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RAPID PROTOTYPING: THE REVOLUTIONARY TECHNOLOGY AND APPLICATIONS REVIEW

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ABSTRACT

The competition in the world market for manufactured products has intensified tremendously in recent years. It has become important, if not vital, for new products to reach the market as early as possible, before the competitors. To bring products to the market swiftly, many of the processes involved in the design, test, manufacture and market of the products have been squeezed, both in terms of time and material resources. The efficient use of such valuable resources calls for new tools and approaches in dealing with them, and many of these tools and approaches have evolved. They are mainly technology driven, usually involving the computer. This is mainly a result of the rapid development and advancement in such technologies over the last few decades.

In product development, time pressure has been a major factor in determining the direction of the development and success of new methodologies and technologies for enhancing its performance. These also have a direct impact on the age-old practice of prototyping in the product development process. This paper throws light on the Revolutionary Technology and Applications of Rapid Prototyping (RP).

KEYWORDS: Rapid Prototyping, Prototype, Principles and Applications.

INTRODUCTION

A prototype is an important and vital part of the product development process. In any design practice, the word “prototype” is often not far from the things that the designers will be involved in. Prototyping is the process of realizing these prototypes. Here, the process can range from just an execution of a computer program to the actual building of a functional prototype. Rapid prototyping typically falls in the range of a physical prototype, usually are fairly accurate and can be implemented on a component level or at a system level. The versatility and range of different prototypes, from complete systems to individual components, that can be produced by RP at varying degrees of approximation makes it an important tool for prototyping in the product development process. Adding the major advantage of speed in delivery, it has become an important component in the prototyping arsenal not to be ignored. Worldwide, the most commonly used term is Rapid Prototyping. The term is apt as the key benefit of RP is its rapid creation of a physical model. However, prototyping is slowly growing to include other areas. Soon, Rapid Prototyping, Tooling and Manufacturing (RPTM) should be used to include the utilization of the prototype as a master pattern for tooling and manufacturing. The commonly used terms include Direct CAD Manufacturing, Desktop Manufacturing and Instant Manufacturing. CAD Oriented Manufacturing is another term and provides an insight into the issue of orientation. Layer by layer addition as opposed to traditional manufacturing methods such as machining which is material removal from a block. E.g. Layer Manufacturing, Material Deposit Manufacturing, and Material Addition Manufacturing.

1.1 PROTOTYPE FUNDAMENTALS

1.1.1 Definition of a Prototype

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version. It covers all kinds of prototypes used in the product development process, including objects like mathematical models, pencil sketches, foam models, and of course the functional physical approximation of the product. Prototype is a tool for designer to validate his design before starting the actual production of the component. Manual prototyping was the traditional practice to make prototypes. However, recently machining by using CNC is used to manufacture prototypes. Prototyping process is more time consuming and costly.

1.1.2 Types of Prototypes

1. The implementation of the prototype: This aspect of the prototype covers the range of prototyping the entire product (or system) itself to its sub-assemblies and components of the product usually implemented full-scale as well as being fully functional.
2. The form of the prototype: This aspect of the form of the prototype takes into account how the prototype is being implemented from a virtual prototype to a physical prototype.
3. The degree of the approximation of the prototype: This aspect covers the degree of approximation or representativeness of the prototype from a very rough representation to an exact replication of the product. These prototypes are used to test and study certain problems of the product development.

1.1.3 Roles of the Prototypes

The roles of the prototypes in the product development process are the following:

1. Experimentation and learning
2. Testing and proofing
3. Communication and interaction
4. Synthesis and integration
5. Scheduling and markers

The prototypes can be used to help the thinking, planning, experimenting and learning processes while final product designing during product development. Design issues can be addressed by building and studying the prototype. Prototypes can also be used for testing and proofing of ideas and concepts relating to the development of the product. The prototype also serves the purpose of communicating information and demonstrating ideas to the product development team, management and clients since three-dimensional representation is often more superior than that of a two-dimensional sketch of the product. A prototype can also be used to synthesize the entire product concept by integrating the various components and sub-assemblies together to ensure that they will work together. Prototyping also serves to help in the scheduling of the product development process and is usually used as markers for the end or start of the various phases of the development effort.

2. HISTORICAL DEVELOPMENT

The development of Rapid Prototyping is closely tied in with the development of applications of computers in the industry. The declining cost of computers, especially of personal and mini computers, has changed the way a factory works. The increase in the use of computers has marked the advancement in many computer-related areas including Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Computer Numerical Control (CNC) machine tools. CAD is essential for Rapid Prototyping (RP) systems, advancement in manufacturing system and selection and usage of materials.

