

## **AC 2008-2307: RAPID PROTOTYPING IN THE DESIGN METHODOLOGY**

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# RAPID PROTOTYPING IN THE DESIGN METHODOLOGY

## Abstract

The main objective of a design course is to teach a procedure to practice the fundamental engineering knowledge as repeatable design techniques. A popular approach to teach undergraduate engineering design is by solving open ended design problems. Tools are available now to students allowing them to evaluate the cost, manufacturing, usability, and environmental consequences of their designs. However aesthetical success of the design can only be verified subjectively and cannot be imagined from 2D drawings or 3D models. Observing and touching the products prototype may help overcome this obstacle. Rapid prototyping (RP) techniques allow creation of prototypes in short amount of time. RP enables realization of a design and promotes the enthusiasm and motivation in students. This paper describes the visualization of the design ideas and the position of the RP in the design methodology.

## 1. Introduction

Design as activity involves creativity and innovation but it is constrained by high quality and low cost to meet customer expectations. Customers are increasingly demanding both innovation and value. Methodological design courses exist in engineering education with the objective of teaching engineering design fundamentals. A popular approach to teach undergraduate engineering design is through a structured, problem solving method that students use to tackle open-ended design problems<sup>1-4</sup>. Classical engineering design process<sup>5</sup> has the following general steps,

- 1) Recognition of need
- 2) Definition of Problem,
- 3) Synthesis,
- 4) Analysis & Optimization,
- 5) Evaluation,
- 6) Presentation.

The native language of design has evolved from the technical drawing to a 3D model. Ability to visualize the ideas and communication among design teams are possible with visual-spatial perception of the design concepts. The visualization of technical artifacts started with scratched stone tablets, continued freehand sketches on papyrus or paper and with digital age and CAD it has advanced to another level<sup>6</sup>. Solid models provide the ability for easy modification and enable structural/thermal analysis and simulations. Another advantage is that the traditional tasks of a designer, drafter, analyst, and prototype maker may be all performed by a single engineer using digital engineering design tools. Digital 3-D models can be easily shared and accessed through web-based tools on the internet, which provide a collaborative design environment for geographically distributed design teams<sup>7</sup>. Next step for design visualization and verification is Rapid Prototyping (RP), which started a few years ago but stumbled because of the large capital investments required and hidden expenses for the consumables<sup>8</sup>.

## 2. Process of Realizing a Rapid Prototype

Sketching is a natural language of creative ideation, and is always one of the earliest steps of the engineering design process. Freehand sketching is very useful on this first stage to visualize the ideas and concepts. While computer sketching may be more accurate than manual freehand sketching, the quirks and complexity of learning sketching software may hinder creativity. Computer aided parametric modeling in design starts with a two dimensional (2D) sketch on a planar grid. Computer drawing software offers a variety of 2D primitive elements, such as line, circle, rectangle, arc, spline, and ellipse. In order to complete 2D profiles (section of the part), the software includes 2D editing functions such as extend, trim, mirror, offset, and array. Parametric dimensions and other geometric constraints are then added to the profile to initially fix the geometry. When a 2D sketch is complete, it is then either extruded or revolved to form the three dimensional (3D) model of the part. More 2D sketches can be created on the work planes, and these secondary profile sketches can then be used to cut through the base part or to add more material. Design features, such as fillets, rounds, chamfers, ribs, bosses, cuts, and holes, are also available with simple commands that do not require sketches. Parametric solid modeling has following advantages:

- 1) Accurate description of the part/concept/idea
- 2) Easier to find errors and solution
- 3) Fast calculations of the consequences and simulation
- 4) Easy modification of the model
- 5) Direct data transfer for the CAM.

Currently, the ability to use a 3D parametric solid modeling software package has become one of the standard tools acquired by mechanical engineering graduates. 3D solid modeling allows designer to rotate, zoom or pan the graphics on the screen. These visual objects give him immediate and satisfactory feedback of his work. But, again some feeling is missing. Since aesthetical success of the design needs to be verified by ones mind, nothing can replace a reel prototype. It is not easy to build a prototype for a student with his limited experience and knowledge. Advances in rapid prototyping technology allow them to produce inexpensive prototypes from the 3D solid models. Some universities have provided facilities for students to produce rapid prototypes of their design concepts. Once the 3D geometry of the model has been constructed, a rapid prototype of the individual parts can be made. Most of the software packages give the user ability to save the parts in stereolithography (STL) file format. This STL format approximates the surfaces of a solid model with triangular facets. The STL file is interpreted by the RP machine and parts produced layer by layer deposition or etching.

