

# Rapid Prototyping & Tooling In China

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Rapid prototyping & tooling (RP&T) is one of the most timely and cost effective tools for product design, evaluation, development and manufacturing. In the past several years, RP&T research and applications in China have achieved great progresses. In this paper, using the example of Tsinghua University RP Lab, we recall the development history, introduce the present status, discuss and identify the frontiers and questions encountered of RP&T research and applications in China.

## 1 Introduction

Rapid prototyping (RP) refers to the physical modeling of component or tooling geometry using layered manufacturing technologies. It is a fast growing area in the manufacturing processes. It deploys the computer-aided design (CAD), laser and computer numeric control technologies to quickly fabricate the polymer, wax, powder or paper-based prototypes from the solid CAD models. This process slices the 3D models into the 2D thin layers and then builds the prototype one layer at a time and stacks layer by layer until the part is finished. Thus it is also called as layered manufacturing or free form fabrication. Initially used for design tool, the use of RP technologies logically extends to rapid tooling such as molding, investment casting and sand casting [1].

Rapid tooling (RT), an emerging area in manufacturing technology, is regarded as one of the most important applications of RP technology. In the past several years, RT has been growing very fast and obtained tremendous success in the new product development, evaluation, tooling, and production manufacturing. These applications are widely used in the injection molding and metal casting industries.

To decrease the lead-time and cost of new product development and manufacturing thus to strengthen the competitive edges of industries, the academic fields have initiated the research on rapid prototyping and tooling at the beginning of nineties in China. At present, there are many educational institutes and companies have put tremendous efforts to educate the industry, to develop the RP&T equipment and processes, to transfer the technology from the research to the applications. After ten years' development, the RP&T research and application have obtained great progress. In this paper, we briefly introduce the overview of the present status,

development history, main achievements, applications and some special events to give the reader a briefly image of RP&T industry in China.

## 2 Overview of RP&T in China

Through 10 years' development, RP&T technologies have obtained great achievements in China. These include the equipment and process development, material research and development, proprietary software coding, rapid tooling process development and application, reverse engineering application and simulation, technology transfer and education, etc.

### 2.1 Machine Usage and Development

It is estimated that there are around 50 RP machines installed in China, including the machines developed in domestic and imported from overseas. These machines are distributed around universities and industries. The machines imported are mainly focusing on SLA, FDM, LOM and EOS. EOS has set up the first sales branch of the foreign RP&T companies in China in 1998.

In domestic, there are several universities and industrial companies developing the RP&T process and equipment. These developers include Tsinghua University (TU), Huazhong University of Science & Technology (HUST), Xi'an Jiaotong University (XJTU) and Beijing Longyuan Automated Fabrication System Co., LTD. The machines developed are shown in Table 1 [2].

**Table 1** RP equipment or process developers in China

Company Name	Equipment or Process Developed
Tsinghua University	<ol style="list-style-type: none"> <li>1. Multi-functional RP Systems (M-RPMSI, M-RPMSII)</li> <li>2. Slicing solid manufacturing (SSM500, SSM1600)</li> <li>3. Melted Extrusion Manufacturing (MLM250)</li> <li>4. Patternless Casting Modeling (PCM100)</li> </ol>
Beijing Longyuan Automated Fabrication System Co., LTD	<ol style="list-style-type: none"> <li>1. AFS RP Machine (AFS-300)</li> <li>2. AFS Rapid Measurement System</li> <li>3. AFS Rapid Casting and Molding System</li> </ol>
Xi'an Jiaotong University	<ol style="list-style-type: none"> <li>1. Laser Prototyping System (LPS-600, LPS-600A, LPS-350)</li> <li>2. Compact Prototyping System (CPS-250)</li> <li>3. Graphite Electrode Tool (GET-500A)</li> </ol>
Huazhong University of Science & Technology	Huazhong RP (HRPIIA, HRPIII)
Nanjing University of Aeronautics & Astronautics	Developing an experimental equipment
Huabei Institute of Technology	Developing an experimental equipment

### 2.2 Academic and Professional Activities

In the past several years, RP&T community in China have sponsored and organized several important RP conferences and professional associations. In 1993, the first rapid prototyping research center -- Laser Rapid Forming Center of Tsinghua University in Beijing -- was set up.

