# Rapid Prototyping and Virtual Prototyping Product Design and Manufacturing

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## ABSTRACT

A Prototype is the first or original example that has been or will be copied or developed; it is a model or preliminary version. It is an approximation of a product or its components in some form for a definite purpose in its implementation.

Rapid prototyping (RP) is the production of a physical model from a computer model without the need for any jig or fixture or numerically controlled (NC) programming. This technology has also been referred to as layer manufacturing, material deposit manufacturing, material addition manufacturing, solid freeform manufacturing and three-dimensional printing. In the last decade, a number of RP techniques have been developed. These techniques use different approaches or materials in producing prototypes and they give varying shrinkage, surface finish and accuracy.

Virtual prototyping (VP) is the analysis and simulation carried out on a fully developed computer model, therefore performing the same tests as those on the physical prototypes. It is also sometimes referred to as computer-aided engineering (CAE) or engineering analysis simulation.

This proposed study is aimed at studying the relevance of Rapid prototyping and Virtual prototyping in product design. This study will compare the two prototyping techniques and there by investigates the suitability and effectiveness of both techniques with identification of their merits and limitations by considering two sample engineering components.

## 1.INTRODUCTION

Prototyping or model making is one of the important steps to finalize a product design. It helps in conceptualization of a design. A prototype is the first or original example of some thing that has been or will be copied or developed; it is a model or preliminary version.

Prototypes have been created as models for various aspects of software systems, including user interfaces, functional requirements relating outputs to inputs, and performance issues such as response times. A model or prototype will accurately reflect chosen aspects of a system, while deviating from the proposed system in other respects.

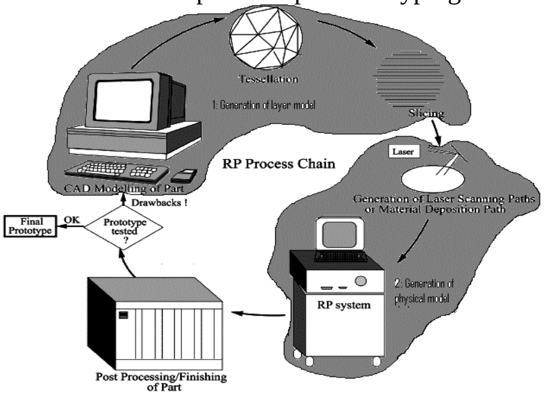
Prototyping is the process of realizing the prototypes. The roles that prototypes play in the product development process are several. They include Experimentation and learning, Testing and Proofing, Communication and interaction, Synthesis and integration, Scheduling and markers.

### RAPID PROTOTYPING:

Rapid prototyping (RP) is emerging as a key prototyping technology with its ability to produce even complicated parts virtually overnight. It enables product designers to shorten the product design and development process.

Rapid prototyping (RP) is the production of a physical model from a computer model without the need for any jig or fixture or Numerically Controlled (NC) Programming. This technology has also been referred to as layer manufacturing, material deposit manufacturing, material addition manufacturing, solid freeform manufacturing and three-dimensional printing.

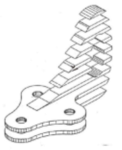
Basic Principal of Rapid Prototyping

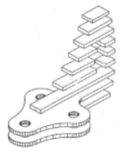


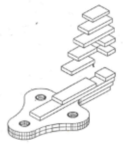
- A model or component is modeled in a Computer -Aided Design / Computer –Aided Manufacturing.
- A Solid or surface model to be built is next converted into a STL (Stereo Lithography) file format.
- Slices for the model are made.
- Later generation of physical model is done.
- Final prototype is obtained after Post processing.
- Observed drawbacks are sent to remodel the part.

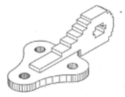
RP uses layer by layer additive approach to build shapes; RP systems use liquid, powder or sheet materials to form physical objects.


(a) CAD model


(b) Slicing the model


(c) Squaring edges of model


(d) Stacking and pasting layers


(e) Physical prototype


(f) Finished physical prototype

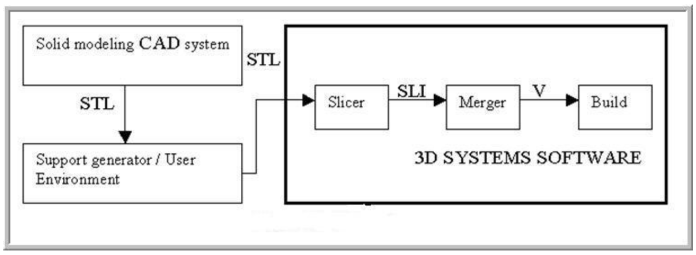
## The Basic Process

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model.

