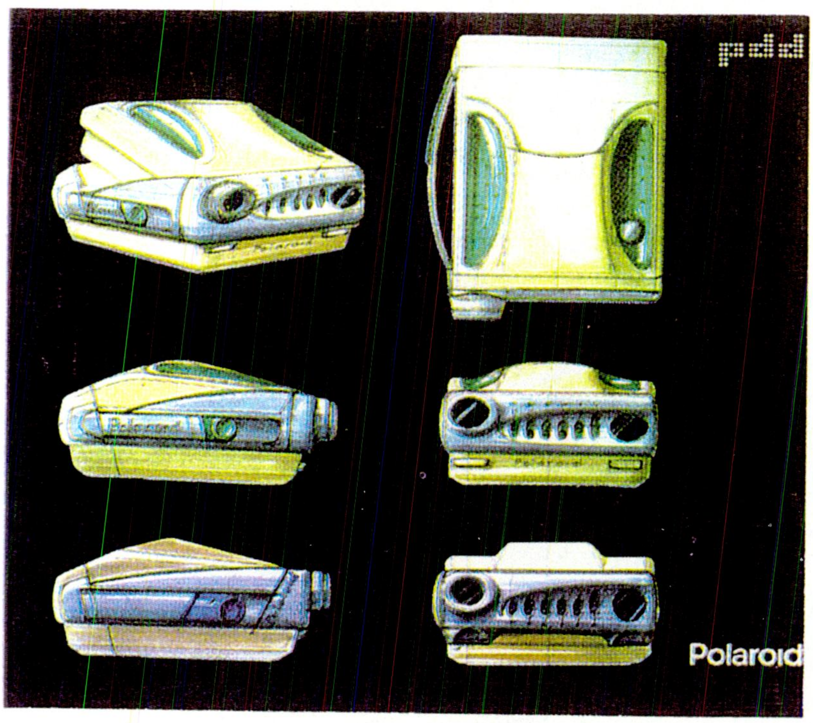


Fig. 2. Marker rendering.

Drawings and sketches play a major role in the concept stage of the design process and are important in the early stage of development. But as the process progresses these concept sketches must be verified and the only way this can be done efficiently is if the concepts are made into concept models.

Designers must produce a three-dimensional model to fully illustrate their design. The designer may have a full understanding of the solution themselves but others, such as manufacturers or engineers, need to be able to visualise and fully understand the design and all the details involved. Therefore there are certain limitations in using two-dimensional drawings. While computer software, such as 3-D Studio where the computer produces a perspective rendering of the design, has been developed to try and overcome some of these problems it still is necessary to produce a solid model to fully understand the product. The ability to pick up or touch the object is very important to get a feel for the form and to understand the functions of the product. Model-making is the key in the creation of new products. Models provide a mode for observation. Three-dimensional models are necessary to get a more real visual representation. Certain characteristics, such as textures and details, can only be finalised by using prototypes. Models are used as a fine-tuning tool for the product. The advantage that Rapid Prototyping brings to this area of the design process is that a model can be produced in less than half the time it takes to produce one using traditional methods.

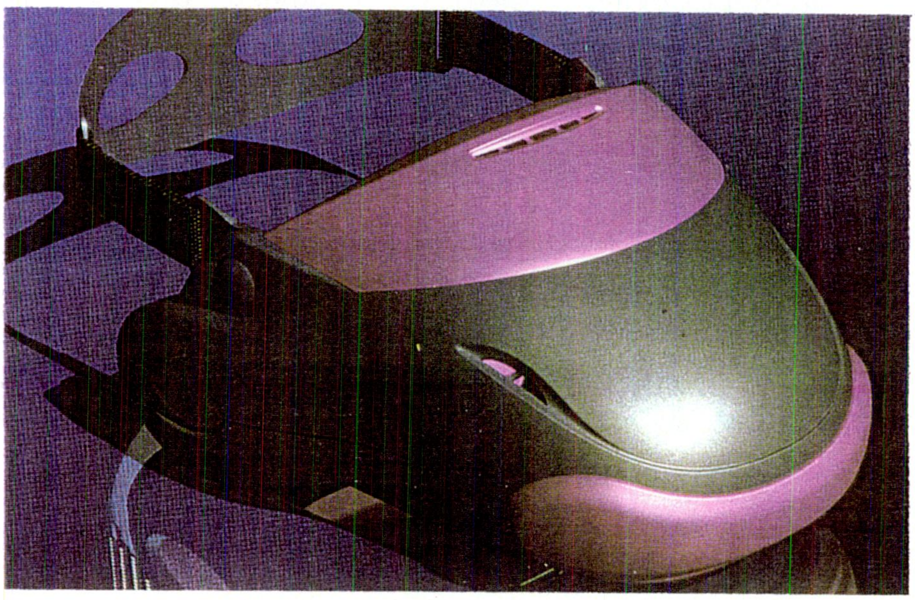


Fig. 3. Computer rendering.

There is a difference between models and prototypes, models only look like the product and are used to give a three-dimensional representation of the product, this helps with finalising details and also plays a part with client approval. Prototypes, on the other hand, not only give a realistic model

of the product but also they can be used for fit and function testing and posses the properties of the final product. Prototypes can be used as a learning tool answering questions like "How does the product work?" and "How well does the product work?".(Ulrich,1995, pg.46)

Prototypes can also have functions other than that of testing and analysis, they can function as a mould making pattern using silicone rubber casting, metal spraying or electropositioning to produce the mould cavities. This helps to speed up the process of producing moulds for small production runs or for producing moulds for metal parts. Prototypes are made by very skilled and trained technicians, and are rarely made onsite. This in turn adds expense to the transporting of the prototype. Prototypes, as mentioned previously, are manufactured from the end use material and must exhibit the same mechanical properties as the finished product in order to achieve a good analysis of the part. If the part is to be manufactured in metal then the part must be made from metal. The method used to manufacture these parts can be turned or milled using CNC (computer numerical controlled) machines. These often take weeks to manufacture and cost a company quite alot of money as the first prototype is never perfect and therefore after the company has made the changes to the design they must then send out the drawing to the prototyping workshop to have another part made. The prototype can be a reusable pattern for sand casting or investment casting for metal components.

Investment casting.

Investment casting (sometimes known as the lost wax process) utilises a one piece mould. The mould is made by surrounding a wax or plastic replica of the part with investment material. After the investment material solidifies, the wax or plastic replica of the part is melted out and metal is poured into the resulting cavity. The investment casting process is most apt to be employed when an intricate shape, close tolerances, small sizes or high-strength alloys are required. It is best suited to low or medium production levels.

Sand casting.

Sand casting is the most popular of the casting processes. Wood patterns are normally used for the mould. Sand is packed tightly around the pattern and then the pattern is removed. The mould is made in two parts with an opening for the liquid metal to enter, known as a sprue. The metal is poured into the mould and is allowed to cool. It is then removed with the required form.

The pieces that are produced using rapid prototyping to create a pattern for a mould are perfect for this purpose as they are cheap to produce, as will be explained in Chapter 4. This is one of the more recent applications of rapid prototyping. Developments have meant that soft tooling patterns can be made directly from the RP part, this is known as rapid tooling. It is important to fully understand the advantages that rapid tooling holds and the possible development in the future. We are at a time now when finished parts can be made directly from CAD data with little human intervention. As research and development continues there will come a time when rapid prototyping and tooling will replace alot of today's manufacturing processes.

The traditional and most common use for prototypes is the technical development and the testing of the product and to finalise details. Three-dimensional models of the product also help with the manufacture by relating to the most efficient method of manufacture. For example if there are blind holes, complex interior passageways or compound curved surfaces in the design it might be difficult to visualise how the product could be manufactured in the most efficient way unless there is a solid model of the product to use as a reference.

Rapid changes in technology and the short life-cycles of products mean that there is a demand for getting new products on the market before the competition. It is important that companies are able to react quickly. Firms must have good facilities to produce high quality prototypes so that designers can test, analyse and modify their designs without it costing the company a fortune in time and money.

Previous to the recent development of rapid prototyping, prototype workshops often took months to produce solid models of a design. Using traditional methods of manufacture such as milling and turning a lot of skill and time is required in the process. Milling involves the removal of material, using a milling machine, by moving a cutting tool around the material until the desired form has been produced. Traditional methods are not fast enough to keep companies competitive. Problems can occur quite often, such as the problem of accuracy and fit measurement, which will cause long delays in time and cost the company a lot of money and more importantly set back the release date of the product. In order for companies to stay competitive they must utilise the technologies that exist. Concepts need to be transformed into products in a matter of days rather than weeks or months.

While rapid prototyping has advantages over CNC machining, such as the ability to produce complicated and highly detailed surfaces without any problems and at twice the speed, CNC machining does have a few advantages over rapid prototyping. CNC machining is still better at

producing smooth surfaces. Also CNC allows the part to be milled directly from the material that will be used in the final part. CNC machines are more tolerant of less accurate CAD data. As will explained later the CAD data inputted into the RP machines must be perfect. Because of these factors more RP companies are offering CNC services and more CNC companies are offering RP services.(CARP, 1995, pg.35)

Fig. 4. CNC machining.

It is therefore obvious that both models and prototypes have their place in the design process, having design functions and manufacturing functions.

Summary

It is obvious that companies must react quickly to the changes in the market and to be able to do this they must have the facilities to allow the shortest possible development stage in the process. Designers must utilise the technology that is around them to it's fullest advantages. Companies have to develop and test their new products and to be able to find any problems or faults in the design as early as possible.

To fully understand a product designers and engineers need to visualise it in a three-dimensional form. The only way this possible is if they have an example of the product. Models are used to give a realistic visualisation of the product. Much more information is held within a model rather than a drawing. Models are used to show new ideas to potential customers. The improvements in computer graphics software means that models can be replaced by graphical representations at early stages in the design process. Prototypes on the other hand are more than just three-dimensional representations. They are used to test the product for ergonomics and are also used for functional testing as prototypes are often made from the finished material and therefore exhibit the desired mechanical

properties. Therefore prototypes have a great impact on all the areas of the design process and the success of any product relies strongly on the development of the prototypes. Also the prototype provides great assistance to the manufacturer in that they can examine the part and decide the best way to manufacture the final product.

