# UNIT V

## APPLICATION-MATERIAL RELATIONSHIP

Areas of applications are closely related to the purposes of prototyping and consequently the materials used. In case, the physical and behavioral characteristics of the RP materials are closer to the traditional prototyping materials, then applications range can be increased. Unfortunately, there are marked differences in these areas between current RP materials and traditional materials in manufacturing. The key to increasing the applicability of RP technologies therefore lies in widening the range of materials.

In the early development of RP systems, the emphasis was aimed towards the creation of "touch-and-feel" models to support the design i.e., creating 3D objects without regard to their function and performance. These are broadly classified as "Applications in Design'. It is the result that influenced, and in many cases limited by, the materials available on these RP systems.

However as the initial costs of the machines are high, vendors are constantly in search for more areas of applications i.e., functional evaluation and testing applications, and eventually tooling. This requires improvements in the RP technologies in terms of processes to create stronger and more accurate parts, and also in developing an even wider range of materials, including metals and ceramic composites.

Applications of RP prototypes were first extended to "Applications in Engineering, Analysis and Planning" and later extended further to "Applications in Manufacturing and Tooling". The major breakthrough of RP technologies in manufacturing is in enhancing and improving product development while at the same time reducing the costs and time required to take the product from conception to market.

**Rapid Prototype**

**Finishing Process**

- Machining: milling, lathe, boring, grinding, etc.
- Sand blasting
- Coating
- Polishing
- Painting (varnishing)

**Applications**

| *Design* | *Engineering, Analysis and Planning* | *Manufacturing and Tooling* |
|---|---|---|
| • CAD-model verification (design specification)<br>• Visualizing objects<br>• Proof of concept<br>• Marketing and presentation model | • Form and fit-models<br>• Flow analysis<br>• Analysis of stress distribution<br>• Pre-series parts<br>• Diagnostic and pre-surgical operation planning<br>• Design and fabrication of custom protheses and implants | • Tooling mold parts<br>— direct soft tools<br>— indirect soft tools<br>— direct hard tools<br>— indirect hard tools<br>• Casting<br>— sand-casting<br>— investment casting<br>— evaporative pattern casting<br>— die casting<br>• EDM electrodes<br>• Master models |

**Industries**

- Aerospace
- Automotive
- Biomedical
- Jewelry
- Coin
- Tableware
- Consumer electronics
- Home appliances
- etc.

**Figure 7.1:** Typical application areas of RP

## FINISHING PROCESSES

As there are various influencing factors such as shrinkage, distortion, curling and accessible surface smoothness, it is necessary to apply some post-RP finishing processes to the parts just after they have been produced. These processes can be carried out before the RP parts are used in their desired applications. Furthermore, additional processes may be necessary in specific cases, e.g., when creating screw threads.

### Cutting Processes

In most cases, the resins or other materials used in the RP systems can be subjected to traditional cutting processes, such as milling, boring, turning, and grinding. These processes are particularly useful for the following: (1) Deviations in geometrical measurements or tolerances due to unpredictable shrinkage during the curing or bonding stages of the RP process. (2) Incomplete generation of selected form features. This could be due to fine or complex-shaped features. (3) Clean removal of necessary support structures or other remainder materials attaching to the RP parts. In all these cases, it is possible to achieve economic surface finishing of the objects generated with a combination of NC machining and computer-aided NC programming.

### Sand-Blasting and Polishing

Sand blasting or abrasive jet deburring can be used as an additional cleaning operation or process to achieve better surface quality. However, there is a trade-off in terms of accuracy. Should better finishing be required, additional polishing by mechanical means with super-fine abrasives can also be used after sandblasting.

### Coating

Coating with appropriate surface coatings can be used to further improve the physical properties of the surface of plastic RP parts. One example is galvano-coating, a coating which provides very thin metallic layers to plastic RP parts.

### Painting

Painting is applied fairly easily on RP parts made of plastics or paper. It is carried out mainly to improve the aesthetic appeal or for presentation purposes, e.g., for marketing or advertising presentations.

## APPICATIONS IN DESIGN

### CAD Model Verification

This is the initial objective and strength of RP systems, in that designers often need the physical part to confirm the design that they have created in the CAD system. This is especially important for parts or products designed to fulfill aesthetic functions or that are intricately designed to fulfill functional requirements.

### Visualizing Objects

Designs created on CAD systems need to be communicated not only amongst designers within the same team, but also to other departments, like manufacturing, and marketing. Thus, there is a need to create objects from the CAD designs for visualization so that all these people will be referring to the same object in any communications.

### Proof of Concept

Proof of concept relates to the adaptation, of specific details to an object environment or aesthetic aspects (such as car telephone in a specific car), or of specific details of the design on the functional performance of a desired task or purpose.