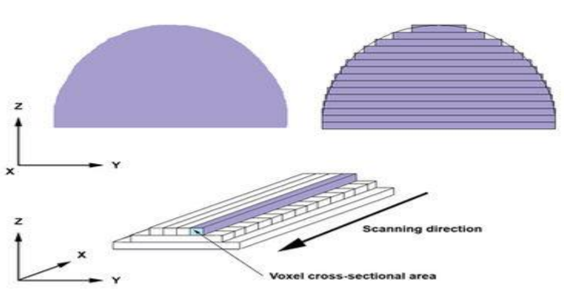
**CAD Model Creation:** First, the object to be built is modeled using a Computer-Aided Design (CAD) software package. Solid modelers, such as Pro/ENGINEER, tend to represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results. The designer can use a pre-existing CAD file or may wish to create one expressly for prototyping purposes. This process is identical for all of the RP build techniques.

**Conversion to STL Format:** The various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL (stereo lithography, the first RP technique) format has been adopted as the standard of the rapid prototyping industry.



The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles, "like the facets of a cut jewel." [6] The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces exactly. Increasing the number of triangles improves the approximation, but at the cost of bigger file size. Large, complicated files require more time to pre-process and build, so the designer must balance accuracy with manageability to produce a useful STL file. Since the stl format is universal, this process is identical for all of the RP build techniques.

**Slice the STL File:** In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location and orientation of the model. Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another.



For example, prototypes are usually weaker and less accurate in the z (vertical) direction than in the x-y plane. In addition, part orientation partially determines the amount of time required to build the model. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening build time. The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick, depending on the build technique. The program may also generate an auxiliary structure to support the model during the build. Supports are useful for delicate features such as overhangs, internal cavities, and thin-walled sections. Each PR machine manufacturer supplies their own proprietary pre-processing software.

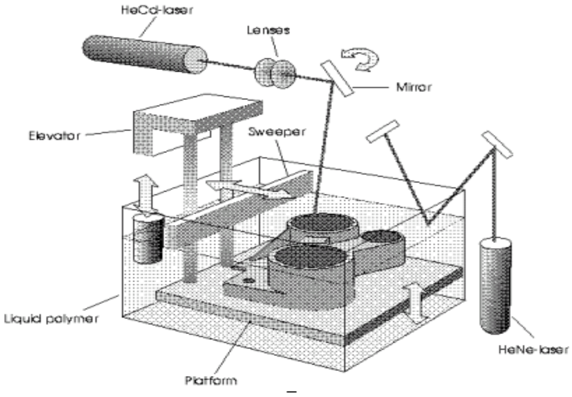
**Layer by Layer Construction:** The fourth step is the actual construction of the part. Using one of several techniques (described in the next section) RP machines build one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention.

**Clean and Finish:** The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

**Rapid Prototyping Techniques:**

Most commercially available rapid prototyping machines use one of six techniques. At present, trade restrictions severely limit the import/export of rapid prototyping machines, so this guide only covers systems available in the U.S.

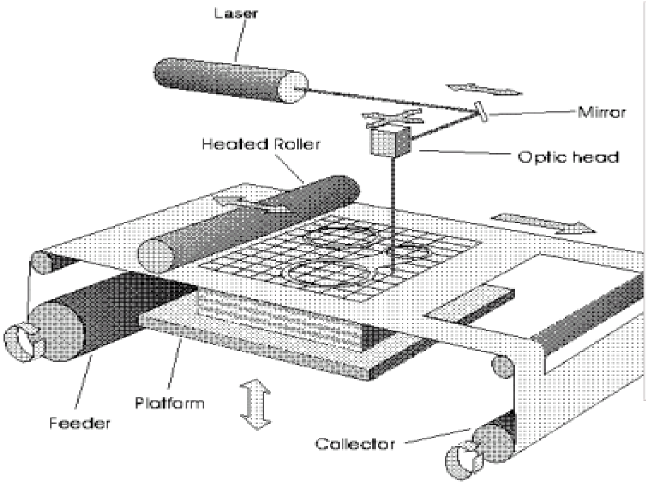
**Stereolithography:** Stereo lithography started the rapid prototyping revolution. The technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light. As shown in the figure below, the model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin. A low-power highly focused UV laser traces out the first layer, solidifying the model's cross section while leaving excess areas. Next, an elevator incrementally lowers the platform into the liquid polymer. A sweeper re-coats the solidified layer with liquid, and the laser traces the second layer atop the first. This process is repeated until the prototype is complete.