Now there are at least 8 similar centers were established. In 1995, the first National Rapid Prototyping Conference of China was held in Tsinghua University. In 1997, the first RP association in China -- the Rapid Forming Technology Committee (RFTC), part of which is a third organization the Chinese Mechanical Engineering Society (CMES) -- was set up. The RFTC is also affiliated to the Chinese Electro-machining Association (CEMA). In 1998, there are several important events happened to Chinese RP&T community. First, the First International Conference on Rapid Prototyping Manufacturing has been held in Beijing. This is the first international event in RP&T area in China. In this meeting, 117 papers were received and more than 60 RP&T colleagues attending this meeting, including researchers, vendors, government officials, and service representatives [3]. Second, the Rapid Forming and Rapid Mold Manufacturing Conference was held in Xi'an. The third, the Rapid Forming Technology Committee has joined the Global Alliance of RP Associations, an organization dedicated to information sharing across international borders. As a part of this sharing, its participants from around the world explore and conduct activities that help convey the benefits of rapid prototyping and related technologies.

There are many educational and research institutes, and companies involving RP&T research and applications, such as Tsinghua University (TU), Xi'an Jiaotong University (XJU), Huazhong University of Science & Technology, Nanjing University of Aeronautics & Astronautics (NUAA), Beijing Long Yuan Automated Fabrication System Co., Ltd., National Huaqiao University (NHU), Shenzhen Productivity Center (SPC), North China Institute of Technology (NCIT), Nanjing University of Science & Technology (NUST), Dalian University of Science & Technology (DUST), Nantong Institute of Technology (NIT), Beijing Polytechnic University (BPU), Shanghai University (SU), Beijing University of Aeronautics & Astronautics (BUAA), Guangzhou China Weal Business Machinery Co. Ltd., Dongfeng Hanzhou Motor Corporation Heavy Machinery Plant, etc.

In the past several years, Chinese Natural Science Foundation (CNSF) has given the great support to the RP&T research and applications in China. There are many important projects and research teams receiving fund from this organization.

### **3 Research Areas**

#### ***3.1 RP Process Study and Development***

RP processes are widely investigated in China since the beginning of 1990s. The investigation covers the basic process, accuracy improvement, laser and control systems, post-processing, CAD data transfer interface, etc. The most studied processes are SLA, LOM, FDM, SLS and multi-functional RP systems.

Stereolithography Apparatus (SLA) process is investigated by several universities, such as TU, XJTU, HUST. In 1992, a SLA250 machine was installed in the Center of Laser Rapid Forming (CLRP), Tsinghua University. This is the first RP equipment in China. Now XJTU conducts a systematic study on the SLA. They have developed resin-based RP process --Laser Prototyping System (LPS-600, LPS-600A, LPS-350) and Compact Prototyping System (CPS-250). This system uses the optical fibers to conduct the laser to polymerize the resin. According to their experiences, the most important problem is automatic stability of the liquid surface of the resin.

Laminated Object Manufacturing (LOM) process is studied widely in China. The CLRF in TU developed a sheet-paper based RP system --Slicing Solid Manufacturing. This system is mainly used for academic and experimental purposes. After several years' efforts, the CLRF has developed the largest work size RP machine (SSM-1600, 1600x800x700 mm<sup>3</sup>) and the first multi-functional RP system (M-RPMSI and M-RPMSII) which integrates the paper-sheet based and powder based RP processes. HUST has also developed a sheet-paper based RP system, which is incorporated with a Singaporean company for commercialization.

(3) Fused Deposition Modeling (FDM) process is mainly studied by the CLRF, TU. They developed another new RP method-Melted Extrusion Manufacturing, which is similar to FDM method, but has its own distinguish features. They are working on development of special nozzle design, filament fabrication of different materials, such as wax, nylon and ABS.

(4) Selective Laser Sintering (SLS) process is also studied in China. Beijing Long Yuan Automated Fabrication System Co., Ltd, a joint venture of China and US, has developed and commercialized a SLS-like RP system -- AFS300. They have sold several machines. A laboratory in NUAA puts their efforts to develop their own experimental system. This new machine has some different features, not only different with DTM, but also different from Long Yuan Co.'s AFS system.

(5) Multi-functional Rapid Prototyping Manufacturing System (M-RPMS) is studied and developed by the CLRF, TU for 6 years. It integrates the requirements of industrial applications and academic research and development. The development of this machine adheres to three basic principles: new concept, new design and new product.