### Marketing and Commercial Applications

Frequently, the marketing or commercial departments require a physical model for presentation and evaluation purposes, especially for assessment of the project as a whole. The mock-up or presentation model can even be used to produce promotional brochures and related materials for marketing and advertising even before the actual product becomes available.

## APPLICATIONS IN ENGINEERING, ANALYSIS AND PLANNING

Other than creating a physical model for visualization or proofing purposes, designers are also interested in the engineering aspects of their designs. This invariably relates to the functions of the design. RP technologies become important as they are able to provide the information necessary to ensure sound engineering and function of the product. What makes it more attractive is that it also save development time and reduce costs.

### Scaling

RP technology allows easy scaling down of the size of a model by scaling the original CAD model. In the case of designing bottles for perfumes with different holding capacities, the designer can simply scale the CAD model appropriately for the desired capacities and view the renderings on the CAD software. With the selected or preferred capacities determined, the CAD data can be changed accordingly to create the corresponding RP model for visualization and verification purposes.

### Form and FIT

Other than dealing with sizes and volumes, forms have to be considered from the aesthetics and functional standpoint as well. How a part fits into a design and its environment are important accepts, which have to be addressed.

For example, the wing mirror housing for a new car design has to have the form that augments well with the general appearance of the exterior design. This will also include how it fits to the car door. The model will be used to evaluate how it satisfies both aesthetic and functional requirements.

Form and fit models are used not just in the automotive industries. They can also be used for industries involved in aerospace and others like consumer electronic products and appliances

## Flow Analysis

Designs of components that are affected by air or fluid flow cannot be easily modified if produced by the traditional manufacturing routes. However, if the original 3D design data can be stored in a computer model, then any change of object data based on some specific tests can be realized with computer support. The flow dynamics of these products can be computer simulated with software. Experiments with 3D physical models are frequently required to study product performance in air and liquid flow. Such models can be easily built using RP technology. Modifications in design can be done on computer and rebuilt for re-testing very much faster than using traditional prototyping methods.

Flow analysis are also useful for studying the inner sections of inlet manifolds, exhaust pipes, replacement heart valves or similar product that at times can have rather complex internal geometries. Transparent parts can also be produced using rapid tooling methods to aid visualization of internal flow dynamics.

Flow analysis is necessary for products manufacturing in the aerospace, automotive, biomedical and shipbuilding industries

## Stress Analysis

In stress analysis using mechanical or photo-optical methods, physical replicas of the parts being analyzed are necessary. If the material properties or features of the generated objects are similar to those of the actual functional parts, they can be used in these analytical methods to determine the stress distribution of the product.

## Mock-Up Parts

These are used for final testing of different aspects of the parts. Generally, mock-up parts are assembled into the complete product and functionally tested at pre-defined conditions, e.g., for fatigue. Some RP techniques are able to generate “mock-up” very quickly to fulfill these functional tests before the design is finalized.

## Pre-Production Parts

In case of mass-production, once the prototype design has been tested and confirmed, pilot-production runs of ten or more parts will be started. The pilot-production parts are used to confirm tooling design and specifications. The necessary accessories such as fixtures, chucks, special tools and measurement devises required for the mass production process are prepared and checked. Many of the RP methods are able to quickly produce pilot-production parts, thus helping to shorten the process development time, thereby accelerating the overall time-to-market process.

## Diagnostic and Surgical Operation Planning

In combining engineering prototyping methodologies with surgical procedures, RP models can complement various imaging systems, such as magnetic resonance imaging (MRI) and computed tomography (CT) scanning, to produce anatomical models for diagnostic purposes. These RP models can also be used for surgical and reconstruction operation planning.

This is especially useful for procedures that have to be carried out by different teams of medical specialists and where inter-department communication is of essence.

## Design and Fabrication of Custom Prosthesis and Implant

RP can be applied to the design and fabrication of customized prostheses and implants. A prosthesis or implant can be made from anatomical data inputs from imaging systems, e.g., laser scanning and computed tomography (CT).

Ex: To produce ear prostheses, a scan profile can be taken of the good ear to create a computer-mirrored exact replica replacement using RP technology.

These models can further refine and processes to create the actual prostheses or implants to be used directly on a patient. The ability to efficiently customize and produce such prostheses and implants is important as standard sizes are not always an ideal fit to the patient. Also, if the prosthesis does not fit properly, especially for artificial joints and weight bearing implants, it often results in accumulation problems and damage to the surrounding tissue structures.