Table 1.1: Historical development of RP and related technologies

Year	Technology
1770	Mechanization [4]
1946	First Computer
1952	First Numerical Control (NC) Machine Tool
1960	First commercial Laser [5]
1961	First commercial Robot
1963	First Computer-Aided Design (CAD) System
1988	First commercial Rapid Prototyping System

Table 1.1 shows the historical development of RP and related technologies from the estimated date of inception.

2.1 Three Phases of Development Leading to Rapid Prototyping

Prototyping or model making in the traditional sense is an age-old practice. The intention of having a physical prototype is to realize the conceptualization of a design. Hence, a prototype is usually required before the start of the full production of the product. Prototyping processes have gone through three phases of development, the last two of which have emerged only in the last 20 years [7]. Like the modeling process in computer graphics [8], the prototyping of physical models is growing through its third phase. Table 1.1 shows the parallels between computer/geometric modelling process and prototyping for each phase. The three phases are described as follows:

Geometric Modeling	Prototyping

First Phase: 2D Wireframe
• Started in mid-1960s
• Few straight lines display may be:
  • Circuit path on a PCB
  • Plan view of a mechanical component
• Natural drafting technique
	First Phase: Manual Prototyping
	• Traditional practice for many centuries
	• Prototyping as a skilled crafts is:
	  • Traditional and manual based on material of prototype
	• Natural prototyping technique

Second Phase: 3D Surface Modeling • Mid-1970s • Increasing complexity • Representing more information about precise shape, size and surface contour of parts	**Second Phase: Soft/Virtual Prototyping** • Mid-1970s • Increasing complexity • Virtual prototype can be stressed, simulated, and tested, with exact mechanical and other properties
Third Phase: Solid Modeling • Early1980s • Edges, surfaces and holes are knitted together to form a cohesive whole • Computer can determine the inside of an object from the outside • No longer ambiguous but exact	**Third Phase: Rapid Prototyping** • Mid1980s • Benefit of a hard prototype made in a very short time (relies on CAD modeling) • Hard prototype can also be used for limited testing • It can also assist in the manufacturing of the product

Table 1.2: Parallels between geometric modeling and prototyping

2.1.1 First Phase: Manual Prototyping

Prototyping had begun as early as humans began to develop tools to help them live. Prototypes typically are not very sophisticated and fabrication of prototypes takes on average about four weeks, depending on the level of complexity and representativeness [9]. The techniques used in making these prototypes tend to be craft based and are usually extremely labor intensive.

2.1.2 Second Phase: Soft or Virtual Prototyping

As application of CAD/CAE/CAM become more widespread, the early 1980s saw the evolution of the second phase of prototyping - Soft or Virtual Prototyping. Virtual prototyping takes on a new meaning as more computer tools become available- computer models can now be stressed, tested, analyzed and modified as if they were physical prototypes. For example, analysis of stress and strain can be accurately predicted on the product because of the ability to specify exact material attributes and properties. With such tools on the computer, several iterations of designs can be easily carried out by changing the parameters of the computer models. Also, products and as such prototypes tend to become relatively more complex - about twice the complexity as before [9]. Correspondingly, the time required to make the physical model tends to increase tremendously to about that of 16 weeks as building of physical prototypes is still dependent on craft-based methods though introduction of better precision machines like CNC machines helps. These include material limitations (either because of expense or through the use of materials dissimilar to that of the intended part), the inability to perform endless what-if scenarios and the likelihood that little or no reliable data can be gathered from the rapid prototype to perform finite element analysis (FEA). Specifically in the application of kinematic/dynamic analysis, he described a program which can assign physical properties of many different materials, such as steel, ice, plastic, clay or any custom material imaginable and perform kinematics and motion analysis as if a working prototype existed. As such there is no guarantee that the virtual prototype is really problem free.

2.1.3 Third Phase: Rapid Prototyping

Rapid Prototyping of physical parts, or otherwise known as solid freeform fabrication or desktop manufacturing or layer manufacturing technology, represents the third phase in the evolution of prototyping. The invention of this series of rapid prototyping methodologies is described as a "watershed event" [11] because of the tremendous time savings, especially for complicated models. Though the parts (individual components) are relatively three times as complex as parts made in 1970s, the time required to make such a part now averages only three weeks [9]. Since 1988, more than twenty different rapid prototyping techniques have emerged.