The recent development of rapid prototyping has allowed prototypes to be manufactured in a matter of hours. This saves both money and time and allows companies to develop their products in a shorter time frame. This is very important as products on the market today often only have a life of a few months and therefore it is essential that companies get new products on the market as quickly as possible to allow them to stay in competition.

CNC machining still cannot be matched for producing accurate parts with smooth surfaces. But in realistic terms, companies cannot afford to waste the time and cost of CNC machining for producing concept models. Rapid prototyping is the answer to this problem.

CHAPTER 2.

The advent of rapid prototyping.

The birth of rapid prototyping as a new technology is still in it's early stage as it is only ten years old. Rapid prototyping is the transformation of computer data into a physical form. The company that pioneered this technology was 3-D Systems in California. Rapid prototyping was developed out of the needs that were mentioned earlier. As quick to market time became more important it was necessary for companies to get their product on the market without any problems in the design and production of the product.

All methods of rapid prototyping have a couple of common features, they all have the information inputted in a CAD (**C**omputer **A**ided **D**esign) system which then transfers the information to a "magic machine". Different types of machines are used for different systems of rapid prototyping. It is where the part is made, for example if it is referring to Selective Laser Sintering the machine is called the SinterStation. Also all of the systems are based on the concept of building up the model by "layering" rather than the idea of removing material to create the desired form, as is the method used in traditional model-making.

One of the biggest advantages for using rapid prototyping is that prototypes of products are produced in hours rather than weeks. Because the rapid prototyping model can be generated so quickly it is easy to make any modifications to the design without costing the company in time or money. Companies that try and cut corners will end up paying later.

Another advantage of rapid prototyping is that it allows the designer to "play around" with the concept by changing the textures or details and come to a better decision on the design without wasting time or money. The process for manufacturing a prototype can be briefly outlined as follows:

Firstly, the user designs the product on a CAD system. The CAD system sends the information to the rapid prototyping machine. The machine then builds the part. The prototype is then inspected for errors. The errors can range from inaccuracy to bad surface finish, the latter of which is not as much a problem anymore due to developments in the materials and hardware. The errors are then corrected on the CAD drawing. The corrected part is then verified and built again. A number of parts may be built with variations in the design and then the parts can be tested to find which variation is the best suited. A test part is then produced using the rapid prototyping part. Functional tests are then carried out on this part. When a satisfactory result is achieved move on to the manufacturing process.(Jacobs, 1992, pg.10)

Stereolithography, history of

In the late 70's and early 80's A.Herbert of 3M in Minneapolis, H. Kodama of the Nagoya Prefecture Research Institute in Japan and C. Hull of Ultra Violet Products Inc. in California were all working on different concepts producing solid objects with the use of photopolymers and lasers and then successfully building up models by the layering of cross-sections. Both Kodama and Herbert stopped getting support from their companies but Hull continued to receive the help needed and solved many of the problems that he encountered and finally invented what he called Stereolithography. The patents for Stereolithography were received in 1986 at which time 3-D Systems Inc. was set up. During the period between 1986 and 1987 there was a rush of concepts in the rapid prototyping area.

3-D Systems and other rapid prototyping companies finally developed the computer software to make it possible for the "slicing " of the objects. The first rapid prototyping machine was publicly released in 1987 by 3-D Systems known as SLA-1. 3-D Systems further developed their technology and in 1989 produced the SLA-250 machine. This machine was further developed to create the SLA-500 in 1990, which can build larger models quicker. Research done in 1992 showed that the SLA-250 was the most widely used rapid prototyping machine.(Jacobs, 1992, pp.35)

Before the SLA-1 was developed, Stereolithography parts were built on prototypes made by focusing ultraviolet radiation from a mercury lamp through a fibreoptic tube. The tube was positioned by a plotter's X/Y traveller. Software drove the plotter and the elevator. The process was repeated until the model was complete. The original patents were based on this system.(Jacobs 1992,pg.119)

The most common of the rapid prototyping materials are photopolymer resins. The majority of rapid prototyping systems use photopolymer resins. The problem of shrinkage can occur during the process. New developments are producing materials to overcome this problem. The mechanical properties of the materials used now are suited to the applications of rapid prototyping at present. Future polymer developments are likely to include improved properties such as impact resistance, less brittleness, greater flexibility and improved photospeed, the rate at which the laser cures or hardens the resin to produce the part.

Future developments in rapid prototyping.

Other developments in the area of rapid prototyping include a system known as "the Cyberman Replicator". This system was invented by Joe

Fig. 5. 3-D Systems' SLA-350.

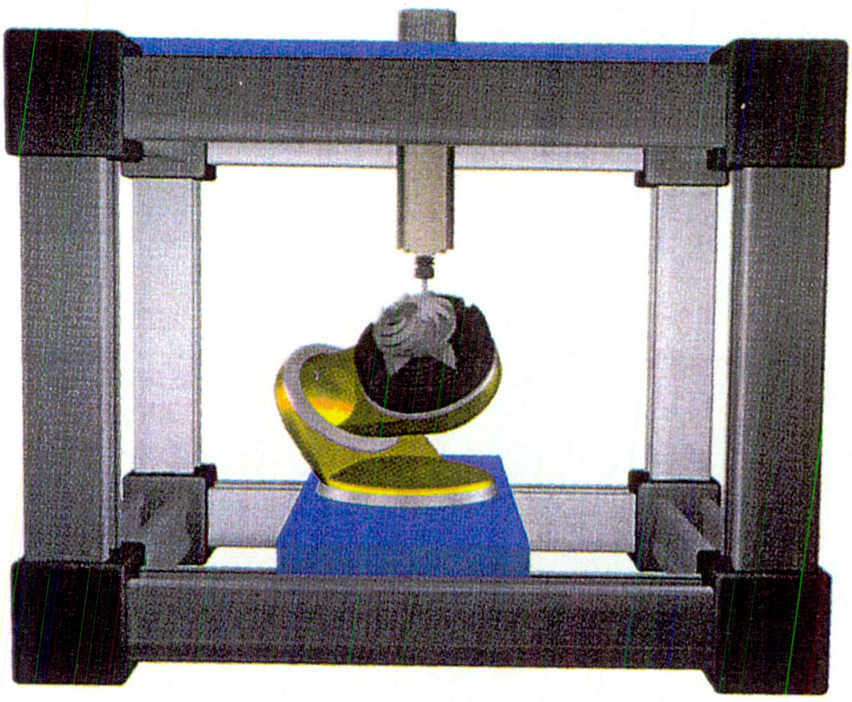


Fig. 6. The Cyberman Replicator.

McClean of Cyberman. It is basically a three-dimensional scanning, digitising and rapid prototyping system. The new system integrates a new concept in CNC machining, quickly recreating models from CAD drawings. The system uses three axes arranged so that they intersect at a central point above the faceplate. The piece that is to be moulded is placed on the faceplate and can be worked with ease of accessibility. The concept of layering to build up the model is still being used in the Replicator.

Another recent development in the area of rapid prototyping is 3D Printing invented by Emanuel Sachs, a mechanical engineer, and Michael Cima, a materials scientist, at the Massachusetts Institute of Technology. As the name suggests the system works in the same manner as ink printers. With further development the 3D Printer can be made faster. The main advantage of this machine is that materials can be mixed to give different properties. Another advantage is that small intricate details can be created and there are also cooling channels which mean that there is uniform cooling throughout the model and this prevents warpage or shrinkage which occurs in photopolymer systems.

Instead of producing only one prototype, rapid prototyping allows the designer to create a number of models at the same time. Each part can have a small or large variation so that the designer can test a number of the designs. The cost of the production of these models is relatively cheap, compared to other methods that it encourages the designer to experiment with the design. If traditional methods of prototyping are used only one model can be made at a time on a machine. Therefore the designer will only be able to test one prototype at a time and if there are changes to be done the designer must send new drawings to the toolmaker and wait a few more weeks before receiving a new part. This is time consuming and is therefore obvious that rapid prototyping offers the designer, manufacturer and company so much more.

<u>The use of Virtual Reality.</u>

Computer software developments have opened new doors for the designer in helping to save time with making changes to the design. It also offers a photorealistic image of the product but, as was mentioned earlier, one cannot get a feel for the product.

To try and overcome this problem to some degree designers are now using Virtual Reality. In manufacture there is an awareness and an understanding that the design process could be made faster if Virtual Reality and CAD-based technologies were integrated. Various reports have been written since 1993 assessing the role of Virtual Reality in the area of rapid

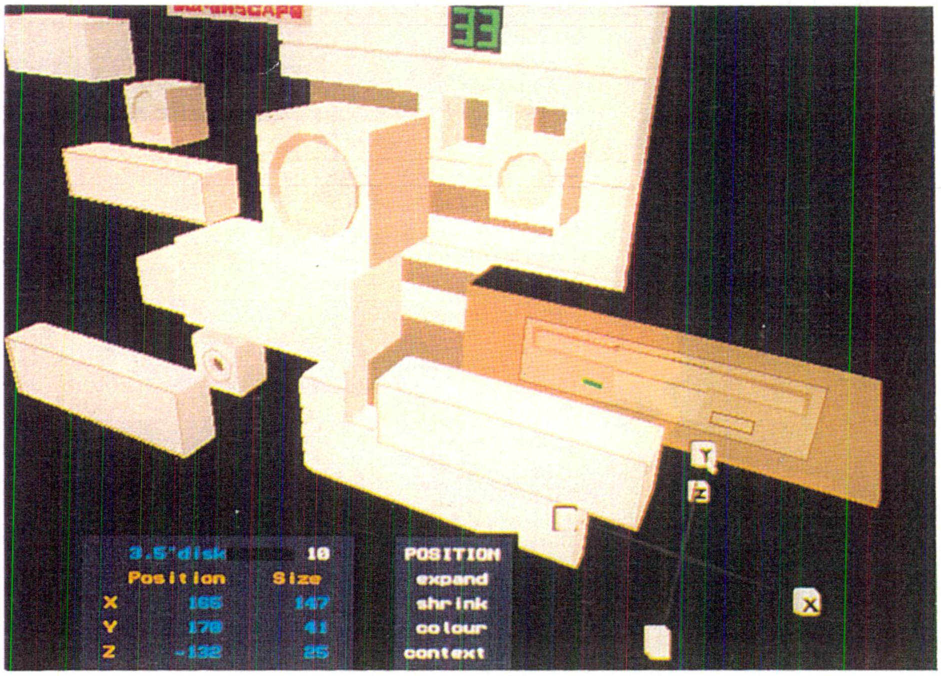


Fig. 7. Use Virtual Reality as a concept tool.