## 3. Rapid Prototyping Equipment

Rapid Prototyping refers to the automatic construction of physical objects using solid freeform fabrication directly from a CAD model. The first equipments for rapid prototyping became available in the late 1980s and were used to produce models and prototype parts. Today, a large number of equipments are available in the marketplace. They are used for a much wider range of applications and are even used to manufacture production fully functional parts in relatively small numbers. Additive methods join together liquid, powder or sheet materials to form complex parts layer by layer, their main differences are found in the way layers are built to create

parts. Some are melting or softening material to produce the layers (SLS, FDM) where others are laying liquid materials thermosets that are cured with different technologies.

Different techniques are,

- Melting, Solidifying/Fusing
- Cutting, gluing/joining
- Joining, binding
- Photo curing
  - One Laser
  - Multi laser
  - Masked lamp

The major rapid prototyping methods and the names of the developers are listed in Table 1.

Process name	Forming agent	Material	Developer
Stereolithography (SLA)	laser	polymer	3D Systems <sup>9</sup> , EOS <sup>10</sup>
Selective Laser Sintering (SLS)	Laser	Polymer, metal, ceramic	3D Systems, EOS
Solid Ground Curing(SGC)	UV light	Photopolymer, liquid monomer, wax	Cubital <sup>11</sup>
Laminated Object Manufacturing (LOM)	laser	Paper, polymer	Helisys, Cubic Technologies <sup>12</sup>
Fused Deposition Modeling (FDM)	Extrusion	Polymer, ABS	Stratasys
3 D Printing	Liquid adhesive	Metal, ceramic as powder	MIT, ZCorp
-Inkjet Printing	Liquid jets	Acrylics, Elastomeric	3D Systems
-Jetted photopolymer	UV light	Photopolymer	Objet <sup>13</sup>

Table 1 Major RP Methods

The first and most known RP process is Stereolithography (SLA) was developed by 3D Systems of Valencia, California, USA, founded in 1986. A vat of photosensitive resin contains a vertically-moving platform. The part under construction is supported by the platform that moves downward by a layer thickness (typically about 0.1 mm / 0.004 inches) for each layer. A laser beam traces out the shape of each layer and hardens the photosensitive resin. It provides the greatest accuracy with an excellent surface finish. SLA parts are durable and these functional parts are suitable for wide variety of applications e.g. pre production, Product verification, Form/Fit/function testing, Snap fit assemblies, thin walled parts.

Selective Laser Sintering (SLS) process primarily used to rapidly produce 3D prototypes, parts, tools, direct mold inserts, or lost-wax casting patterns. SLS process provides durable, metal, plastic or rubber like prototypes directly from CAD model. These prototypes can be used as test

parts for form, fit and function. SLS technology provides broad range of materials e.g. rigid thermoplastics, stainless steel, polystyrene, thermoplastic elastomers, cast form plastic for lost-wax casting process.

Solid Ground Curing (SGC) was developed and sold by Cubital. While the method offered good accuracy and a very high fabrication rate, it suffered from high acquisition and operating costs due to system complexity. This led to poor market acceptance. Cubital is a spin-off company from Scitex Corporation. While the company no longer exists and its intellectual property has been acquired by Objet Geometries, Ltd., it's still an interesting example of the many technologies other than stereolithography that utilize photopolymer materials<sup>14</sup>. Cubital's SGC system was an additive process that uses ultraviolet (UV) light to selectively cure thin layers of liquid monomer. The primary material is photopolymer resin, and the secondary material is wax.