CURRENT CHALLENGES FACING THE INDUSTRIES

The common challenges facing the industries today are described as follows:

1. Quality
2. Productivity
3. Reduced costs
4. Customer satisfaction
5. Time-to-market: Responsiveness in bringing the new product to the market places.

To cope up with the customer's requirement along with current market demand and challenges, time compression engineering formerly called as concurrent engineering in product development is essential to the industries. This concept allows to product development team to construct a functional prototype within very short time span by saving approx. around 75% time in comparison with time required to build same prototype with traditional method of prototyping. RP new technology can help to face global competition, accelerate product obsolescence, meets continued demand for cost savings and customer driven product customization. Terry Wohlers defined RP as "A technology that produces models and prototype parts from 3D computer-aided design (CAD) model data, CT and MRI scan data and model data created from 3D object digitizing systems". One can turn a design concept into a solid prototype and test it for form, fit, and function at a fraction of the cost and time of traditional prototyping methods.

APPLICATIONS OF RAPID PROTOTYPING

4.1 Application in Education and Industry

4.1.1 Application in Product Development

- Prototype Design Evaluation - CAD provides Viewing, Shading, Rotating and Scaling functions. However, there is no substitute for physical model.
- Prototype for Function Verification - Verification of Functionality, Kinematics, and Aerodynamics.
- Prototype for Manufacturing Process Validation - Evaluating process compatibility (Casting/Machining).

4.1.2 Application in Reverse Engineering (RE)

- RE is the science of taking an existing physical model and reproducing its surface geometry in a 3D data file on a CAD system.
- In many cases, only the physical model of an object is available.
  Eg: Handmade prototypes, craft works, reproduction of old engineering objects, and sculptured bodied in medical and dental applications.
- In order to facilitate downstream applications (CAM/CAE/RP), it is essential to establish a CAD model.
- RP can be used to fabricate the physical part of the corresponding CAD model or even we can modify the design and test the performance of the new design.

4.1.3 Application in Casting and Pattern Making

- The patterns and cores for the casting process are made using the RP process.
  Eg: Investment casting for jewelry, dental fixtures, small mechanical components, and blades for turbine engines in gold, titanium, bronze, silver, brass etc.
- Master patterns for other casting applications.
- Cores for sand casting applications.

4.1.4 Application in Rapid Tooling (RT)

- RT is the process of making tools quickly - Direct Tooling and Indirect Tooling.
- Faster and less expensive Tooling solution.
- Toyota saved in tooling cost $200,000 for door handle, which are created from FDM masters, rather than CNC machining.
- More than 20 RT methods are available.

4.1.5 Application in Medicine

- Medical Applications of RP are increasing every day, making the future more and more promising.
- To design, develop, and manufacture of medical devices and instrumentation.
- Anatomical models and surgical implants.
- Medical models can be constructed from RP, can be used to prepare for delicate surgery or to determine other treatment options.

4.1.6 Application in Rapid Manufacturing (RM)

- **Aerospace:**
  - **Boeing's Rocketdyne Division** has successfully used RP and RT to manufacture hundreds of parts for applications on the International Space Station and space shuttle fleet.
  - **F -18 fighter jet** parts are also manufactured using RP.
- **Automotives:** The students of SAE Formula 1 team Loyola Marymount University used RP parts as final production parts which includes intake manifold, side-view mirrors, and various molds and models for the vehicle.
- **Dental:** Invisalign technology to straighten teeth without braces (metal/wire).

ADVANTAGES OF RAPID PROTOTYPING

- Low development costs
- Short time of development
- Short time to market
- Functional test of parts in early design
- Direct transfer of CAD data
- Easy transfer from a virtual model to a real part
- No tooling investment
- True flexible manufacturing
- Eliminates waste and costly late changes
- Earlier detection and reduction of design errors
- Reduced lead times to produce prototyped components
- Improved ability to visualize the part geometry due to its physical existence
- Increased capability to compute mass properties of components and assemblies

LIMITATIONS OF RAPID PROTOTYPING

- High material cost
- Less accuracy
- Less surface finish
- High machine cost
- Low build volume
- Low production speed
- Limited range of material variety

CONCLUSION

From the above literature review, it can be concluded that the Rapid prototyping is moving towards tool-less manufacturing applications as materials and systems improve. RP has wide range of applications in each front of engineering.

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