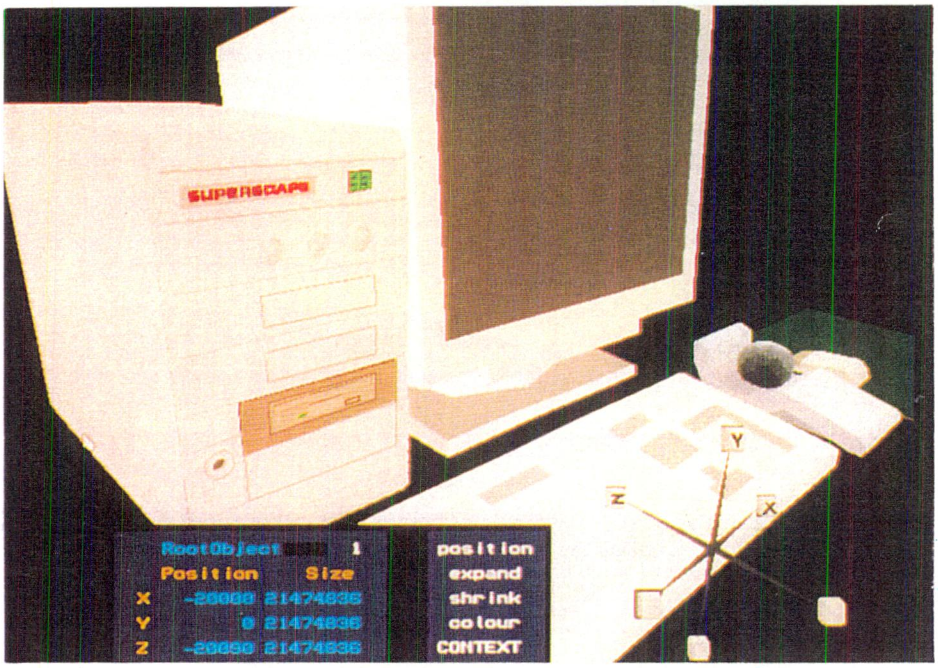


Fig . 8. Possible layout of computer panel using Virtual Reality.

prototyping. Virtual Reality can be used to build an interactive, visual knowledge base that can then be used with traditional CAD systems as an intelligent concept design tool. What this means is that the designer can create a situation or environment in which a product can be tested on computer. Virtual Reality offers the most realistic representation of the product without having to create it in a physical form.

The reason that Virtual Reality is so useful, as opposed to three-dimensional rendering systems, is that the environment can be modelled and tested. It can provide a real time visualisation tool in which virtual objects can be created, examined and manipulated. It may be possible that the need for early physical models will be reduced because of the manipulation applications and design developments of virtual models.

One experiment carried out to show the possibilities of Virtual Reality in design utilised the front panel of a computer. The panel was made up of several sub-panels that formed specialised elements such as buttons, disk drives and LEDs (light emitting diodes). Firstly, the elements were laid out in front of a blank mounting panel. The designer was then able to place these components in various positions, shapes and colours to assess the different layouts for ergonomics and aesthetics and come up with the best arrangement for the panel.

Although it has been shown that Virtual Reality is easy to understand and use, the assessment of the product is made on aesthetic and ergonomic levels rather than functional levels. Virtual Reality could be used as an excellent concept design tool but as it has been pointed out the assessment of the product would be very inconclusive. The part could not be tested in the "real" world and a true analysis would not be possible. Therefore it has been shown that it is necessary to produce a three-dimensional solid model to fully test and analyse the part. Using the example of the computer panel, if models had been used the designer would have been able to get a better feel for the product in terms of how the design of the panel would work although using Virtual Reality saved the expense of producing the models.

The CAD process.

The quality of the finished prototypes produced the various methods of rapid prototyping depends strongly on the quality of the CAD information inputted into the system. The systems use this information to produce the parts and if inadequate information is used then the part made will also be inadequate. The data must facilitate the generation of the closed paths, meaning there must be no gaps on the surface of the CAD model, and differentiate between the outside and the inside of the part. Cross-hatching is used to solidify the areas within the boundaries of the part. The boundaries of the part must be fully closed as this will lead to problems, such as the cross-hatching escaping out through the gaps and therefore the correct area will not be solidified when the laser is curing the resin.

The boundary data must also define the orientation of the part. If this information is incorrect problems will occur with the part such as the part having zero wall thickness or twisted surfaces with conflicting part orientation.(Jacobs,1992, pg.156.)

Surface modelling.

Surface modelling is still necessary for the creation of doubly curved, three-dimensional shapes. Surface modelling lacks the ability to describe the interior of the part. As suggested by the name, surface modelling only allows the user to operate on the surface of the part. The surface maybe built up over a network of curves or building up a number of cross-sections along the length of the object and then produce a surface over the outside of the cross-sections. It can also be called "wire-frame" modelling. This allows the user to build up a wire frame representation of the object by joining points in space with lines, arcs or curves. Surfaces can then be placed over this wire-frame.(The CARP Project, 1995, pg.10)

Rapid prototyping has traditionally been associated with solid modelling CAD systems as the models produced by surface modelling systems can often have gaps on the surface and this will cause problems as mentioned earlier. There are at present developments in the area of surface modelling which will make it possible to make the system more reliable. It is important that surface modelling is not forgotten about as it is easier to produce more complex surfaces through surface modelling.

The CAD is outputted from the computer and inputted into the RP system as a STL (**ST**ereo**L**ithography) file. This is another common factor that all RP systems share. STL file were developed by 3-D Systems and were originally devised for Stereolithography and has become the most popular

and most reliable method of data transfer. More intricate detailed objects will increase the size of the STL file. The larger the STL file the longer the slice time and therefore the longer it will take to build the part.

Part orientation.

The orientation of the part being manufactured by the RP system must be defined in the positive X,Y and Z axis. The position of the part in the building chamber will have an impact on the build time and the surface finish. The build time will be affected because if the part is placed in the chamber so that the Z axis, the height, is minimised this will decrease the height and therefore the number of slices to be produced and thus decrease the time it takes to build the part.

Unlike other rapid prototyping systems, Stereolithography allows the part to be built in multiple layer thickness' within a build cycle.(Jacobs, 1992, pg.160) the advantage of this over other rapid prototyping systems is that the part can be built quicker, i.e. there are lees amounts of layers therefore less time required to build them. Another advantage is that curves can be built more accurately as the "stair stepping" effect can be minimised.

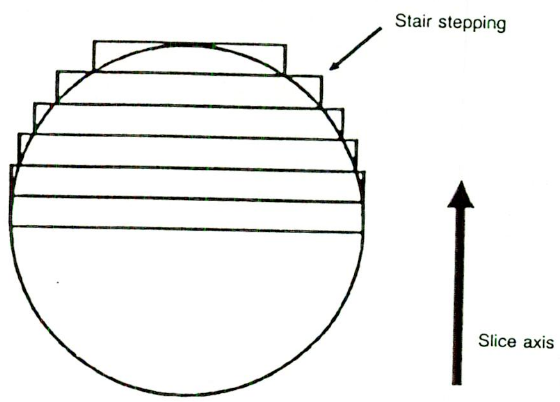


Fig. 9. "Stair stepping" effect due to layering.

Supports.

With the exception of water, every material undergoes shrinkage when transforming from a liquid to a solid. Increased density, without any change of mass, requires a loss of volume, thereby producing shrinkage. Unconstrained shrinkage leads to curl. Because of this it is necessary that supports are used. Supports are generated by CAD and are stored as a separate file from the part that is being made. The first layer that is attached

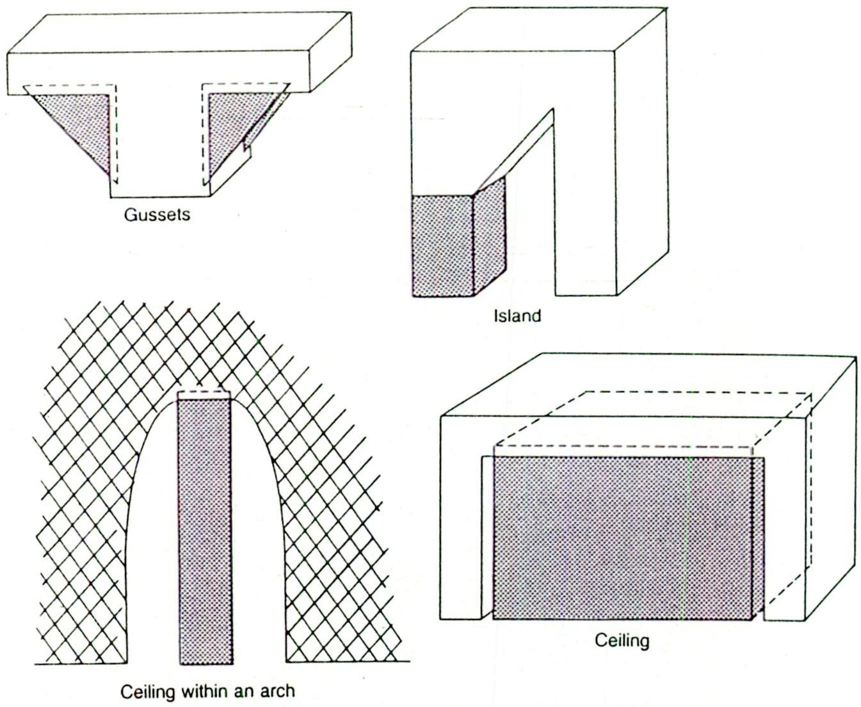


Fig. 10. Supports that are used during RP process.