## APPLICATIONS IN MANUFACTURING AND TOOLING

Central to the theme of rapid tooling is the ability to produce multiple copies of a prototype with functional material properties in short lead times. Apart from mechanical properties, the material can also include functionalities such as color dyes, transparency, flexibility and the like. Two issues are to be addressed here: tooling proofs and process planning. Tooling proofs refer to getting the tooling right so that there will not be a need to do a tool change during production because of process problems. Process planning is meant for laying down the process plans for the manufacture as well as assembly of the product based on the prototypes produced.

Rapid tooling can be classified into soft or hard, and direct or indirect tooling.

- Soft tooling, typically made of silicon rubber, epoxy resins, low melting point alloys and foundry sands, generally allows for only single casts or for small batch production runs. Hard tooling, on the other hand, usually made from tool steels, generally allows for longer production runs.
- Direct tooling is referred to when the tool or die is created directly by the RP process. As an example in the case of injection molding, the main cavity and cores, runner, gating and ejection systems, can be produced directly using the RP process. In indirect tooling, on the other hand, only the master pattern is created using the RP process. A mold, made of silicon rubber, epoxy resin, low melting point metal, or ceramic, is then created from the master pattern.

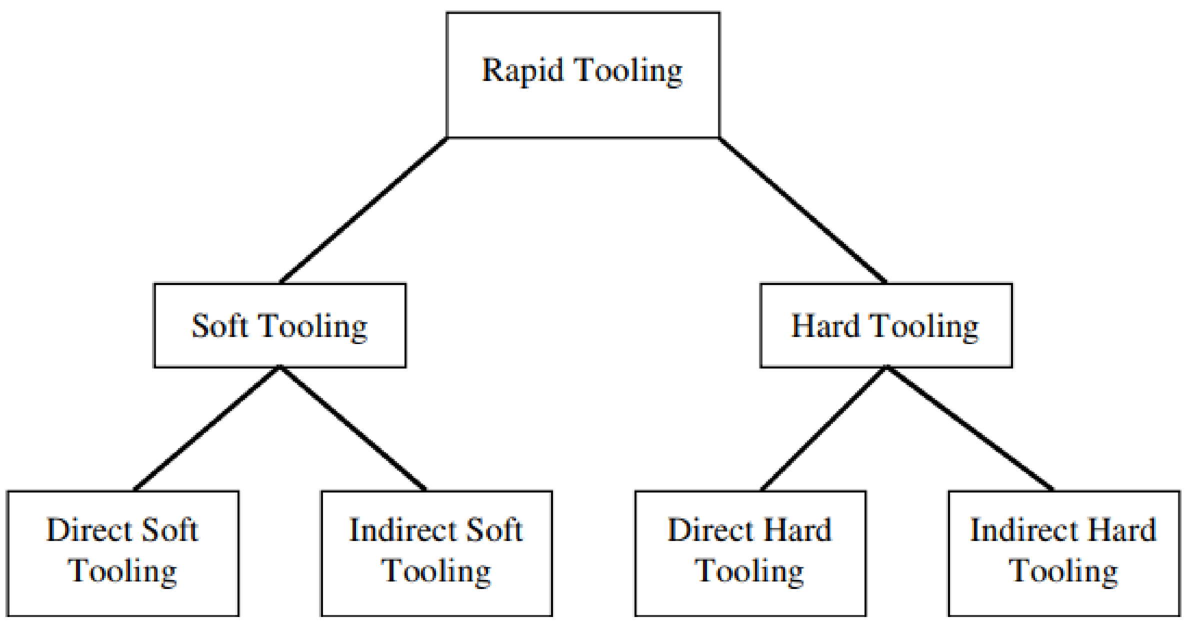


**Figure 7.3:** Classification of rapid tooling

## AEROSPACE INDUSTRY

There are abundant examples of the use of RP technology in the Aerospace industry. The following are a few examples.

**Design verification of an airline electrical generator**

**Case Study:** Sundstrand Aerospace, which manufactures electrical generators for military and commercial aircrafts, needed to verify its design of an integrated drive generator for a large jetliner. It decided to use LOM to create the design verification model.

The generator is made up of an external housing and about 1200 internal parts. Each half of the housing measures about 610 mm in diameter and 300 mm tall and has many intricate internal cavities into which the sub assemblies must fit. Such Complex designs are difficult to visualize from 2D drawings.

A physical model of the generator housing and many of its internal components is a good way to identify design problems before the expensive tooling process. But the time and cost involved in constructing the models by traditional means are prohibitive.

Thus Sundstrand decided to develop the physical model using RP technologies. Initial designs for the generator housing and internal sub-assemblies were completed on a CAD and parts are developed by LOM. Sundstrand assemble the various parts and examine them for form, fit and limit function. Clearances and interferences between the housing and the many sub assemblies were checked. After the initial inspection, several problematic areas were found which would have otherwise been missed. These were corrected and incorporated into the CAD design and in some cases new RP models were made.