In the Laminated Object Manufacturing (LOM) process profiles of object cross sections are cut from paper or other web material using a laser. The paper is unwound from a feed roll onto the stack and first bonded to the previous layer using a heated roller which melts a plastic coating on the bottom side of the paper. The models are created layer-by-layer and have the look of wood before they are sealed with protective lacquer. The process is commonly used for creating large sand casting patterns.

Fused Deposition Modeling (FDM) is the second most widely used rapid prototyping technology, after stereolithography. The system consists of a build platform, extrusion nozzle, and control system. A plastic filament supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a control system which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic. The cross section quickly solidifies, and the platform descends where the next layer is extruded upon the previous layer. This continues until the model is complete.

3D Printing is the less costly process of rapid prototyping which turns the 3D CAD data to quickly produce a three dimensional model. Where an ordinary printer lays down a single 2D layer of ink on a sheet of paper, these printers add the extra dimension by printing layer after layer until you have a real, 3d object similar to your CAD model. This process was developed at MIT. It's often used as a direct manufacturing process as well as for rapid prototyping. Mono /multi ink jets deposit melted material or adhesive material on a powder chamber. The process starts by depositing a layer of powder object material at the top of a fabrication chamber. The jetting head deposits liquid adhesive in a 2D pattern onto the layer of the powder. To accomplish the part layer by layer, a measured quantity of powder is first dispensed from a similar supply chamber by moving a piston upward incrementally. The roller then distributes and compresses the powder at the top of the fabrication chamber.

Materials used in these methods are SLA, (laser cured epoxy), SLS, (laser sintered polymer), FDM, (molten polymer layering), LOM, (bonded paper layering). Industrial materials can be

used with FDM and SLS and fully functional parts can be produced in small batch sizes. Sometimes prototypes from solid block of metal or plastic block can be manufactured by CNC to get the maximum strength. This called subtractive method for RP<sup>15</sup>.

#### **4. Role of Rapid Prototyping in Redesign of Products for New Requirements**

As a component of engineering design education in Engineering Design course (MAK 422E), students must undertake a project that includes the redesign of a product. The main redesign objective is to make them lighter and stylish namely travel-friendly. For this purpose the students are divided into design teams of five to seven members, which aids in innovative thinking and concept generation<sup>16-18</sup>. The emphasis is to redesign home appliances with the objective to make them attractive for frequent travelers. Home appliances like electric irons and kettles were chosen for the study. The students, in the course, are expected to progress through three phases of product development study, which can be listed as clarification of the task/specification, conceptual design and embodiment. These steps can be redefined in the aspect redesign since redesign is the detailed study and analysis of an existing product to collect information, remake the design decisions and improve the product designed initially by the original design team. (Figure 1) It is an iterative procedure that consists of information, definition, innovation, evaluation and presentation steps.

Searching for customer needs and market analyses initiate the effort of redesigning the product. By using these information and market analysis data, the teams have to prepare a short requirement list as a kickoff document. However, not to limit the creativity of the team members the requirement list can be modified during the redesign project. This also maintains the open-ended nature of the design process

