

NOVEL RAPID TECHNOLOGY APPROACH USED IN DENTAL MEDICINE

НОВ НАЧИН ЗА БЪРЗА ТЕХНОЛОГИЈА, ИЗПОЛЗВАН В ДЕНТАЛНАТА МЕДИЦИНА

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Abstract: *The main idea of this article is to give some recent rapid prototyping views as a modern additive manufacturing process, to explain and eliminate the confusion over terminology, design, materials and processing differences of that. In the distant future it is evident that, there is no doubt, computers will be used to automatically manufacture objects, products and systems of every description and kind with no limit to material and geometrical complexity. The inputs to these fabrication systems will simply be raw materials and usually CAD data. This technology will be reminiscent of desktop publishing - but instead of documents and printed matter, the diverse products that we need or desire to use in our lives will be manufactured for us on the spot. In the future, we'll also be able to efficiently make complex things in small volumes without tooling. Through a good collaborative effort between the Society of Manufacturing Engineers SME and ASTM International, additive manufacturing gets its first standards for the industry issued in 2010.*

Keywords: RAPID PROTOTYPING, ADDITIVE MANUFACTURING, FREEFORM FABRICATION, LAYERED MANUFACTURING

1. Introduction

Rapid prototyping is the name given to a host of related technologies that are used to fabricate physical objects directly from CAD data sources [1]. Rapid prototyping means many things i.e. to explore the process of conceptual modeling, functional prototyping, and manufacturing tools to end-use parts. It is very useful to know how additive fabrication systems such as 3D printers, rapid prototyping systems, and direct digital manufacturing systems are changing future product development and manufacturing. These methods are unique in that they add and bond materials in layers to form objects. Such systems are also known by the names additive fabrication, three dimensional printing, solid freeform fabrication and layered manufacturing. Some, not all, characteristics of the process can be mentioned as:

- Objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly;
- Objects can be made from multiple materials, or as composites, or materials can even be varied in a controlled fashion at any location in an object;
- Additive fabrication systems reduce the construction of complex objects to a manageable, straightforward, and relatively fast process.

These properties have resulted in their wide use as a way to reduce time to market in manufacturing. Today's systems are heavily used by engineers to better understand and communicate their product designs as well as to make rapid tooling to manufacture those products. Surgeons, architects, artists and individuals from many other disciplines also routinely use the technology.

The names of specific processes themselves are also often used as synonyms for the entire field of rapid prototyping [2]. Among these are stereolithography (SLA for stereolithography apparatus) shown on figure 1, selective laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM), inkjet-based systems and three dimensional printing (3DP).

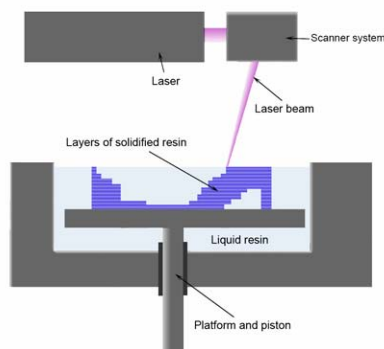


fig. 1. stereolithography apparatus

Each of these technologies - and the many other rapid prototyping processes - has its singular strengths and weaknesses. They offer advantages in many applications compared to classical subtractive fabrication methods such as milling or turning.

On a corporate level, the benefit of rapid prototyping is that it is instrumental in slashing time-to-market while protecting product quality. The bottom line is increased market share and revenue. The obvious benefit of rapid prototyping is speed. However, working closely with product development professionals, the companies have found that the real value of the rapid prototype is that it quickly delivers a better design communication tool.

The "real", physical prototype quickly and clearly communicates all aspects of a design [2]. Eliminating ambiguity, rapid prototyping facilitates the early detection and correction of design flaws.

In its simplest form, the benefit of rapid prototyping is confidence in the integrity of the design. This confidence is best expressed as the peace-of-mind that results from a design that is completed on time and correctly. Furthermore, rapid prototyping techniques can deliver parts in spec resins and spec alloys that allow for real world testing, bridge to production and short run production.

The terminology that is used to describe the many technologies and applications of additive fabrication is extremely confusing. The purpose of this article is to provide a roadmap and enough etymological history to show the relationships. There are many additional terms and technologies which aren't referenced here in the article.