- The New Concept is the new designing principle. It is the most important guarantee for the developing success of the production.
- The New Design is used for the new technology of software, process and equipment.
- The New Product is the M-RPMS-II machine. This laser rapid forming machine is intellectual property of Tsinghua University. Each function provided by this machine could match or exceed the quality of single-functional machines. Fig.1 shows the principle diagram of the M-RPMS-II machine [4]. The distinguished advantages of this machine are the low operating costs and the short operating time.

### **3.2 CAD Modeling & Data Transfer**

The commercial CAD packages used in China are Pro/ENGINEER, AutoCAD, I-DEAS and SolidWorks, and the hardware/platform is PC and Workstation with Win95, UNIX and NT. Time taken to create a CAD model varies from several days to several months depending on the geometry complex and technical experiences of the computer operators. Models can be created from 3D CAD modeling, modified from the existing data, scanning or reverse engineering. Since the RP systems can only use the 3D solid models to build the part, it may be a time-consuming for model creation either from CAD packages or laser digitizing. Fig.2 shows a scheme of the data processing used in the CLRF, TU [5]. They have developed three versions of interface and data processing software for DOS, Windows95 and Windows NT respectively. The most recent

version is based on Windows NT. The software can display, edit, slice, fill cross-sectional area, add support, divide part in Z axis direction of the STL file.