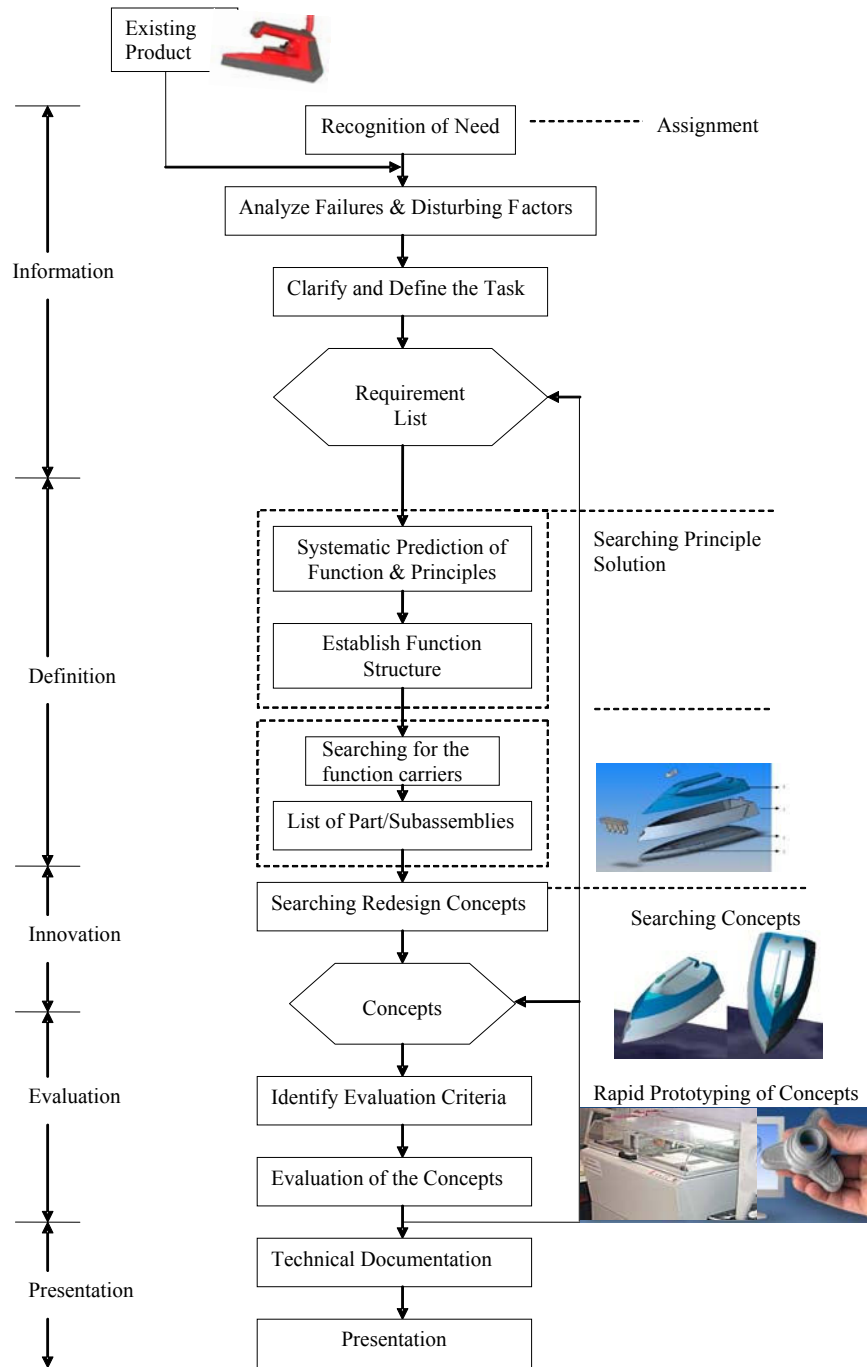


Figure 1 Redesign Steps in the Course

After systematic prediction of the functions and searching for principle solutions that fulfill the needs in the requirement list, a function structure can be established. The intention in this activity is to fully understand the physical principles and design parameters for the product. A reverse engineering study of the existing product is undertaken by carrying out the disassembly of the product. This disassembly step helps the student in understanding the actual function and

form of the product and each component as well. Modeling and analysis of the existing product will give the students the chance to create new ideas.