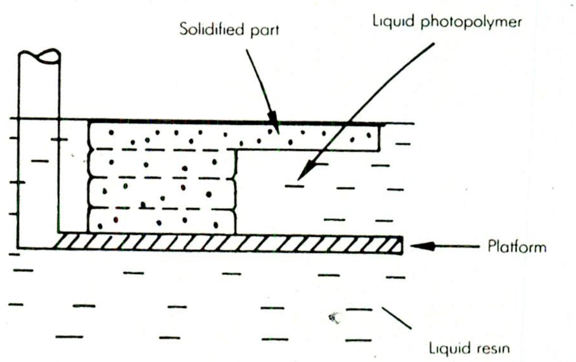


Fig. 11a. Showing the deformation when supports are not used.

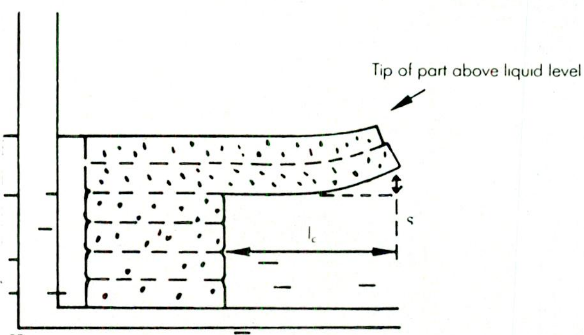


Fig. 11b. Second layer is built.

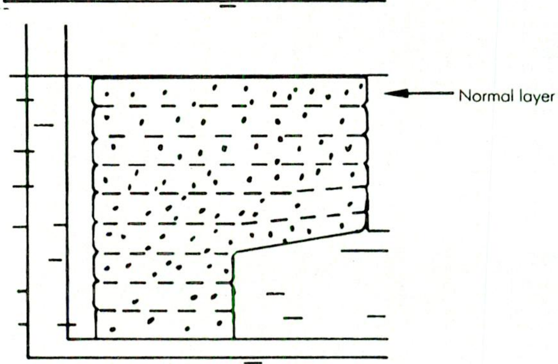


Fig. 11c. Distortion after several layers.

to the platform is a support and any layer that overhangs the previous layer requires a support to prevent deformation.

Gussets.

As mentioned earlier if there are any overhangs on the part they will exhibit curl. Supports , in the form of triangles, called gussets are used to hold the overhang and prevent any deformation.

Islands.

Islands are layers that are added onto the part that would not otherwise be there. Islands must be connected to the platform and to the part.

Ceiling.

Arches are self-supporting structures but if there is a flat in the arch then it will need a support to stop it from sagging.

Resin.

As mentioned previously different rapid prototyping systems use different resins. Before deciding on a system it is necessary to consider the characteristics required from the prototype as different resins give different properties such as greater temperature resistance while other resins allow very thin walls to be built.

Summary

About 95% of all rapid prototyping systems are very similar to 3-D Systems' Stereolithography while the other 5% are quite different. All systems are based on the idea of layering. All of the rapid prototyping methods use computer generated models of the product and the object is then converted into cross-sections or "slices". It is therefore obvious that 3-D Systems' Stereolithography was one of the most innovative concepts in the area of design, prototyping and manufacture.

By choosing rapid prototyping over other methods of prototyping companies are cutting time scale by half. It has been shown that RP systems can produce parts at twice the speed of other methods, the advantage in this is companies can get product on the market earlier than their competitors. Another advantage is that the designer can test the parts at earlier stages in the design process and therefore spend more time solving problems that occur in the testing phase in the process. Rapid prototyping also allows more than one part to be produced at a time. If the part is small enough to allow other parts to fit into the build chamber of the RP machine then the designer can have a number of parts with different design variations built in the same build cycle. This creates huge time and money savings for the company.

While Virtual Reality does have a place in the design process, it's influence in the manufacturing process is nowhere near that of RP. Virtual Reality acts as design tool and not a testing tool. The testing that is done using Virtual Reality is based on aesthetic levels only and functional tests are not possible. Also the designer cannot offer the customer or client a feel for the part.

The CAD data that is used in the production of parts using RP must have no flaws as inaccurate CAD data will lead to the production of an inaccurate part. While CNC machining is more tolerant of inaccurate data, rapid prototyping does not allow for any gaps or overlaps in the data. The method of data transfer that all systems accept and is the most widely method used was developed by 3-D Systems and was originally developed for Stereolithography. All systems break the CAD data into cross-sections. It is important to remember that because of these cross-sections there is a "stair stepping" effect. This means that all parts finished from RP must be hand finished by sanding. Stereolithography allows the designer to build the part in multiple cross sections and means that the parts produced are more accurate.

CHAPTER 3.

Descriptions of rapid prototyping systems.

The following are descriptions of the five main types of rapid prototyping, any of the other systems are based on these. I feel it is necessary that the systems are outlined so that a good comparison can be made. Each method of rapid prototyping has it's own significant factors that influence the customer to choose that method. These factors include part accuracy, build time and cost.

Stereolithography.

The beginning of the process involves the generation of a CAD model of the object. After the CAD model has been generated the next operation involves the boundary surfaces of the CAD model to be tessellated. This means they are formed as an array of connecting triangles. The size of the triangles is dictated by the user. Small triangles are used for curved surfaces and complex shapes, as they offer better accuracy in the part. While larger triangles are used for parts with simpler geometry and take up less memory storage, they are not as accurate as smaller triangles.

Then the CAD model is generated into a file known as a STL file or Stereolithography file. The STL file consists of the X,Y and Z co-ordinates of the triangles as well as the orientation of the triangles. The STL file is the most widely used storage file for rapid prototyping systems.

A "slice" file is then created which just means the part is broken up into two-dimensional cross-sections. Recent developments have allowed the thickness, or Z co-ordinate to become as small as the thickness of a piece of paper. The thickness is important as bigger cross-sectional thickness' lead to a stair-stepping effect (see fig. 12). This is an important factor to consider for all RP systems.

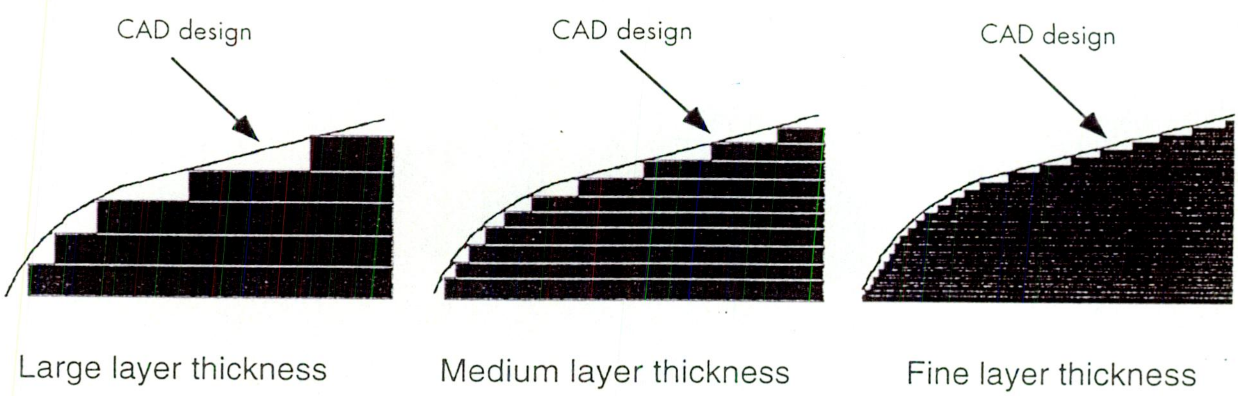


Fig. 12. Diagram showing the difference between layer thickness.

The final build file is then created, including the presence of supports. The part is then made by a laser passing over a bath of photosensitive polymer resin and solidifying the areas as described by the build file. After the first layer is solidified the platform lowers one layer thickness. The platform is controlled by computer and driven by a precision stepper. Resin then flows over the previous part. A recoater blade then passes over to remove excess resin.

The procedure is then repeated for the next layer. The system will automatically correct itself for the cure depth for each cross-section so that each layer sticks to the previous layer. The system will continue without any human operation.

When the build is finished the platform is elevated out of the resin with the solidified part. The user takes the part, including the supports, off the platform and any unsolidified resin is cleaned off. The supports are removed. Then the part is placed in a post-cure apparatus where it is exposed to ultraviolet radiation. This is to make sure the part is fully solidified. Now the part is ready for milling, sanding, painting etc.

With recent development in the hardware for Stereolithography machines, it holds the record for RP accuracy and it can now do this at twice the speed it was able to do previously.

Laminated Object Manufacturing.

The Laminated Object Manufacturing (LOM) process was developed by Helisys, California. LOM builds the part by laminating and laser trimming material delivered in sheet form. Each new sheet is attached to the block by using heat and pressure.

Like other RP systems the first step involves a CAD generated model of the part and then a STL file is created. Unlike other RP systems LOM involves the subtraction of material rather than the part being built up.