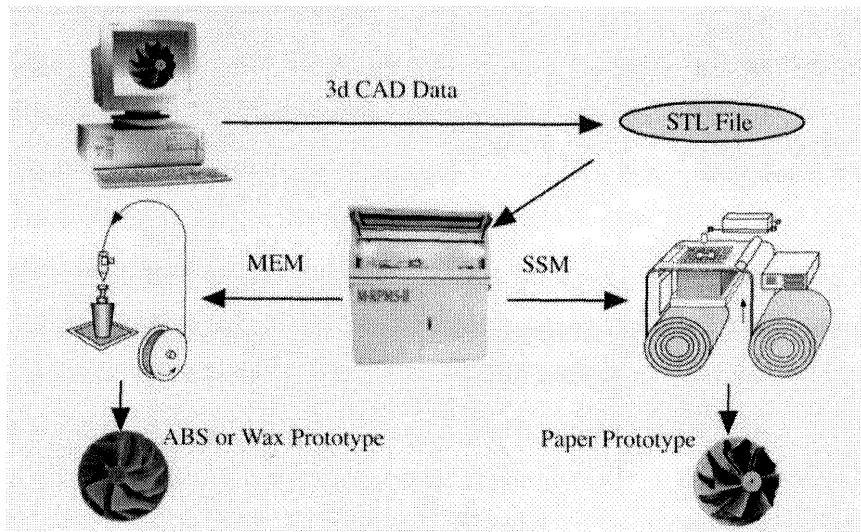


Fig 1. The principle diagram of M-RPMS-II machine

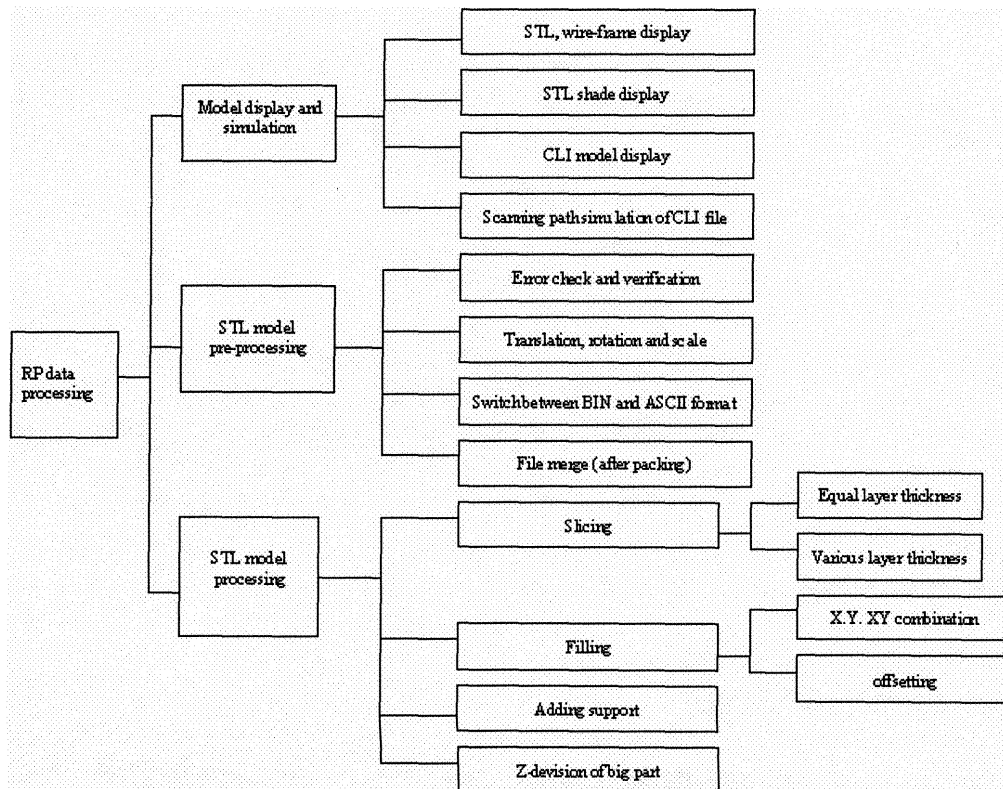


Fig 2 Data processing scheme of CLRF, Tsinghua University

### **3.3 Material Research**

Material research is an important area for rapid prototyping technology. There are several research institutes in China dedicated in this area, such as Chemistry Department in Tsinghua University, Zhejiang University, Huazhong University of Science & Technology. The materials studied include the polymer, coated sheet-paper, binder materials, powder materials of ABS, wax and nylon, etc. The material properties studied cover the physical and chemical properties of RP materials, the mechanism of reaction, accuracy improvement, mechanical properties and improvement, distortion and warpage, etc.

### **3.4 Rapid Tooling and Manufacturing**

Rapid tooling and manufacturing may be the most important application of rapid prototyping because the manufacturing capability may determine the future development of rapid prototyping industry. Because of the rapid building of physical models, RP prototypes provide a tremendous potential for rapid tooling and manufacturing. RP technologies are very limited if they can only be for design evaluation and functional testing. Through rapid tooling process, RP models can be easily used for injection molding and metal casting operations to manufacture the parts quickly, less costly and efficiently. Using CAD-solid modeling, part geometry can be expected to increase in design and manufacturing complexity. Designers and tool engineers can view the solid model prior to prototyping because of the properties of CAD-solid modeling. Molds and dies are normally required for effective mass production of plastic or metal products and components in manufacturing industry.

Because of the wide range of RP materials used such as wax, plastics, ceramics, cements, papers, and metallic powders covered with binders, RP prototypes can also be used as mold inserts or cores for injection molding and sand casting. One most frequent casting process using RP technology is investment casting. CLRF has developed the Ceramic Sheet Casting (CSC), a precise casting process. It has been used for automobile covered parts in the Changchun No 1 Automobile Factory. This process obtains SSM prototypes of positive and negative molds for an automobile covered part, then transfers to metal mold [6].

Another important rapid tooling process is called the Patternless Casting Molding (PCM). This innovative machine is focusing on making large or medium size casting mold. The material used in PCM is commonly used in resin sand casting so that the cost is relatively low. The process is still under development. The present disadvantage is that the surface finish is not very good due to the large size of sand, i.e. about 0.5mm in diameter, compared with powder used in DSPC and SLS, in which the particle size is smaller than 60 microns, and the experimental nozzle designed and fabricated by themselves [6].

## **4 The Center for Laser Rapid Forming**

To introduce the RP&T in China, we cannot help but mention the Center for Laser Rapid Forming (CLRF) in Tsinghua University. The CLRF is the first research center dedicated to RP&T research, imports the first RP machine (SLA250), develops the first RP machine, and is the flag research institute of RP&T in China.

## **4.1 Basic Data**

The CLRF was established in 1992 by Professor Yongnian Yan of Mechanical Engineering Department in Tsinghua University. The basic statistics is as below:

- People:  
4 full professors, 2 Ph.D. advisors; 15 Ph.D. candidates, 10 odd master candidates, 3 post-doctorates, several visiting scholars; 18 Ph.D. and master students graduated from this lab.
- Facilities and hardware:  
PMS-II, 1 M-220 (developed by CLRF), 1 PLCM-100 (Patternless casting molding), 2 SGI workstations, more than 30 PCs, 400 m<sup>2</sup> lab area and 400 m<sup>2</sup> workshop.
- Software:  
3D solid CAD/CAM/CAE software packages; RP data processing software packages: Larc 97 and 98; Numeric control software based on PARK numeric control systems: Carc 97 & 98; and 3D object reconstruction software (non-sequential 3D points and CT image).