Schematic diagram of stereolithography

. Afterwards, the solid part is removed from the vat and rinsed clean of excess liquid. Supports are broken off and the model is then placed in an ultraviolet oven for complete curing. Stereolithography Apparatus (SLA) machines have been made since 1988 by 3D Systems of Valencia, CA. To this day, 3D Systems is the industry leader, selling more RP machines than any other company. Because it was the first technique, stereolithography is regarded as a benchmark by which other technologies are judged. Early stereolithography prototypes were fairly brittle and prone to curing-induced warpage and distortion, but recent modifications have largely corrected these problems.

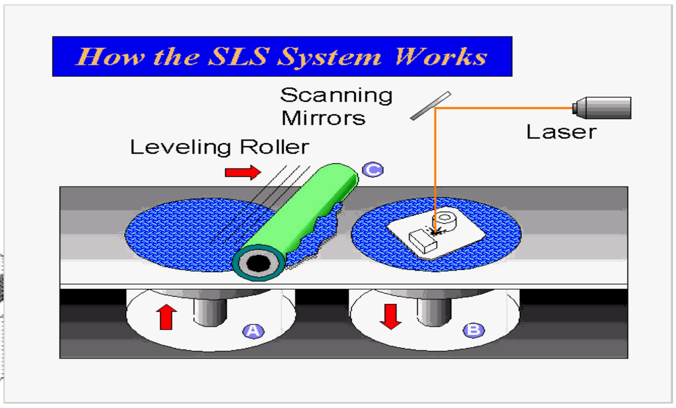
**Laminated Object Manufacturing**: In this technique, developed by Helisys of Torrance, CA, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. As shown in the figure below, a feeder/collector mechanism advances the sheet over the build platform, where a base has been constructed from paper and double-sided foam tape. Next, a heated roller applies pressure to bond the paper to the base. A focused laser cuts the outline of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype).



Schematic diagram of laminated object manufacturing

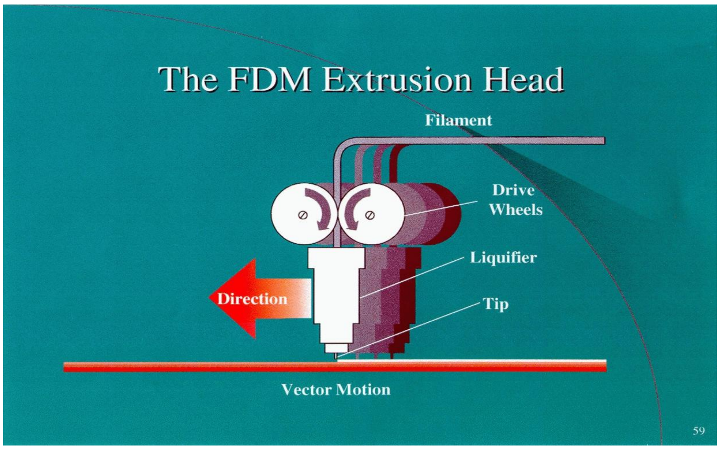
Cross-hatching breaks up the extra material, making it easier to remove during post-processing. During the build, the excess material provides excellent support for overhangs and thin-walled sections. After the first layer is cut, the platform lowers out of the way and fresh material is advanced. The platform rises to slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. Because the models are made of paper, they must be sealed and finished with paint or varnish to prevent moisture damage..

**Selective Laser Sintering**: Developed by Carl Deckard for his master's thesis at the University of Texas, selective laser sintering was patented in 1989. The technique, shown in Figure 3, uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object. Parts are built upon a platform which sits just below the surface in a bin of the heat-fusable powder. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete. Excess powder in each layer helps to support the part during the build. SLS machines are produced by DTM of Austin, TX.