Apart from design verification Sundstrand was able to use the physical models to help tool makers plan and design casting patterns. The models were also used for manufacturing process design, tool checking and assembly sequence design.

Though the approximate cost for the RP models was US $ 16 500, the savings realized from removing engineering and design changes were immeasurable and the time saved was significant.

**Engine Components for Fanjet Engine**

In an effort to reduce the development time of a new engine, AlliedSignal Aerospace used 3D Systems' QuickCast to produce a turbofan jet engine for a business aviation jet. Basically, RP is used for the generation of the casting pattern of an impeller of compressor shroud engine component. This part is the static component that provides the seal for the high-pressure compressor in the engine. Three different designs were required for testing the cold rig, hot rig and first engine.

Using QuickCast, the 3D Technology Center was able to directly produce patterns for investment castings using the stereolithography technology.The patterns produced were durable, had improved accuracy, good surface finish and were accurate enough that a design revision error in the assembly fixture was easily detected and corrected.

With the use of these RP technologies, production time was reduced by eight to ten weeks, and a savings of us $50000 for tooling in the three design iterations and realized.

**Prototyping Air Inlet Housing for Gas Turbine Engine**

Case Study: Sundstrand Power Systems, a manufacturer of auxiliary engines for military and commercial aircraft, needed prototypes of air inlet housing for a new gas turbine engine. It first needed mock-ups of the complex design, and also several fully functional prototypes to test on the development engines. The part, which measures about 250mm in height and 300 mm in diameter has wall thickness as thin as 1.5 mm. It would have been difficult and costly to build using traditional methods.

To realize the part, DTM's SLS system was chosen to build the evaluation models of the housing and then generate the necessary patterns for investment casting. The SLS system is chosen primarily because the air inlet housing has several overhanging structures from which removal of supports would have been extremely difficult.

Sundstrand designed several iterations of the housing as solid models on its CAD system. These models were converted to STL format and sent to build the nylon evaluation models. As the designs were finalized, new SLS versions of the part were created as tooling for investment casting. Polycarbonate patterns were created, sealed with wax and sent for casting.

The patterns were first coated with a thin layer of polyurethane to fill any remaining surface pores and provide the necessary surface finish. Then the patterns were used to cast the part in Inconel 718 steel.

In all, Sundstrand saved more than four months of tooling and prototyping time, and saved more than US$88000.

**Fabrication of Flight-Certified Production Castings**

Bell Helicopter has successfully used stereolithography, first to verify parts design, then to aid with fit and functional testing, and finally to produce investment casting patterns for the manufacturing of components. About 50 componenets that made up the new helicopter's flight control system were developed with stereolithography. The largest support structure for the hydraulic system, measured approximately 500mm*500mm*200mm, and the smallest, 25 mm*25mm*1.1mm.

In production, all parts will be made by investment casting process, most in aluminum while others will be in steel alloys. Initially, half-scale models were used for design verification, as they were large enough to confirm design intent and were much quicker to fabricate on the SLA machines. Once a design was finalized, full-size SLA models were fabricated for use in ‘Virtual Installation’.

In virtual installation, full-sized SLA parts were assembled with other components and installed on the actual production helicopter in order to test the fit and kinematics of the assembly. Problems associated with interferences and clearances were identified and rectified before they could arise in later stages. After virtual installation, Bell made ‘QuickCast’ investment casting patterns of each part and sent for casting.

By the use of RP technology, the overall development time was reduced to 6 months (originally 45 weeks) and also resulted in substantial cost savings and a better product.

## AUTOMOTIVE INDUSTRY

**Prototyping complex gearbox housing for design verification**

Volkswagen has utilized to speed up the development of a large complex gearbox housing for its cars. The CAD model for the housing was extremely complex and difficult to visualize. VW wanted to build a LOM part to check the design of the CAD model and then use the part for packaging studies.

Using traditional methods such a prototype would be costly and time consuming to build, and it may not be always possible to include all fine details of the design. Fabrication of the model based on drawings was often subjected to human interpretation and consequently is error prone.
All these difficulties were avoided by using RP technology as the fabrication of the model was based entirely on the CAD model created. The model was first used for verifying the design and subsequently to develop sand casting tooling for the creation of metal prototypes.

The RP process reduce the time for development of the prototype from 8 weeks to less than 2 weeks (8 to 10 days) and considerable time and cost savings were achieved.