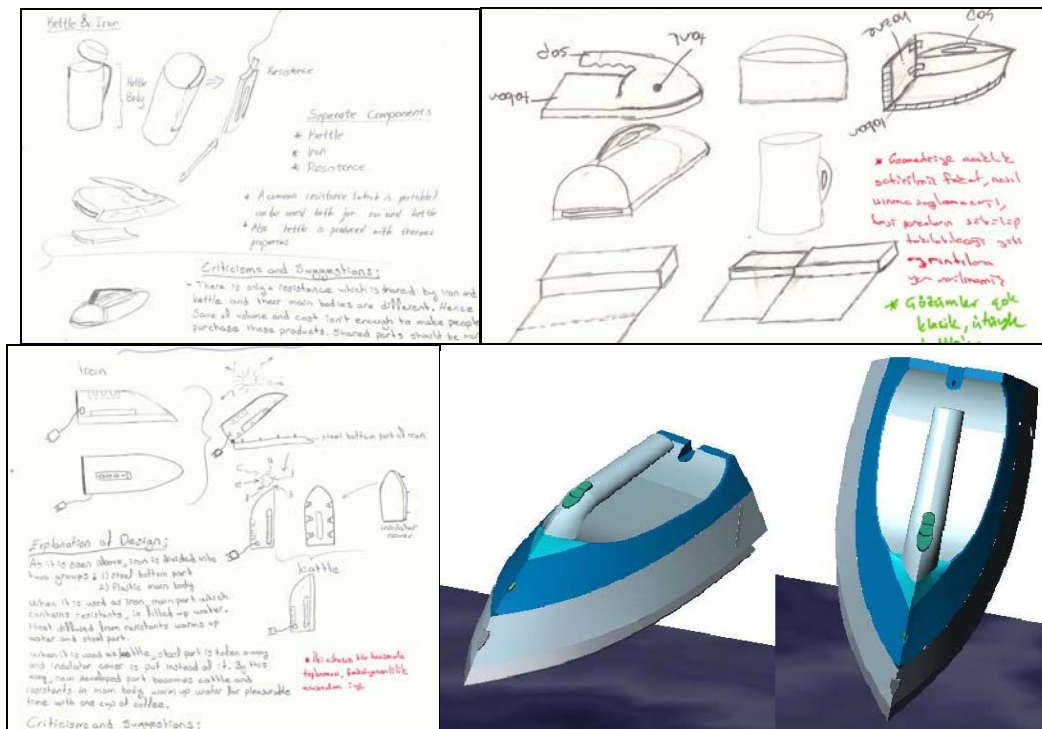


Figure 2 Hand Sketches and 3D solid models used in the Gallery Method

After the student have an understanding of the existing product, the idea generation step for redesign is done, where every team members is encouraged to independently generate their concepts. The students are free to make hand sketches or parametric solid models that can be modified to express their ideas (Figure 2). Design ideas/concepts are evaluated with criteria of the cost, manufacturing, usability, and environmental consequences. Selected concepts are prototyped and observed for aesthetic verification (Figure 3).



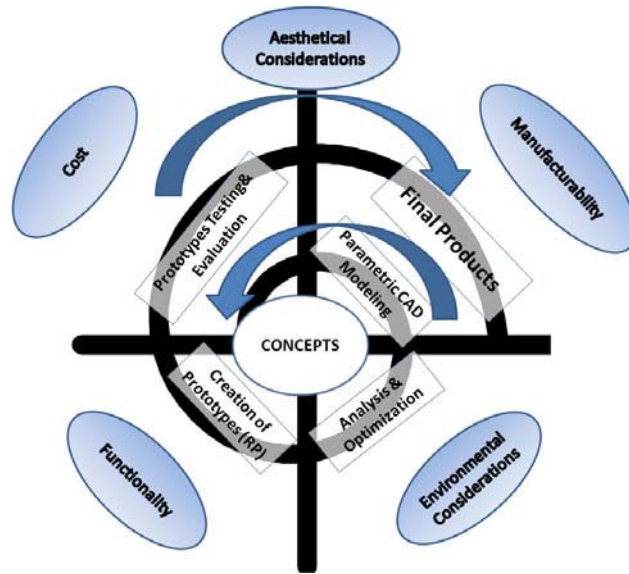


Figure 3 Evaluation of the Concepts

Students were able to choose PTC ProE Wildfire or Solidworks as 3D modeling software (Figure 4). Created 3D models are converted to STL files and transferred to the ZCorps' 3D printer (Figure 5). RP used at least once by each design group under supervision of a technician or a TA. The project ends with a final report and presentation of the concepts developed by each team.