The material is introduced into the work space in a continuous way from a roller. The excess material is spooled away (see fig. 14). The platform is computer driven and is lowered after each layer has been added. A CO^2 laser cuts out the cross-sectional shape. Then the laser cuts the outside materiel into squares known as “tiles”, which allow them to be removed at a

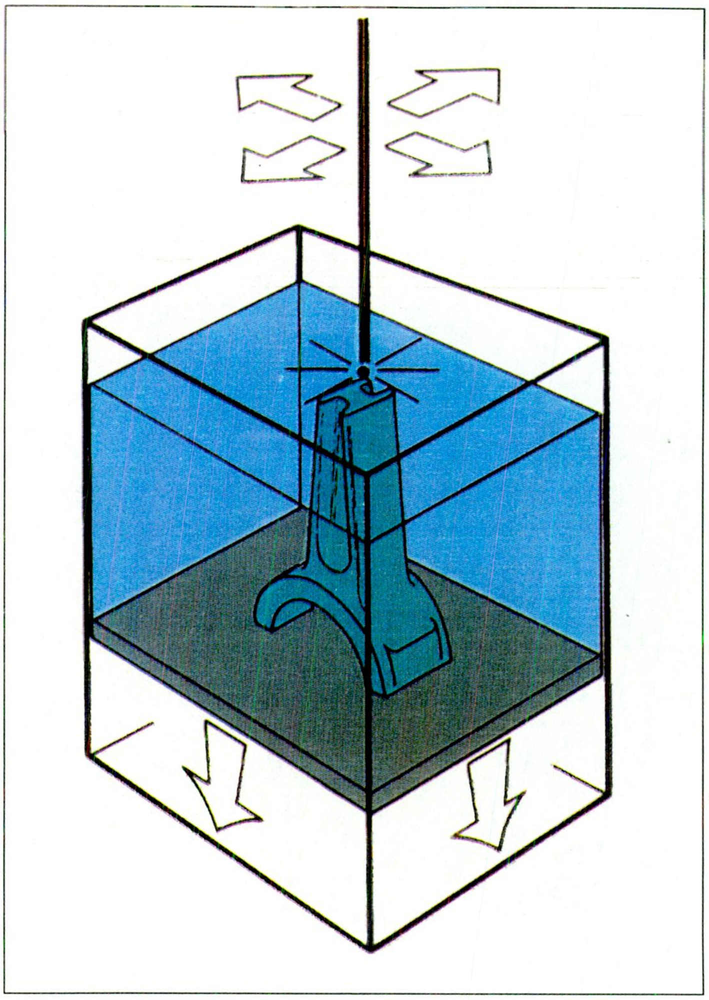


Fig. 13. Stereolithography process.

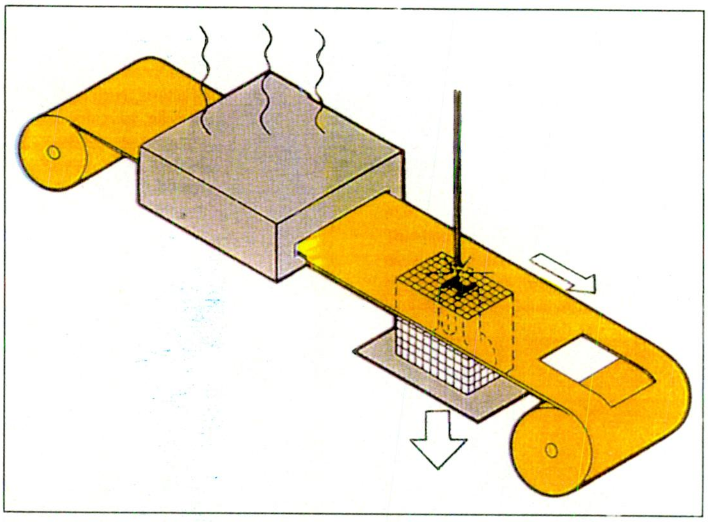


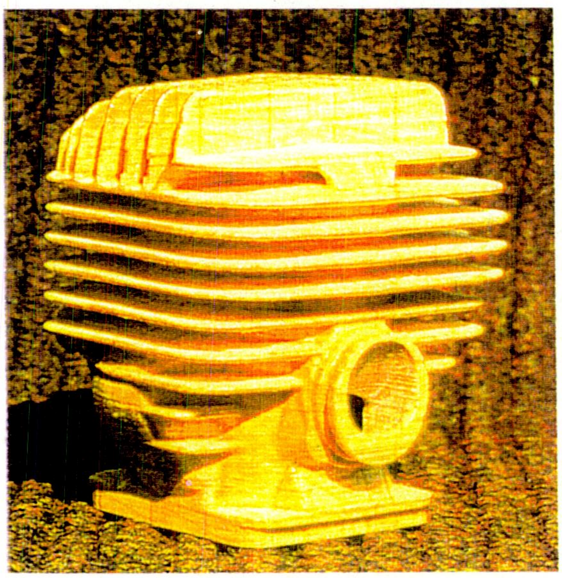
Fig. 14. Laminated Object Manufacturing process.

later stage. There is a roller which applies the adhesive located above the laminate. There is no need for supports as the surrounding material acts as the support. After the LOM process is finished the part is embedded in a block of material which can be removed. The removal of the material is quite complex. It can prove to be difficult to remove material form interior passageways or to make sure the part does not get damaged when removing the material.

It is quite difficult to produce fine details using LOM. The clean-up process is achieved manually and care must be taken so that only the waste material is removed.

Because there are alternative layers, i.e. material and adhesive, it is difficult to get the correct properties. For example, the strength of the part is different in relation to parallel forces and perpendicular forces. Another concern is the delamination of the adhesive.(Jacobs, 1992, pg. 414) Delamination means that the layers become detached from each other because the laminate is not able to cope with the stress that is placed on the part. For this reason LOM parts are not often used for functional testing.

An advantage of LOM is the prevention of distortion to the part during build, because of the support of the surrounding material.



Because of the wood-like appearance and texture of the part it's best application is for sand-casting as wood patterns are used. Also sand-casting does not involve intricate patterns. It is difficult to produce intricate details on the LOM part as they will get damaged when the surrounding material is being removed.

Fig. 15. Finished part.

There has been no literature to date published on the part accuracy of LOM. (Jacobs, 1996, pg.10) But from the information available parts produced by LOM would not be as accurate as Stereolithography because of the manual work is needed in removing the part and unless care is taken too much material maybe removed.

Fused Deposition Modelling.

Fused deposition modelling (FDM), developed by Stratasys, Minnesota, uses a thin wire-like spool of thermoplastic filament. The thermoplastic is heated just beyond boiling point in the delivery head, and is then extruded through a nozzle in locations dictated by the computer. Again STL files and "slice" files are used.

The part is built upwards on a platform. The thermoplastic solidifies in place and the part is built in layers. The liquid plastic quickly bonds with the previous layer. It is important that the delivery head is kept in motion as the plastic will quickly solidify and will cause bumps on the surface of the part. The layer thickness can be varied by changing the speed of the delivery head.

Flat or near flat surfaces require supports. These must be cut off after the process has been completed.

There are a couple of advantages in relation to FDM and the material used. As the material is only used in a delivery only process. This results in a saving of expense that would otherwise result from a wastage of material from vats of resin or cut away material in other processes. But the price of material for FDM is very high and therefore care must be taken otherwise it may prove to be much more expensive than other processes such as Stereolithography.

Another advantage is that a number of thermoplastics can be used. These materials can allow the part to be used for investment casting or to be machined. It can also apply different properties to the prototype.

Selective Laser Sintering.

The Selective Laser Sintering (SLS) process was developed by the University of Texas and is now sold by DTM, Texas.

The SLS process is based on the selective fusing or sintering of small particles by using a high powered CO^2 laser. As with Stereolithography, the SLS process is a layer additive process, building parts from a CAD file. Powdered material is moved upwards by a piston within a feed cylinder and is spread over a work area by means of a roller. Now there is a thin layer of

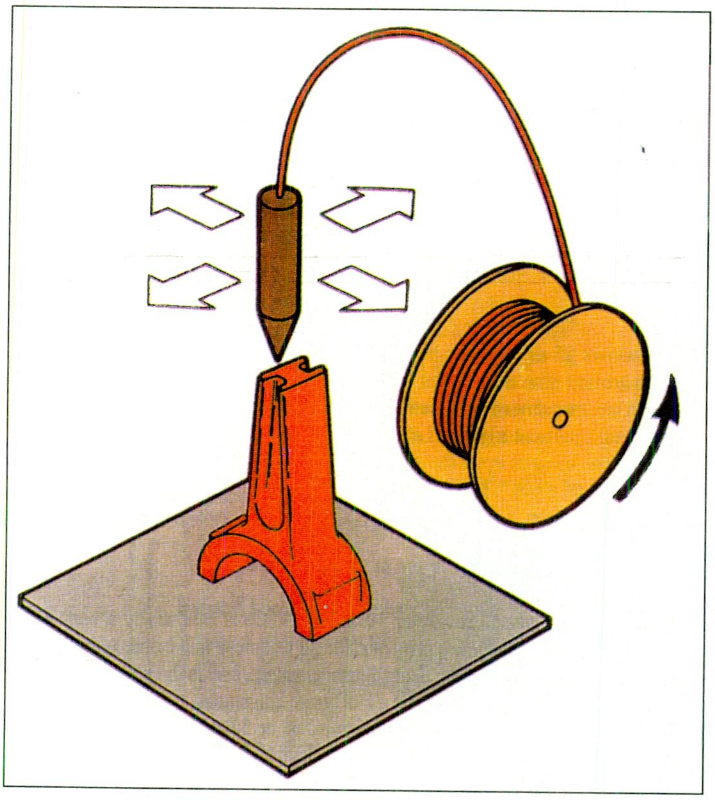


Fig. 16. Fused Deposition Modelling process.