## **4.2 Divisions**

There are 4 divisions in the CLRF: RP Reverse Engineering and Simulation, Data processing and RP CAD, Mechanical Design and Control System, Innovation for RP Technology and Materials.

### **4.2.1 RP Reverse Engineering and Simulation**

CAD modeling for RP products can be based on the RP reverse engineering, metrical simulation and imitation for RP process. The research activities include:

- Reverse engineering with Computed Tomography (CT) and Magnetic Resonance Imaging (MRI);
- 3D Laser scanning measurement;
- Computer simulation for three kinds of RP processes (SSM, MEM and SL);
- Size precision simulation for process using MARC software for RP Metallic Moulds.

### **4.2.2 Data processing and RP CAD**

Slicing file CLI can be finished and output through data processing according to the input from STL, DXF and / or STEP files. The research activities include:

- 3D Computer-Aided Design (CAD) model within Pro/Engineer;
- Data processing, diagnosis, and revision of STL software;
- Supporting structure software for different RP technologies;
- RP CAD software;
- Control software for SSM, MEM and M-RPMS of RP machines.

#### 4.2.3 Mechanical Design and Control System

Design and manufacturing for mechanical system and control system of the laser rapid forming machines and devices. The research activities include:

- Multi-functional RPM testing platform;
- Slicing Solid Manufacturing (SSM) machine;
- Melted Extrusion Manufacturing (MEM) machine;
- Multifunctional RPM System (M-RPMS);
- Large scale SSM machine.

#### 4.2.4 Innovation for RP Technology and Materials

New RP techniques and research and development for RP materials. The research activities include:

- StereoLithography (SL) technology;
- UV curable resin for SL;
- Slicing Solid Manufacturing (SSM) technology;
- Sticky paper for SSM;
- Melted Extrusion Manufacturing (MEM) technology;
- Waxy, nylon and ABS filaments for MEM;
- Selective Laser Sintering (SLS) technology;
- Powders (wax, polymers and metals) for SLS;
- Intelligent Design / Manufacturing System (IDMS) for metallic forming mold;
- Patternless Casting Molding (PCM) technology.

#### 4.3 Research Activities

The main research activities in the CLRF are as below:

- Melted Extrusion Manufacturing (MEM) technology (process & equipment);
- Slicing Solid Manufacturing (SSM) technology (process & equipment);
- Integration of MEM and SSM process and equipment;
- RP process based on micro-drop technology;
- RP materials (coated paper, ABS wire, wax wire, high-strength, high-temperature & high-polymerization materials);
- Development of super-large size of RP equipment (1.600x800x700 mm<sup>3</sup>), two laser systems working concurrently;
- Patternless casting molding technology;
- No-baking ceramic casting process to produce metal parts from RP models.

### 5 Future Directions and Problems

It can be expected that the future development of RP&T in China will still heavily counted on the educational institutes. The industrial application may increase rapidly because of the intensified market competition and the unique advantages of RP&T technologies. From the research points of view, the following fields may be regarded as the future research directions:

rapid prototyping of the living materials such as human bones, automobile shape mold used for sheet metal extension and bending, and biotic shaping technology.

But there are also some problems existing in the PR&T development in the future. There are at least three problems perplexing the Chinese RP community. First, there is no sufficient funding. RP research, just like any other high-tech industry, needs a great deal of financial support to cover the high cost in academic and application research. Second, the Chinese industry needs time to fully realize the benefits RP&T can bring to their product design and manufacturing. This may somehow affect the development speed of RP&T in China. Third, there are not enough researchers to participate in this research field. Most graduated students move to overseas or change their career paths after graduation from universities.

## 6 Summary

This paper briefly introduces the present status, research activities, main research achievements and future research directions of RP&T technology in China. We first review the basic situations of RP&T in China including the RP equipment usage and development, and the academic research forces and professional activities. Then we discuss the main research areas and their achievements. To understand more detailed research activities, the CLRF in Tsinghua University is briefly introduced. Finally, the future research directions and difficulties encountered are also presented.

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