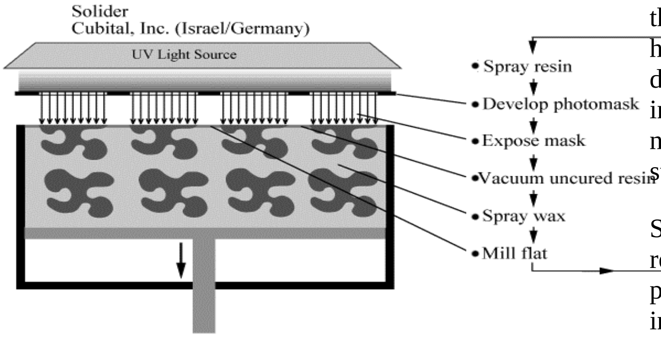
Schematic diagram of selective laser sintering.

**Fused Deposition Modeling:** In this technique, filaments of heated thermoplastic are extruded from a tip that moves in the x-y plane. Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens. After the platform lowers, the extrusion head deposits a second layer upon the first. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction.



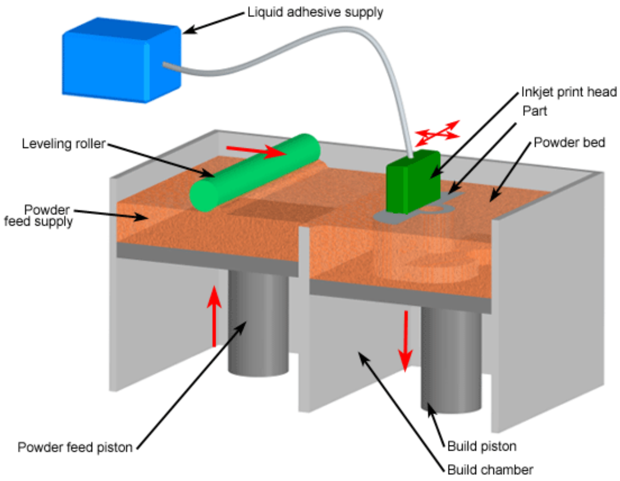
Schematic diagram of fused deposition modeling.

**Solid Ground Curing:** Developed by Cubital, solid ground curing (SGC) is somewhat similar to stereolithography (SLA) in that both use ultraviolet light to selectively harden photosensitive polymers. Unlike SLA, SGC cures an entire layer at a time. Figure 5 depicts solid ground curing, which is also known as the solider process. First, photosensitive resin is sprayed on the build platform. Next, the machine develops a photo mask (like a stencil) of the layer to be built. This photo mask is printed on a glass plate above the build platform using an electrostatic process similar to that found in photocopiers. The mask is then exposed to UV light, which only passes through the transparent portions of the mask to selectively harden the shape of the current layer. After the layer is cured, the machine vacuums up the excess liquid resin and sprays wax in its place to support the model during the build. The top surface is milled flat, and then the process repeats to build the next layer. When the part is complete, it must be de-waxed by immersing it in a solvent bath. SGC machines are distributed in the U.S. by Cubital America Inc. of Troy, MI. The machines are quite big and can produce large models.



Schematic diagram of Solid Ground Curing

**3D Ink-Jet Printing:** Ink-Jet Printing refers to an entire class of machines that employ ink-jet technology. The first was 3D Printing (3DP), developed at MIT and licensed to Soligen Corporation, Extrude Hone, and others.



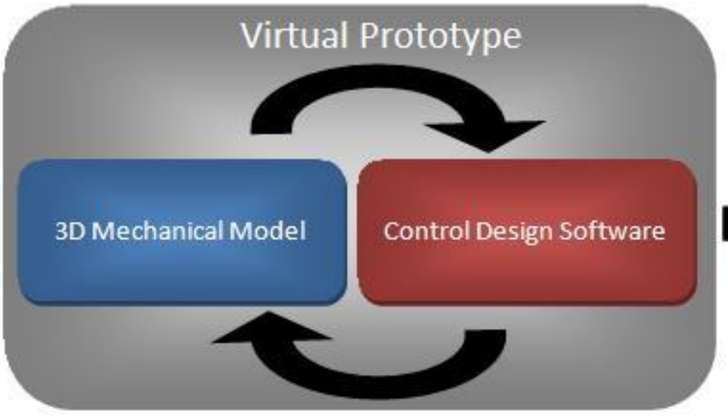
The ZCorp 3D printer, produced by Z Corporation of Burlington, is an example of this technology. As shown in Figure 6a, parts are built upon a platform situated in a bin full of powder material. An ink-jet printing head selectively deposits or "prints" a binder fluid to fuse the powder together in the desired areas. Unbound powder remains to support the part. The platform is lowered, more powder added and leveled, and the process repeated. When finished, the green part is then removed from the unbound powder, and excess unbound powder is blown off. Finished parts can be infiltrated with wax, CA glue, or other sealants to improve durability and surface finish. Typical layer thicknesses are on the order of 0.1 mm. This process is very fast, and produces parts with a slightly grainy surface.