2. Process cycle description

Several different additive fabrication processes are commercially available or are currently being developed [2]. Each process may use different materials and different techniques for building the layers of a part. However, each process employs the same basic steps, listed below.

- **Create CAD model** - For all additive processes, the designer must first use Computer-Aided Design (CAD) software to create a 3-D model of the part.

- **Convert CAD model into STL model** - Each form of CAD software saves the geometric data representing the 3-D model in different ways. However, the STL format (initially developed for Stereolithography) has become the standard file format for additive processes. Therefore, CAD files must be converted to this file format. The STL format represents the surfaces of the 3-D model as a set of triangles, storing the coordinates for the vertices and normal directions for each triangle.

- **Slice STL model into layers** - Using specialized software, the user prepares the STL file to be built, first designating the location and orientation of the part in the machine. Part orientation impacts several parameters, including build time, part strength, and accuracy. The software then slices the STL model into very thin layers along the X-Y plane. Each layer will be built upon the

previous layer, moving upward in the Z direction.

- *Build part one layer at a time* - The machine builds the part from the STL model by sequentially forming layers of material on top of previously formed layers. The technique used to build each layer differs greatly amongst the additive process, as does the material being used. Additive processes can use paper, polymers, powdered metals, or metal composites, depending upon the process.

- *Post-processing of part* - After being built, the part and any supports are removed from the machine. If the part was fabricated from a photosensitive material, it must be cured to attain full strength. Minor cleaning and surface finishing, such as sanding, coating, or painting, can be performed to improve the part's appearance and durability. The rapid prototyping process is shown on figure 2.

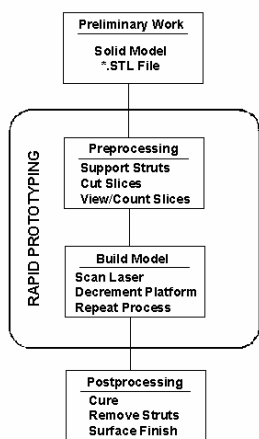


fig. 2. the rapid prototyping process

3. Prototype manufacturing technology

Additive fabrication refers to a class of manufacturing processes, in which a part is built by adding layers of material upon one another [2]. These processes are inherently different from subtractive processes or consolidation processes. Subtractive processes, such as milling, turning, or drilling, use carefully planned tool movements to cut away material from a workpiece to form the desired part. Consolidation processes, such as casting or molding, use custom designed tooling to solidify material into the desired shape. Additive processes, on the other hand, do not require custom tooling or planned tool movements. Instead, the part is constructed directly from a digital 3-D model created through Computer Aided Design (CAD) software. The 3-D CAD model is converted into many thin layers and the manufacturing equipment uses this geometric data to build each layer sequentially until the part is completed. Due to this approach, additive fabrication is often referred to as layered manufacturing, direct digital manufacturing, or solid freeform fabrication.

The most common term for additive fabrication is rapid prototyping. The term "rapid" is used because additive processes are performed much faster than conventional manufacturing processes. The fabrication of a single part may only take a couple hours, or can take a few days depending on the part size and the process. However, processes that require custom tooling, such as a mold, to be designed and built may require several weeks. Subtractive processes, such as machining, can offer more comparable production times, but those times can increase substantially for highly complex parts. The term "prototyping" is used because these additive processes were initially used solely to fabricate prototypes. However, with the improvement of additive technologies, these processes are becoming increasingly capable of high-volume production manufacturing, as will be explored in the section on applications.

Started out nearly twenty years ago, the process being called "rapid prototyping" (RP). At the time, that was fairly descriptive of what it did. Early machines were used to make things that represented the general physical shape of some final part or other items. Since these parts or objects didn't have the material

properties nor probably the accuracy that were required for actual use, they were just prototypes – examples. The next step of the process would find the corrections added. Maybe another prototype was made, possibly even many - but also maybe not. One prototype might be all that was required. Seeing and feeling something in the approximate form it would ultimately take turns out to be a very good way of short-circuiting the process of going from an idea on paper or a screen, to making something that actually works.

This was one reason why the process of design became faster and put the rapid in "rapid prototyping," but it wasn't the only one. Instead of having to cut a material away to sculpt a part, we could just give a computer file to the machine and it could spit out even a very complicated part fairly quickly. Quickly is relative: Sometimes it took days to make a part, and often it still does. But it might take much longer to make the same thing by cutting material away using subtractive fabrication. So these additive processes were rapid in comparison to that, and that made for another reason to call them "rapid."