**Prototyping Advanced Driver Control System with Stereolithography.**

Delco Electronics, the electronic subsidiary of the General Motors was involved in the development of the Maestro project. Maestro project designed to blend an advanced Audio System, a hands free cellular phone, GPS navigation, Radio Data System RDS information and climate control into a completely integrated driver control system. With many uniquely shaped push buttons, 2 active matrix LCD screens and a local area network (LAN) allowing for future expansion, the time needed to develop the system was the most critical factor.

Delco Electronics developed the first renderings and concept drawings for the Maestro project. In order to speed up the project, the designers needed the instrument panel with its myriad of push –buttons working early in the design cycle. Unfortunately, the large number of buttons meant a corresponding large number of rubber molds with all the problems associated with the conventional molding process. From the stylist's concepts, models for each button face were manually machined.

Once the designs were confirmed, the machined models were laser scanned, generating the CAD data needed for the creation of SLA models. The final prototype buttons needed to be accurate enough to ensure proper fit and function. The SLA models generated were accurate enough to be finished, painted and installed in the actual prototype vehicle, eliminating the need for rubber molds.

In less than 4 months, Delco was able to complete the functional instrument panel with all 108 buttons built using the SLA.

**Creating cast metal engine block with RP process**

As new engine design and development is an expensive and time consuming process, the ability to test a new engine and all its auxiliary components before connecting to tooling is important in ensuring cost and time savings. The Mercedes Benz division initiated a program of physical design verification and prototype engines using SLA parts for initial form and fit testing. After initial design reviews, metal components were produced rapidly using the 'QuickCast' process.

Their first project was the design and prototyping of a 4 cylinder engine block for the new Mercedes Benz car. The aim was to cast the engine block directly from stereolithography QuickCast pattern. The engine block was designed on CAD system and from this data, the one piece pattern of the block was built on the SLA machine. The full scale investment casting pattern was generated in 96 hours. The pattern was then sent for shell investment casting of the engine block being cast in just 5 weeks.

The entire prototyping process using RP technology lasted only 6 weeks compared to 15 to 18 weeks using traditional methods and the approximate cost savings US $150000 as compared with traditional methods.

**Using stereolithography to produce production tooling**

Ford motor company has used 3D systems QuickCast to create the production tool of a rear wiper motor cover. The part was to be injection molded with polypropylene during production. Traditional methods would have provided the necessary tools for molding in 3 months.

Ford first built the SLA model of the cover and fit it over the wiper motor to verify the design. Dimensional and assembly problems were identified and rectified before the design was confirmed.

Initially CAD model is developed and created negative mould halves. The QuickCast process was then used to build the patterns of the actual tool inserts. They were then investment cast out in tool steel. Once cast, the tool inserts would be fitted on to an injection molding machine and used to produce the plastic wiper motor covers.

With the application of such rapid tooling techniques, Ford was able to start durability and water flow testing 18 months ahead of schedule with cost reduction of 45% and time savings of more than 40%.

## ELECTRONIC INDUSTRY:

Wherever electricity or heat is flowing, you will typically require a high-performance heat exchanger. Industrial 3D printing is extremely promising for the manufacturing this kind of temperature management part. It allows you to surpass heat transfer limitations and enables very complex geometries and larger surfaces to be realized. Resulting in highly efficient heat transfer with minimal space usage. Additionally, the process is ideal for manufacturing particularly light components within a cost-effective framework.

## JEWELRY INDUSTRY:

The jewelry industry has traditionally been regarded as one which is heavily craft-based, and automation is generally restricted to the use of machines in the various individual stages of jewelry manufacturing. The use of RP technology in jewelry design and manufacture offers a significant breakthrough in this industry.

SLA (from 3D Systems) was used successfully to create fine jewelry models. These were used as master patterns to create the rubber molds for making wax patters that were later used in investment casting of the precious metal end product.

In an experiment with the design of rings, the overall quality of the SLA models were found to be promising, especially in the generation of intricate details in the design. Though post-processing of SLA models is necessary in the manufacture of jewelry, the ability to create models quickly (a few hours compared to days or even weeks, depending on the complexity of the design) and its suitability for use in the manufacturing process offer great promise in improving design and manufacture in the jewelry industry.

## COIN INDUSTRY:

Similar to the jewelry industry, the mint industry has traditionally been regarded as very labor-intensive and craft-based. It relies primarily on the skills of trained craftsmen in generating the “embossed” or relief designs on coins and other related products.