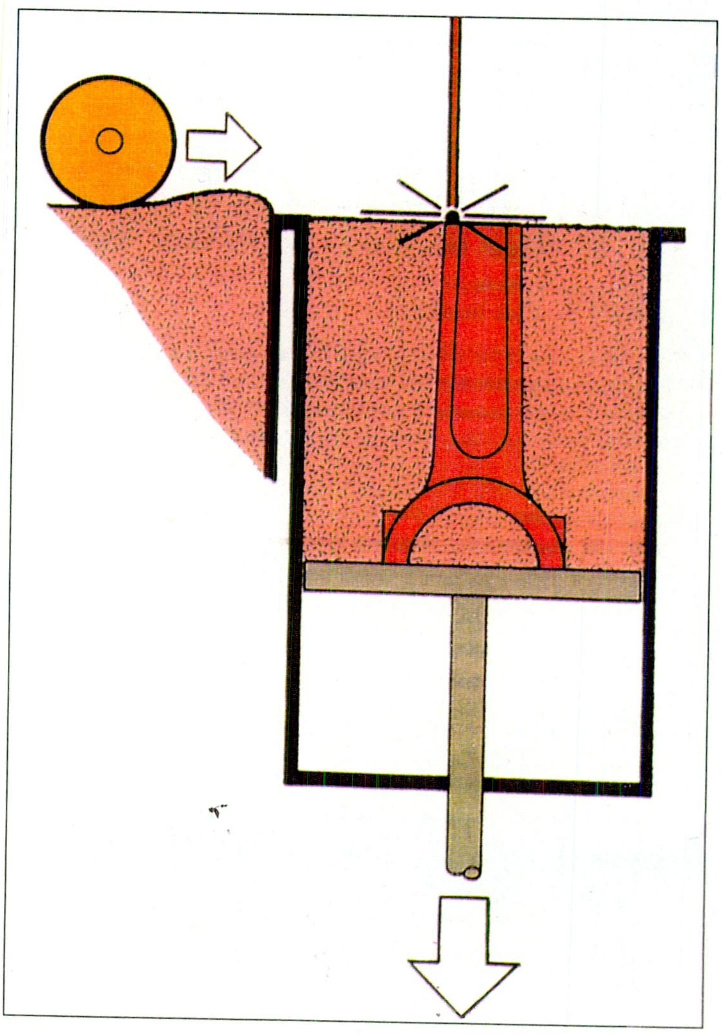


Fig. 17. Selective Laser Sintering process.

material over the working area. If there is any excess material it is moved onto a second feed cylinder and is later used to form the next layer.

The CO2 laser emits infrared radiation onto the material. The material is heated to a temperature just below the heat that is necessary to fuse the particles. This is done to minimise the laser output. Also the oxygen level in the chamber is kept at about 2% to avoid contamination of the part or to avoid an explosion.

Different materials can be used in the SLS process. For materials such as PVCs and polycarbinate the laser causes the particles of the powdered material to soften and to bond to one another at the point of contact. For other materials such as nylon or wax, the laser locally melts the material to produce a fully dense part. The disadvantage of these materials is that the level of shrinkage is quite high and therefore the part will exhibit a large amount of distortion. It is quite difficult to produce complex geometric forms accurately. This leads to a trade off between diminished mechanical properties resulting from part porosity and increased dimensional errors due to excessive shrinkage.

The fact that only the points of contact bond with materials like PVC leads to a rough surface finish on the part.

An advantage of the SLS process is the ability to use a large range of materials. Although this does provide the advantage of the part being manufactured in the desired material the part will not possess the correct mechanical properties or characteristics due to the sintering process.

A potential advantage is that the finished part is embedded in the material and as with the LOM process this acts as a support. But there will still be need for additional supports. Developments are presently being researched into the use of metal in the sintering process.

Solid Ground Curing.

Solid Ground Curing (SGC) was developed in 1988 by Cubital, Israel. Of all the rapid prototyping systems it is by far the most complex procedure. The system uses photopolymer resins, the same as Stereolithography, but does not use lasers. The process begins, as do all the RP systems, with a CAD generated model of the part. SGC accepts a number of files including STL files but then all files are transferred into CFL (cubital facet list) files.

The CFL file generates the cross sectional information for the system. CFL uses ionography. Ionography is used to create a charge distribution on a glass plate, this is the cross section for each layer. Black toner powder is then spread over the image. The toner will stick to the charged areas on the glass plate. Excess toner is then removed.

The toner has now formed a black mask. A thin layer of resin is then prepared in the support carriage. The support carriage is then moved to the exposure station. The glass plate is now registered above the carriage in the exposure station and is exposed to ultraviolet radiation. The areas of the resin under the transparent parts of the glass plate are cured. The areas under the black areas stay as uncured resin..

This stage is the followed by the carriage being moved to a wax application system where a layer of wax is coated over the solidified resin and the surrounding area. a cooling plate is then applied to help quickly solidify the wax.

A mechanical fly cutter then mills the structure to the correct layer thickness. This provides a flat surface for the next layer. The chips that cut are vacuumed away. All of these processes are done in separate stations and therefore the structure containing the part must be moved from station. As result of this the Solid Ground Curing process requires a full time operator. This is the only one of the rapid prototyping systems that requires a full time operator and when considering the cost of the process it is important that this factor is taken into account.

Estimating the cost of the process can be quite easy as the build time is the same for all layers no matter the size of the cross section. Therefore the cost can got by multiplying the amount of layers by the build time (not forgetting the cost of labour).

When the part is removed from the machine it is located in the block and the surrounding wax must be removed manually which can prove to be a difficult process.

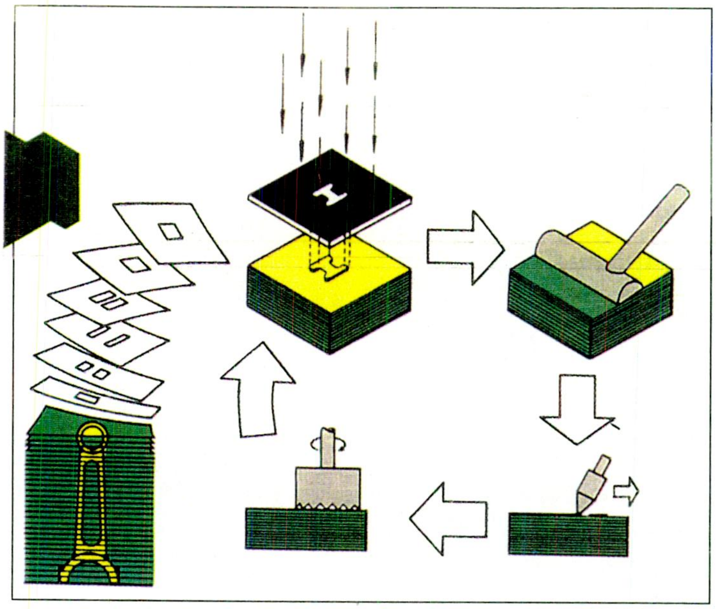


Fig. 18. Solid Ground Curing process.

Summary

From the descriptions of the processes some conclusions can be made. The objective of these conclusions is to show that of the RP systems that are available on the market today Stereolithogaphy offers the designer, manufacturer and the client the best option.

Of all the rapid prototyping systems it has been proven that Stereolithography is the most accurate. This is due to the research and development that has been done in hardware and materials. Michael McAulife replied as to why Pace Technology had chosen Stereolithography as their only source of RP because of the research that 3-D Systems had carried out in the area of RP and the possible developments that are available to Stereolithography.(McAulife,1997)

Parts from all of the systems need to be hand finished but Stereolithography is the best of the processes in the creation of fine details. LOM and FDM have had less success in producing fine details. A contributing factor in LOM's inability to produce fine details is that the part is embedded in a block of material and when this material is being removed it can damage the part. This also applies for SLS. The advantage in having the part being built in this way is that there is no need for supports which have to removed after the process is complete.

Solid Ground Curing has the least amount of advantages available as there is a full time operator needed to keep the machine working. This is not cost effective. Also it is the most complex of the RP processes and requires experience and skill. The other processes only require an operator at the start of the process. This offers the advantage of being able to operate overnight

or over weekends. Stereolithography is the fastest method of producing RP parts on the market at present.(Jacobs,1996,pg.19)

In dealing with the materials that are available for the different processes LOM offers the least amount, but the material used in the LOM process is perfect for sand casting. Resins associated with Stereolithography offer quite a range of properties including strength, durability and can offer other mechanical properties that can be used in the testing of the part.

There is a more in-depth comparison in the following chapter on Stereolithography and Selective Laser Sintering. From the research done for this thesis it was found that there is quite a lot of research and development being done in the area of SLS and with the improvements made in the materials technology it is becoming a reliable method of rapid prototyping.

CHAPTER 4.

Analysis of RP systems.

Applications.

The developments in materials used in rapid prototyping, especially in Stereolithography, have been a key factor in the expanding number of applications for the systems that could never been possible with earlier materials. While improvements have been made in the hardware used in rapid prototyping, the biggest improvements have been made in the materials used. Photopolymer resins in the Stereolithography process have proven to show the greatest improvements. These improvements have led to better dimensional accuracy and improved mechanical properties, Stereolithography has possibly got the largest range of applications.

The dimensional accuracy depends quite strongly on the performance of the resin. For example, systems with limited part accuracy can only be used to produce prototypes that can be used for concept visualisation only. Fit tests can not be done on parts with poor part accuracy. Also systems that produce parts with inferior materials with not exhibit the correct mechanical properties and therefore can not be used for direct functional testing. It is impossible to separate part accuracy and mechanical properties as they both depend on the material.

The applications for the rapid prototyping process will be very limited unless this is taken into account. Various tests carried out by 3-D Systems and the CARP Project have shown that Stereolithography and the resins associated with it make it suitable for such applications as medical, automotive, aerospace as well fit testing and exhibiting the required characteristics.

The developments in photopolymer resins can be summarised as follows:

-Reduced linear shrinkage, therefore better part accuracy.
-Increased overall accuracy.
-Improved flatness.
-Negligible curl.
-Low swell during build.
-Greater resistance to stress.
-Excellent mechanical properties.
-High success in part building the first time.

Future developments in Stereolithography resins continue to advance by improving electrical, optical, thermal and mechanical properties. With these the applications for Stereolithography are expanding.

EXAMPLES OF RP APPLICATIONS.

Medical applications.

With all the various applications for rapid prototyping parts the most extraordinary is the medical applications. The most popular RP system that is associated with these medical applications is Stereolithography because of it's part accuracy and the quality of the finish.