4. Recognize of rapid prototyping

Of course, whoever started using the term "rapid prototyping" for these additive fabrication technologies twenty years ago, either didn't know, or didn't care, that others in completely unrelated fields were using it, as well [1,2]. Some computer programming techniques are called rapid prototyping, as are ways to quickly generate web-sites. Individuals designing advanced control systems for aircraft and similar applications sometimes describe the process as rapid prototyping. Biologists rapid prototype microfluidic systems using a variety of methods such as stamp lithography. Sometimes it isn't easy to tell who's doing rapid prototyping and who's doing additive fabrication.

For example, the name of one technology in particular - stereolithography - is sometimes used as a synonym for "rapid prototyping." A manufacturer of stereolithography equipment might like this a lot. If prospects think rapid prototyping is stereolithography - even though that's only one flavor of additive fabrication - that might be advantageous. This usage seems most prevalent among individuals that are learning about the field for the first time, however.

Along the way "rapid prototyping" has been called by several additional pet names provided by corporations, writers and the academic community. Here are some that we can meet from time to time:

- Desktop manufacturing (DTM) - This was an early term and from which one of the early companies in the field derived its name (DTM, Inc.), [3-6]. Unfortunately, the only "desk" that one of these machines in the early days could have fit on was something like a Nimitz-class aircraft carrier. Only in recent years have any additive fabrication machines been able to fit on anything resembling furniture. There will very likely always be additive fabrication machines that won't fit on desks limiting the generality of the term. DTM doesn't come up often, but it still appears once in a while.

- Solid freeform fabrication (SFF)/freeform fabrication (FFF) - The academic community likes these very much. However, the words don't sing and are too much of a mouthful to lead to great popularity. Nevertheless, they're often used in academic papers and patents, and aren't going to go away soon.

- Solid imaging / solid imager - 3D Systems and some Japanese companies have used these terms, often applying them specifically to stereolithography, but sometimes meaning the entire field. Solid imaging seems to have fallen by the wayside in recent years, but is still seen once in a while.

- Layered manufacturing / layered fabrication - All of the commercial systems do indeed operate by making layers and bonding them - some thicker, some thinner. But additive fabrication systems need not do so by definition. There are other ways to add materials together to make things that have been described in the literature. For example, one could build an object in a cylindrical fashion. It's not likely that other such geometries will be of much commercial interest soon, so layered fabrication is not so bad. The term seems mostly to come up in trade magazines when writers are

explaining the field to an unfamiliar audience.

- New capabilities, but old terminology - the next thing that inevitably happened was that materials and accuracy improved, so rapid prototyping could be used to make functional parts, as well as ones we just looked at. Now, not only was rapid prototyping not very rapid - it wasn't necessarily making prototypes either. There are, however, such things as functional prototypes, and even though some parts may have been used in final applications, "rapid prototyping" still wasn't a complete misnomer at this point.

- Lower prices, but new terminology - some rapid prototyping machines could still not make functional parts and these were called "concept modelers" once others machines could. These technologies were only appropriate for the original application of rapid prototyping, to check the form of something. The term remained current for a few years, and is still seen once in a while. So, some additive fabrication machines got much less expensive. To differentiate this segment of the market from more costly machines, people started calling these machines "3D printers" or "three dimensional printers." Now, there already was a specific technology with a very similar name called Three Dimensional Printing (3DP) (TM) which had been developed and trademarked by MIT. One of its licensees, Z Corporation, actually makes 3D printers using Three Dimensional Printing (TM) technology. But other manufacturers make 3D printers using other technologies. For example, Stratasys makes 3D printers using fused deposition modeling (FDM). Surely, there must be some additional difference between 3D printers and rapid prototyping machines- no, till now, just the price and maybe some specifications. The specifications keep getting better for so-called 3D printers and their prices keep getting lower. So if we base a distinction in terminology on those features today, there's a good chance that we will be wrong, maybe tomorrow.

5. Process of rapid tooling and manufacturing

Rapid prototyping started out by making parts mostly out of plastic in one form or another [2,13-19]. It wasn't very long before some of the technologies were extended to making things out of metals and other more durable substances, as well. That meant that rapid prototyping could then be used to make complex tools like injection molds and die casting molds. The natural extension of the terminology was to call this rapid tooling (RT) - especially so since the speed of fabrication was a paramount reason for the existence of the application in the first place.