In one of coin manufacturing system, the SLA was used successfully with a Relief Creation Software to create tools for coin manufacture. In the system involved RP technology, its working methodology consists of following steps:

1. 2D artwork is read into ArtCAM, the CAD/CAM software used in the system, utilizing a Sharp scanner. In the ArtCAM environment, the scanned image is reduced from a color image to a monochrome image.  Alternatively, the number of colors in the image can be reduced.
2. Generation of surfaces--- The shape of a coin is generated to the required size in the CAD system for model building. A triangular mesh file is produced automatically from the 3D model.
3. Generation of the relief---- In creating the 3D relief, each color in the image is assigned a shape profile. The relief detail generated can be examined in a dynamic Graphic Window within the ArtCAM environment itself.
4. Wrapping of the three dimensional relief onto the coin surface. This is done by wrapping the three dimensional relief onto the triangular mesh file generated from the coin surfaces. The wrapped relief is also converted into triangular mesh files. The triangular mesh files can be used to produce a 3D model suitable for color shading and machining. The two sets of triangular mesh files, of the relief and the coin shape, are automatically combined. The resultant model file can be color-shaded and used by the SLA to build the prototype.
5. Convert the triangular mesh files into the STL file format. This is to be used for building the RP model. After the conversion, the STL file is sent to the SLA to create the 3D coin pattern which will be used for proofing of design.

## Global Inkjet Systems (GIS) APPLICATIONS:-

GIS is the global leader in developing tailored software and system components for industrial markets, with over 12 years of proven innovation in the field. GIS technology is production capable and designed to work reliably in 24/7 rugged industrial settings for key industrial printing applications such as product decoration, labels, textiles, packaging, décor, 3D printing and materials deposition.

## TABLEWARE INDUSTRY

In tableware industry, CAD and RP technologies are used in an integrated system to create better designs in a faster and more accurate manner. The general methodology used is similar to that used in the jewelry and coin industries.

Additional computer tools with special programs developed to adapt decorative patterns to different variations of size and shape of tableware are needed for this particular industry. Also a method for generating motifs along a circular arc is also developed to supplement the capability of such a system.

The general steps involved in the art to part process for the tableware include the following:

(1) Scanning of the 2D artwork.

(2) Generation of surfaces.

(3) Generation of 3D decoration reliefs.

(4) Wrapping of reliefs on surfaces.

(5) Converting triangular mesh files to STL file.

(6) Building of model by the RP system.

Two RP systems are selected for experimentation in the tableware system. One is SLA and the other is LOM.

The SLA has the advantage of being a pioneer and a proven technology with many excellent case studies available. It is also advantageous to use in tableware design as the material is translucent thus allowing designers to view the internal structure and details of tableware items like tea pots and gravy bowls.

On the other hand, the use of LOM has its own distinct advantages. Its material cost is much lower and because it does not need support in its process. It saves a lot of time in both pre-processing and post-processing.

In an evaluation test of making the dinner plate prototype, it was found that the LOM prototype is able to recreate the floral details more accurately. The dimensional accuracy is slightly better in the LOM prototype.

In terms of the build time, including pre- and post- processing, the SLA is about 20% faster than the LOM process. However, with sanding and varnishing, the LOM prototype is found to be a better model which can be used later to create the plaster of Paris molds for the molding of the ceramic tableware.

Apart from these technical issues, the initial investment, operating and maintenance costs of the SLA are considerably higher than that of the LOM, estimated to be about 50% to 100% more.

In the ceramic tableware production process, the LOM model can be used directly as a master pattern to produce the block mold. The mold is made directly as a master pattern to produce the block mold. The mold is made of plaster of Paris. Any slight imperfections, left after hand finishing the LOM model, are reproduced in the block mold and pieces cast from these molds.

Whichever RP technology is adopted, such a system saves time in designing and developing tableware, particularly in building a physical prototype. It can also improve designs by simply amending the CAD model and the overall system is easy and friendly to use.

## BIOMEDICAL INDUSTRY

From manufacturing of medical devices and creating customized implants and prostheses to surgical planning and education, RP can be applied to enhance medical appliances and health care delivery.

### Operation Planning for Cancerous Brain Tumor Surgery

In one case study, a patient had a cancerous bone tumor in his temple area and because of that the surgeon would have to access the growth via the front through the right eye socket. The operation was highly dangerous as damage to the brain was likely which would result in the impairment of some motor functions. In any way, the patient would have last the function of the right eye. However, before proceeding with the surgery, the surgeon wanted another examination of the tumor location, but this time a three dimensional plastic replica of the patient's skull.

By studying the model, the surgeon realized that he could re-route his entry through the patient's jawbone, thus avoiding the risk of harming the eye and motor functions. Eventually, the patient lost only one tooth and of course, the tumor.

The plastic RP model used by the surgeon was fabricated by the SLA from a series of 2D CT scans of the patient's skull. This case study is an excellent example of the potential impact of rapid prototyping in the medical arena.