The Stereolithography process is used with Computer Assisted Tomography (CAT) scans and Magnetic Resonance Imaging (MRI) scans. Both of which produce high resolution images that can be sent to the system.

There are three potentially important areas in medicine that rapid prototyping can benefit:

1. Visualisation.

The models of the image, that are sent to the system, are used as a realistic representation for surgeons and doctors to help with therapy planning and diagnosis. The model serves as communication tool.

2. Simulation.

The physical models can be used for planning surgeries that might be complex , to help save time when in the operating theatre. The surgeons use the models for rehearsal. Examples of which will be given later in this chapter.

3. Prosthesis Generation.

Rapid prototyping helps prosthesis generation by providing an accurate model of the structure. This makes the prosthesis design much easier as the model serves as a replica on which the prosthesis part can be made around prior to the surgery.

There will come a time in the future when the implants will be made directly from the Stereolithography process along with the other types of rapid prototyping.

EXAMPLE 1.

This example involves a patient with Parry Romburg disease (see fig.19). A scan was taken of the patient's skull and a Stereolithography model was made of the skull identical to that of the patient. The main advantage was that the surgeon had a complete overview of what was going to happen during the surgery and could plan any bone displacements prior to the operation. The surgeon could also take all the necessary measurements from the skull. This would save alot of time chipping and fitting during the operation. The surgeon could also determine the fixation procedure.

While there were still a small amount of defects in the nasal and mouth region, the operation was deemed a success.

EXAMPLE 2.

This case study involved the University College of Dublin and Queen's University Belfast's venture, the Product Design and Development Centre. MRI scan information of a patient who had received a hole in their skull during an accident was sent from the hospital to the PDDC. The PDDC then made a model of the patient's skull using Stereolithography. The surgeons were then able to examine the skull and take all the necessary measurements. A titanium plate was built up around the model of the skull. then the plate was used in the patient's head. The use of the model saved critical time for the surgeons.

What makes Stereolithography such a good process for medical applications is that it provides an extremely accurate model which is a necessity in the field of medicine. Stereolithography is able to convert the information sent by the CAT scan or the MRI scan which provide accurate models of the bone structures and therefore this allows Stereolithography to produce an accurate physical model of the bone structures.

Surgical preplanning using rapid prototyping models offers the surgeon a rehearsal and allows them to plan the surgery and thus save time and money and improve the quality of the healthcare.

Benefits of RP in Engine Design and Development.

EXAMPLE 1.

This case study is based on the project undertaken by the Product Design and Development Centre the project was to develop a two stroke engine for a garden strimmer. The aim for the engine were that it was going

Fig. 19. Photograph of patient's forehead.

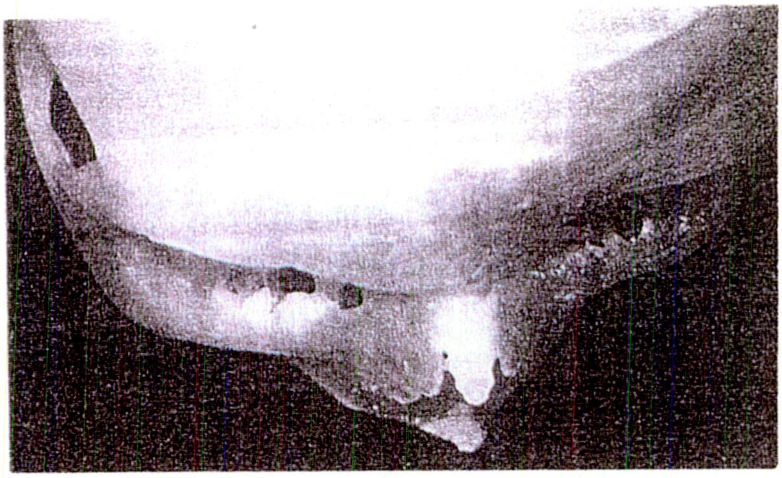


Fig. 20. MRI scan of patient's skull.

Fig. 21. Photograph of patient after the operation.

to be lightweight and that there would be a minimised emission from the exhaust.

Previously it would have taken weeks to work out the emission reductions etc., but the PDDC decided to use RP to produce a model of the part. Also mathematical models could have been used. The following are timescales from a report published by the PDDC showing the reduction in time by using rapid prototyping. Six models were produced by each method.

	Rapid Prototyping Route	CNC Route	CFD Route
1D Simulation	1	1	-
CAD modelling (CADDS5)	1	-	1
CAD modelling (DUCT)	-	1	-
CNC ducts	-	12	-
Port moulding	-	1	-
RP models	1.5	-	-
Scavenge optimisation process	6	6	-
CFD	-	-	25
TOTAL (Days)	9.5	21	26

Fig. 22. Table of results showing the times used by the different methods of modelling.

What these results show is that by using RP, the PDDC was able to produce the models five times faster than the CNC method. The reason for this is that the size models were able to be produced in one cycle using RP while only one model could be made at a time using the CNC method.

COMPARISON BETWEEN SLS AND STEREOLITHOGRAPHY.

It is vital that the user knows what they are looking for when choosing the method of RP. There are numerous factors to take into account when making this decision. It is important to make the decision on what machine is capable of and what the materials offer. Both Stereolithography and Selective Laser Sintering have their strengths and their weaknesses. The materials that on offer from SLS and Stereolithography are:

SLS - Composite nylon, fine nylon, polycarbinate, investment casting wax and TrueForm.
SLA - Epoxy resins.(TCT, 1996, pg.48)

There are a number of materials that one can choose from to give their prototype the required physical requirements. It is obvious that SLS offers the largest amount of materials and because of this offer the largest range of mechanical properties. Stereolithography, on the other hand, will only offer properties similar to that of thermoplastics. But Stereolithography offers greater accuracy in finishing fine details and geometry. The reason for this is that the resins used in the process have a very low shrinkage. Also the prototypes do not suffer from warpage, distortion or curl. Material properties are responsible for the largest trade-off between the processes. It is considered that the user should choose the process that offers the properties that are required by the user.

Stereolithography offers the best level of accuracy and is much greater than that of SLS. Stereolithography materials have a shrinkage of less than 0.4% while SLS has a shrinkage of 3-4%. (TCT,1996, pg.51)

It has also been shown that SLS parts are more dimensionally stable. Stereolithography parts continue to harden after the process. Therefore may differ depending on how soon after the part comes out of the RP machine. Also parts produced by Stereolithography are effected by heat, moisture and chemicals, while SLS parts do not swell when placed in water and can be exposed to heat and chemicals without exhibiting any distortion.

The fig. 23 shows Stereolithography offers an allround better surface finish. But this may differ depending on the amount of hand finishing. The reason for this is because in the SLS process, outlined in Chapter 3, the powdered particles bond together, giving the effect of a number of balls bunched together.

Parts from both of the processes can be machined, but parts from Stereolithography can chip or crack when being milled or drilled.

Because of the precise operation involved with the Stereolithography process The parts produced will produce better feature definition than the SLS process. A disadvantage that Stereolithography has in relation to the quality of the finished part is the need fro supports in the building of the part. Because these supports must be removed care must be taken not to damage the part. SLS parts come put of the process embedded in surrounding material and this acts as the support. The material can be easily removed.

	SLA Epoxy Resin	SLS Composite Nylon	Glass
Top Surface (unfinished)			
RMS Value (uin)	4	416	2
Peak Deviation (uin)	55	2235	35
Side Wall (unfinished)			
RMS Value (uin)	738	506	N/A
Peak Deviation (uin)	4510	3134	N/A
Side Wall (light sanding)			
RMS Value (uin)	176	206	N/A
Peak Deviation (uin)	1532	1493	N/A
Top Surface (sealed, light sanding)			
RMS Value (uin)	N/A	196	N/A
Peak Deviation (uin)	N/A	1351	N/A
Top Surface (sealed, wet sanding)			
RMS Value (uin)	N/A	59	N/A
Peak Deviation (uin)	N/A	554	N/A

Fig. 23. Results showing the difference in surface finishes.

Soft Tooling Applications

The role of the rapid prototyping model has changed from that of the early days. With the developments that have been made in the hardware RP parts are no longer just used for three-dimensional visualisation. Developments in resins have meant that the parts that are built are stronger than they were in the past. Because of this, as well as improved part accuracy, RP parts are being used directly for tooling applications, such as investment casting and sand casting. Patterns that are made by traditional toolmakers take weeks to produce but the normal turnout for rapid prototyping is a number of hours or days.

The moulds that are made from RP parts are used for soft tooling. Soft tools are used to produce a small quantity of components. Materials used for soft tooling relate to the term, they are silicone, rubber, epoxies etc.

While it has been said earlier that rapid prototyping models can and have been used as prototypes, sometimes it is necessary that the prototype must be made of the end-use material. If that material is a metal then it possible to use the rapid prototype part can be used for casting the metal prototype.

Because of the developments that have been done in Selective Laser Sintering and Stereolithography specifically in the area of casting the following outlines these developments and compares them.

Development of QuickCast

One of the major developments in the area of rapid prototyping was made in 1993 by 3D Systems. It was the introduction of QuickCast.

A number of the present applications of RP require functional metal prototypes which are needed at the early stage of development of the product for form, fit and functional testing. Previous to QuickCast metal parts would have been made CNC machining. This would have only been viable if one part was needed but if more parts were needed than sand casting or investment casting would have been necessary. This costs both in time and money.

Now there is a technology to save money and time, where a small number of functional metal components are needed. It is known as QuickCast it produces quasi-hollow patterns. There is no tooling needed. The QuickCast pattern is invested to form a ceramic shell coating. The QuickCast pattern is got rid of by flash firing and then molten metal is poured in. The result is a metal part that can be made in a number of alloys.

Stereolithography models are the most widely used models for investment casting. QuickCast is used as a direct replacement for investment casting. QuickCast moulds are reliable and repeatable. The robust nature of the QuickCast mould make it easy to transport. QuickCast patterns are far superior in robustness in comparison to conventional investment casting materials.