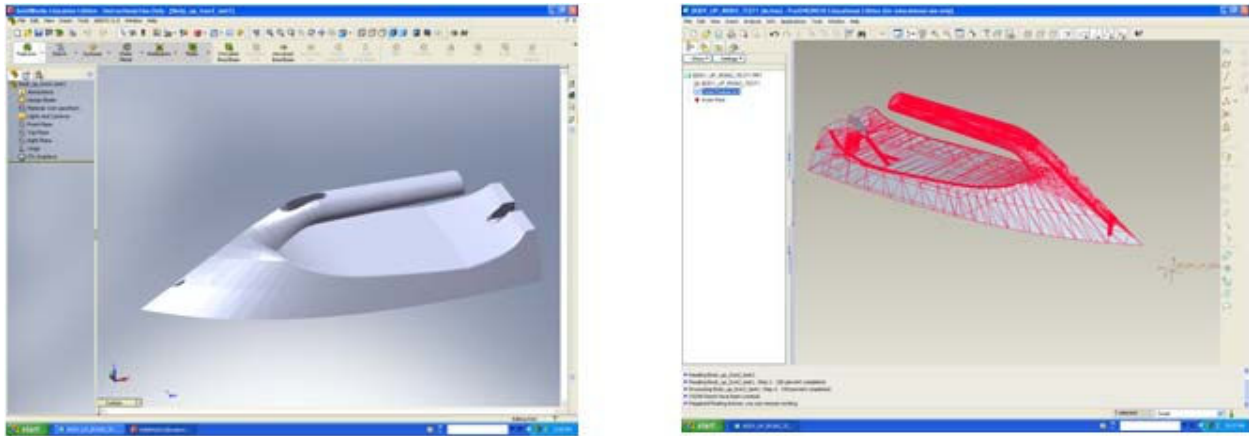


Figure 4 3D CAD models in Solidworks and ProE Wildfire and converted STL Files

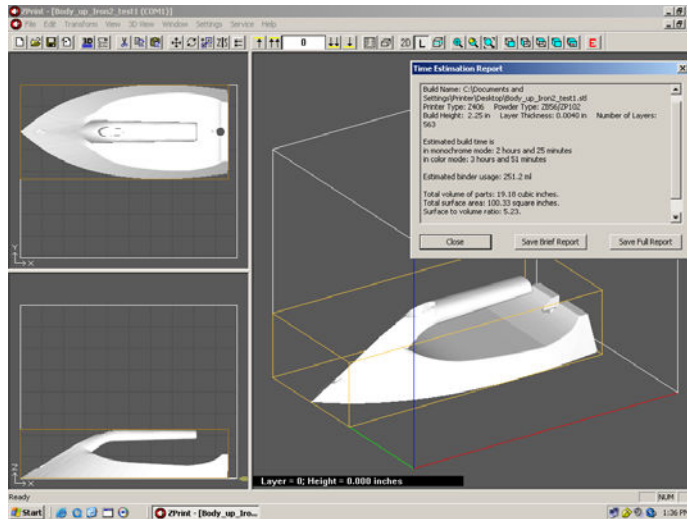


Figure 5 Transferring STL file to the 3D printer using Zprint

For products with human interfaces such as the electric iron, ergonomic ease of use cannot be reliably established with 3D Models. Full scale rapid prototypes enable determination of user comfort. For example, the handle of the electric iron in Figure 5, requires enough clearance for human hands to hold and work with the iron. The distribution of weight and grip comfort can be easily evaluated with a full-scale non-functional prototype.

To evaluate the effectiveness of the course and the projects, the students were asked to provide feedback what they found most beneficial outcome in this course and what they would recommend changing.

The following is a summary of the responses:

- Most valuable benefit was learning how to work as a team and feel the responsibility.
- I learned about sustainability.
- I learned how an engineering design project is prepared.
- I did not realize that the recognition of the need and problem definition so important in the product design.
- We learned the importance of communication and reporting among the team members for the success.
- Construction of a prototypical product was critical in the redesign process.
- More time is needed for better presentations.

## 5. Concluding remarks

Rapid prototyping was incorporated as a key segment in a design project students learned to work in a group and assumed different roles to complete redesign of typical home appliances for new requirements. All students expressed their design concepts individually using graphics and prototypes. They used intuitive and conventional methods like brainstorming, 6-3-5 method, gallery method, etc., so they evaluated and improved their concepts. During the development of the redesign project, students learned have to deal with issues on planning and clarifying task, conceptual design, embodiment design and detailed design, step by step. They realized how to

consider the design criteria such as design for minimum cost, design for environment, design for manufacturability etc. They also experienced and appreciated creation of prototypes for presentation of concepts and for testing the human interfaces of the products.

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