Other case studies relating to bone tumors have also been reported to have had successful results. In all the cases, not only was the patient spared physical disability and the emotional and financial price tags associated with that, but the surgeon gain an invaluable insight into his patient through the RP model. The value added to the surgeon's pre-surgical planning stage resulted also in a reduced duration of the procedure and thus the risk of infection and operation costs.

**Planning Reconstruction surgery with RP Technology**

Due to an accident, a patient has a serious bone fracture on the upper and lateral orbital rim in the skull. In the first reconstructive surgery, the damaged part of the skull was transplanted with the shoulder bone, but shortly after the surgery, the transplanted bone had dissolved. Thus, it was necessary to perform another surgery to transplant an artificial bone that would not dissolve.

The conventional procedure of such a surgery would be for surgeons to manually carve the transplanted bone during the operation until it fitted properly. This operation would have required a lot of time, due to the difficulty in carving bone, let alone during the surgery.

Using rapid prototyping, a SLA prototype of the patient's skull was made and then used to prepare an artificial bone that would fit the hole caused by the dissolution. This preparation not only greatly reduced the time required for the surgery, but also improved its accuracy.

In another case involved at Keio University Hospital of Japan, a five-month-old baby had a symptom of scaphocephary in the skull. This is a condition that may lead to serious brain damage because it would only permit the skull to grow in the front and rear directions. The procedure required was to take the upper half of the skull apart and reconstruct it completely, so that the skull would not suppress the brain as the baby grows.

Careful planning was essential for the success of such a complex operation. Firstly, the prototype of the skull was produced and amputation lines were drawn on the model. Secondly, a surgical rehearsal was first carried out on the mold with the amputation of the skull prototype according to the drawn lines followed by the reconstruction of the amputated part. In this case, the rapid prototype of the skull provided the surgical procedure with:

(1) a good three-dimensional visualization support for the planning process,

(2) an application as training material, and

(3) a guide for the real surgery.

### Craniofacial Reconstruction Surgery Planning

Restoration of facial anatomy is required in case of congenital abnormalities, trauma or post cancer reconstruction. In one case, the patient had a deformed jaw by birth, and a surgical operation was necessary to amputate the shorter side of the jaw and change the position. The difficult part of the operation was the evasion of the nerve canal that runs inside the jawbone. Such an operation was impossible in the conventional procedure because there was no way to visualize the inner canal.

Using CAD model reconstructed from the CT images, it clearly showed the position of the canal and simulation of the amputating process on workstations was a good support for surgeons to determine the actual amputation line. Furthermore, the use of a resin prototype of the jawbone allowed the visualization of the internal nerve canal. The semi-transparent prototype facilitated the determination of the amputation line and enabled an efficient surgery simulation with an actual tool.

### Biopsy Needle Housing

Biomedical applications are extended beyond design and planning purposes. The prototyping can serve as a master for tooling such as a urethane mold.

Baxter Healthcare, a disposable-medical-products company, uses SLA and SGC to create master models from which they develop metal castings. The masters also serve as a basis for multiple sub-tooling processes.

For example, after a master model has been generated via one of the RP machines, the engineers might build a urethane mold around it, cut open the mold, pull out the master, and then inject thermoset material into the mold to make the prototype parts.

This process is useful in situations where multiple prototypes are necessary because the engineers can either reuse the rubber molds or make many molds using the same master. The prototypes are then delivered to customer focus groups and medical conferences for professional feedback. Design changes are then incorporated into the master CAD database. Once the design is finalized, the master database is used for machining of the part.

Using this method, Baxter Healthcare has made models of biopsy needle housing and many other medical products.

### Knee Implants

DePuy Inc., a supplier of orthopedic implants, has integrated CAD and RP into their design environment, using it to analyze the potential fit of implants in a specific patient and then modifying the implant design approximately.

SLA plays a major role in the production process. The prototypes are also used as masters for casting patterns to launch a product or to clinical releases of a product.

For this application, there are several advantages over traditional casting tooling. Firstly, the typical ten-week lead-time is reduced. Secondly, the cost of about US$8000 to US$10000 is reduced too.

**Scaffolds for Tissue Engineering**

Tissue engineering has been used to replace failing or malfunctioning organs such as skin, liver, pancreas, heart valve leaflets, ligaments, cartilage and bone. This has given rise to the interest in applying RP techniques to build scaffolds either to induce surrounding tissue and cell in growth or serve as temporary scaffolds for transplanted cells to attach and grow on to. These scaffolds can be designed in 3D on CAD taking into consideration the porosity and good interconnectivity for tissue induction to occur. RP has been able to lend itself to producing complex geometry scaffolds.