The biggest influence that rapid prototyping is having is in the area of manufacture. While RP parts are excellent for visualisation, the money and time savings that rapid prototyping can make in manufacturing are quite outstanding. It is believed that with the developments in RP that it will replace some of the manufacturing processes, especially in the area of soft tooling.

TrueForm.

After the development of 3-D Systems' QuickCast, DTM developed a way of producing patterns for soft tooling using Selective Laser Sintering. Initially the system used wax as the material for producing the part. Investment casting traditionally used wax for creating the patterns. The problem with using wax patterns form SLS was that the parts needed to be hand finished and as has been mentioned earlier the part would not be accurate enough to use as a pattern. To overcome this problem DTM

introduced polycarbinate into the SLS system. The polycarbinate is porous so it must be sealed prior to being dipped into the ceramic slurry.

It has been noted that there is distortion because of the burning out of the polycarbinate. There is also the possibility of polycarbinate soaking into the shell and causing delamination in the mould and therefore causing inaccuracies in the mould.

The burnout time for is longer than that for QuickCast. In the last couple of years DTM have developed a new material that is perfect for casting. This material is known as TrueForm. TrueForm offers the manufacturer good feature and detail definition and good part accuracy and is an excellent substitute for investment casting wax.

Rapid prototyping has had a big influence on investment casting. It possesses great advantages in that it can produce high quality patterns with reductions in time and costs. Also the pattern is being produced directly from the CAD data. Low casting costs make this RP application perfect for casting small numbers.

Because investment casting requires highly accurate parts it is vital that the rapid prototyping system produces the required quality. With the recent and continuing developments in the materials and hardware in both Stereolithography and Selective Laser Sintering machines, the patterns that are produced by these RP systems have the required accuracy and surface finish.

The results in fig. 24 were compiled from a series of tests done over a four year period by an American company, Sandia National Laboratories operated by Lockheed Martin Corporation for the US Department of Energy. The company is responsible for the design and manufacture of electrical and electromechanical prototypes. Therefore it is vital that the company operates in an efficient manner.(TCT, 1996,pg.62)

The purpose of the tests was to show which of the methods, QuickCast or TrueForm, could produce the most suited pattern for use in investment casting. There are differences between the QuickCast material and the TrueForm material. Firstly, there are higher temperatures needed to burnout the TrueForm polycarbinate material. This has been shown to cause inaccuracies in the mould. The tests that were carried out by Sandia showed that the SLS material tended to flow out of the mould in a manner very similar to traditional wax. This causes problems because the material may build in the areas were it is unable to flow out and thus attacking the ceramic mould.

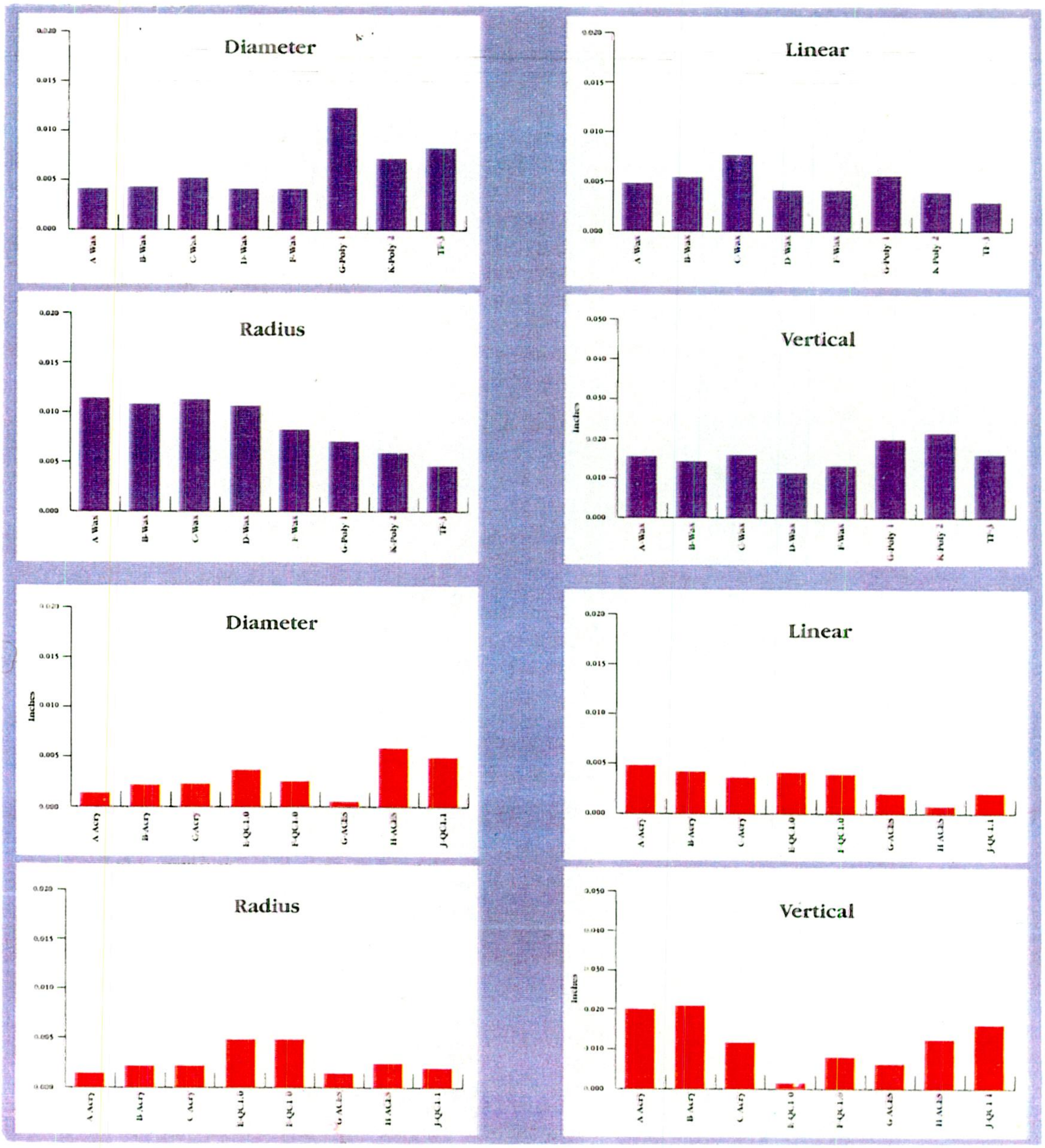


Fig. 24. Table showing the results of tests done comparing the accuracy of Stereolithography and Selective Laser Sintering.

An advantage that TrueForm has over QuickCast is that it does not need to be dipped before it is used.

A disadvantage in using these RP parts as patterns for moulds is that when the part is being sanded holes develop in the outer skin of the part. This is due to the fact that the interior of the part is not solid as mentioned before. These holes must be filled in and sealed before the part can be used for investment casting. Another disadvantage in using RP parts is that higher temperatures and pressures are needed for the QuickCast and TrueForm materials than the traditional investment wax. This can cause a ballooning effect which can crack the mould.

Summary

It is important also to know what the prototype is going to be used for. If it going to be used for a visual aid then the parts from Stereolithography are preferred as they have the best surface finish and can produce fine details without any problems.

If the part is to be used for functional testing then it is important to know what is required from the materials and their properties. SLS offers the more in this area and therefore would be better suited to testing functions than Stereolithography.

If the part is being used as tooling pattern then it is favoured that parts produced by Stereolithography are used. The mould will only be as good as the pattern used and Stereolithography offers better accuracy, surface finish and detail replication.

CONCLUSION.

The designers and engineers can hold examples of their concepts for early visualisation, verification, testing and analysing. This saves time in what previous to the development of rapid prototyping was a time and coat consuming process. The models can serve as a communication tool for simultaneous engineering. The engineer can examine the prototype and determine the best method of manufacture. They can determine if and where jigs, tools and fixtures are required. The prototype can also be used as a three-dimensional representation of a new product for clients and the marketing staff.

Rapid prototypes are very valuable for form and fit testing of components. this can solve problems that would otherwise only appear in the final product. The developments in the materials used in RP can offer the designer properties that very similar to those of the end product. As was discussed in the previous chapter, it is important to know what is required of the prototype and examine all methods to see which offers the desired characteristics.

It is not uncommon for toolmakers to use rapid prototypes to give more accurate quotations.

The models can used the design of packaging for new products.

It is now possible to produce metal components from QuickCast (Stereolithography), Fused Deposition Modelling, Laminated Object Manufacturing and Selective Laser Sintering. The components can then be used for further testing and analysing. With the improved accuracy of Stereolithography parts it is possible to use them to produce cores and cavities for the final manufacture of a product.

While it may be seen as a disadvantage that the systems are expensive to buy and run, the cost saving that a company will benefit from amount to much more.

If one where to ask what the main benefits were for rapid prototyping, the common answer would be that it is faster, cheaper and quality is excellent. Although these are just the tip of the iceberg they are very important . The financial savings for companies can vary between 40% and 80%. Myson Scanglo a Co. Limerick based company, make cast savings

of 75% by using Stereolithography. Also there is a huge time reduction in the development of the product, again anything from 30% to 80% with this available time companies can put more effort into testing and analysing as well as research. This allows designers and engineers to find weaknesses earlier and address them. More time and money can be spent in varying and experimenting with the design. also designs can be tested earlier by potential customers.

As has been pointed out in the final chapter there is no "best" method of rapid prototyping. Each method has it's advantages and disadvantages and a company thinking of investing in a rapid prototyping must know what they are looking for from the machine. It is also important, as was pointed out by Michael McAulife of Pace Technology, to examine the research and development that is being done into each of the systems and the possible improvements in each system. At present Stereolithography offers more in all these areas than any of it's competitors and hence it is the biggest selling rapid prototyping system in the world, leading the market by over 80%. There is no doubt that rapid prototyping and the developments that have followed are the biggest innovation I design and manufacturing that this decade has seen.

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