A number of rapid prototyping technologies, such as selective laser sintering and laser powder forming, can be used to make tools directly in metals and other materials. Applying the term "rapid tooling" to these processes in such applications seemed quite correct. But other additive fabrication methods could be used to make a pattern - or model - from which a tool could also be made using a secondary process. Some of these so-called indirect methods deposit a final material for the tool such as metal right on the pattern. When the pattern is removed, the tool is largely complete. In other cases, these added steps involve a material transfer process. The pattern may be first used to make a mold and a harder final material for the tool is formed from that. Several such transfer steps may be required depending on the particular process.

Sometimes these material transfer processes themselves have also been called "rapid tooling." This is not precisely correct. Many of them existed long before additive fabrication was ever thought of, and virtually all of them can utilize patterns made in any fashion, whether using additive technology or not. There are many such processes. Among them are; RTV silicone rubber molding, aluminum-filled epoxy tooling, KelTool(TM), EcoTool(TM) and others. They can use patterns made by additive fabrication technologies - but they could also use patterns made by hand, or even shells or stones from a beach for that matter.

Therefore, to be very precise, fussy - a material transfer process by itself doesn't qualify as "rapid tooling." However, using one of them in conjunction with a rapid prototyping-generated pattern does, and these combined processes are properly classified as

"indirect methods" of rapid tooling.

Some additive fabrication technologies that are mostly used for rapid tooling applications are described as rapid tooling technologies. This is also incorrect because they can, and often are, used to make other things besides tooling. For example, laser powder forming technologies are frequently used to make injection mold tooling, but they can also be used to make hip implants.

Among the methods that are often thought of as "rapid tooling" technologies are: Direct Metal Deposition (TM), ProMetal (TM), electron beam melting (EBM), selective laser melting (SLM), shown on figure 3 in dental applications and others. Actually, they're just additive fabrication processes that are often used to make tools.



fig. 3. selective laser melting in dental applications

Once rapid prototyping materials and accuracy improved, it became possible to make functional parts that could be used in final applications. So-called "mass customization" consequently arose as a new possibility - manufacturing a product for a limited number of customers, or even for just one individual. While we're not used to thinking of manufacturing with a lot size of one, it's not hard at all to find applications where only a few of something are needed. Additive processes are turning out to be good prospects for many of those applications, especially ones that involve complex shapes.

The term "rapid manufacturing" arose in a natural way, and at least partially as a way to differentiate it from rapid tooling. It describes how rapid prototyping avoids the usually-required lengthy and expensive process of making a manufacturing tool. Of course, just as rapid prototyping is not necessarily rapid, rapid manufacturing can be quite slow, too. In some cases it's very slow indeed.

6. General use of RP

Just as with rapid prototyping, a number of synonyms for rapid manufacturing are used [2]. None of them call it rapid, and all of them are now fighting it out in the literature for supremacy:

- Additive fabrication / additive manufacturing - Additive fabrication is a somewhat more general term than additive manufacturing [9,11]. It's probably best reserved as the umbrella term that subsumes all of the technologies and applications described herein. But both terms are used to mean rapid manufacturing and are often seen. Additive manufacturing is probably the most precise term for what is being done in rapid manufacturing. Not only that, but in early 2009 the ASTM placed its imprimatur on the term after a specially-called meeting of 70+ industry experts hotly debated the topic. Even better - almost no one has used "additive manufacturing" up to now, so it should be easy to see if the opinion of industry experts actually counts for anything.

- Toolless manufacturing - This was an early term for rapid manufacturing, but has become less used recently, possibly because no one knows how to spell toolless, or whether tool-less should be hyphenated. Besides, no one wants to be toolless.

- Digital manufacturing / direct digital manufacturing / digital fabrication / Advanced Digital Manufacturing (ADM) (TM) - The latter is a trademark of 3D systems, but the other variations are much more often seen. They're reasonably descriptive and place the emphasis on the fact that computation is the driving force. But then, computation is the driving force behind nearly everything in modern life and the terminology may not survive because it's insufficiently specific with respect to the technology. Direct digital manufacturing (DDM) has fairly recently been given the blessing of the SME, which group (obviously a large committee) - quite interestingly - uses the term "additive manufacturing" to define it.

- Direct fabrication / direct manufacturing - Not very often