**Customised Tracheobronchial stents**

Stents for maintaining the patency of the respiratory channel has been investigated for production using RP techniques. Customization of these stents can be carried out to take into account compressive resistance with respect to stent wall thickness as well as unique anatomical considerations. Measurements are taken of the actual forces required to open the airway channel to its original dimensions. The data is fed to the CAD system where modification on the stent design is carried out. Upon conformation, the 3D data is fed to an RP system where the master pattern of the model is built. The master pattern then undergoes the silicone molding vacuum casting process reproducing the stent master pattern with a biocompatible material.

**Inter vertebral spacers**

Human spinal vertebrae can disintegrate due to conditions such as osteoporosis or extreme forces acting on the spine. In the management of such situations spacer is usually required as part of the spinal fixation process.

RP has been investigated for the production of such spacers as it is an ideal process to fabricate 3D structures with good interconnecting pose for the promotion of tissue in growth.

Other considerations for producing such an implant are that the material is biocompatible and that the mechanical compressive strength of the spacer is able to withstand spinal loads. A process developed for such a purpose uses a solid RP master pattern of the spacer to produce a soft mould.

Stainless steel bearings coated with a formulated binder system are then cast into the soft mould under vacuum. Up on curing the park is ejected from the mould. The part then undergoes the binding and sintering process to produce the final part. The primary advantage of this process is its ability to use a solid RP pattern to produce from this a porous structure with controllable for sizes and mechanical strengths.

**Cranium Implant**

A patient suffered from a large frontal cranium defect after complications from a previous meningioma tumor surgery. This left the patient with a missing cranial section, which caused the geometry of the head to look deformed. Conventionally, a titanium-mesh plate would be hand formed during the operation by the surgeon. This often resulted in inaccuracies and time spent for trial and error.

Using RP, a computed tomography (CT) scan of the affected area and surrounding regions was taken during the pre operation stage. The 3D CT data file was transferred to a CAD system and the missing section of the cranium topography was generated. After some software repair on the newly generated section, an inverted mold was produced on CAD. This 3D solid model of the mold was saved STL format and transferred to the RP system (SLS) for building the mold.

The SLS mold was produced and used to mechanically press the titanium mesh plate to the required 3D profile of the missing cranium section. During the operation, the surgeon cleared the scalp tissue of the defect area and fixed the plate onto the cranium using self tapping screws. The scalp tissue was then replaced and sutured.

At post-operation recovery, results observed showed improved surgical results, reduced operation time and a reduce probability of complications.

## 3D PRINTING IN FORENSIC SCIENCE

The potential applications for 3D printed reconstructions in forensic science are numerous. Replicas could be utilized across the forensic science process: in crime scenes, in intelligence gathering, analysis and interpretation of materials, in police investigations, and in courtroom presentation of evidence. Furthermore, 3D replicas could be beneficial in forensic science teaching and public outreach programs. In order for 3D printing to be utilized in forensic science, particularly in courts of law, the discipline needs a recognizable evidence-base that underpins its reliability and applicability.
(https://onlinelibrary.wiley.com/doi/full/10.1111/1556-4029.14442)

## BIOLOGICAL ANTHROPOLOGY

Biological anthropology using RP first require making a digital replica of an item that already physically exists, such as a skull, and then reproducing it using the RP technology.. This process is known in the industrial world as reverse engineering. There are several different ways data can be acquired to produce the output for the RP process following a reverse engineering approach. Two of the most common methods for studies in biological anthropology are laser surface scanning and X-ray computed tomography (CT) scanning.

## BIOPRINTING

Rapidly growing application of AM is bioprinting, which allows for the seeding of cells in a spatially defined manner in 3D space . This enables the production of in vitro models for drug screening and disease modeling as well as biofabrication of implantable tissues such as skin, cartilage or bone.

## 3D PRINTING IN DISASTER MANAGEMENT

3D printing can have a positive impact on the environment: it reduces manufacturing waste, lowers the carbon footprint and supports the circular economy. For another, the range of printable materials has increased significantly (plastic, carbon fiber, resin, metal, and even human flesh)

## 3D PRINTING IN THE SPORTS AND FITNESS INDUSTRY

Within the sports and fitness industry, 3D printing has a rapidly growing range of applications. Many top sports manufacturers have seen 3D printing's potential and are beginning to harness it to their advantage. On the cutting edge, Nike, New Balance, Adidas, and Reebok have all been experimenting with this technology's potential within the footwear subindustry.

## APPLICATIONS OF 3D PRINTING IN THE MOVIE INDUSTRY

While special effects have become commonplace in cinema, it seems that additive manufacturing is also making its way into the bright lights. Hollywood is increasingly using 3D technologies to create costumes, props, and all sorts of objects to make their films even more realistic.

https://www.3dnatives.com/en/top-applications-3d-printing-movie-industry-090720214/#!