The benefits of rapid prototyping are chiefly in developing a more accurate understanding of user requirements. The use of rapid prototyping should thus result in lower costs in the long-run from higher quality systems and less software development projects being failures. The introduction of rapid prototyping, as is true of any new tools or new software processes, will incur start-up costs.

Since prototyping is principally useful in requirements engineering, resources for rapid prototyping on the Internet are sometimes intermixed in with requirements engineering resources.

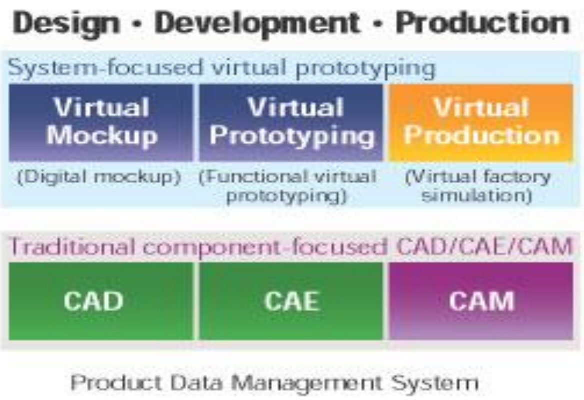
**VIRTUAL PROTOTYPING:** VP is the analysis and simulation carried out on a fully developed computer model, therefore performing the same tests as those on the physical prototypes.

VP refers to the creation of a model in the computer, often referred to as CAD/CAM/CAE. Virtual or computational prototyping is generally understood to be the construction models of products for the purpose of realistic graphical simulation.



VP is often tightly integrated with CAD/CAM software and sometimes referred to as

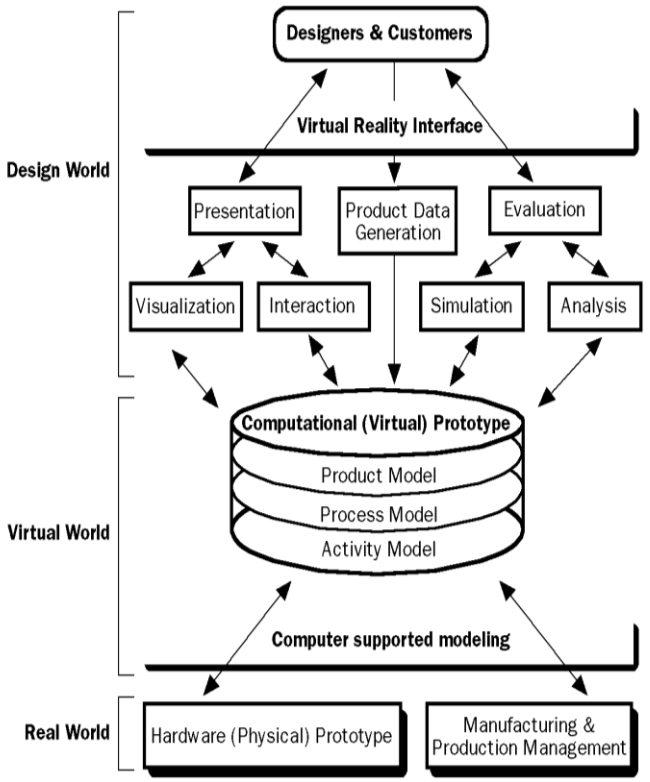
CAE packages like ProE, ANSYS, etc. Virtual prototyping may entail different analysis solutions, depending on the application. VPS automates all required operations, including preprocessing, job submission, and post processing. The automation of analysis routines for designing packages led to the development of the VPS. Through computer automation, Procter & Gamble greatly reduced the time required to do virtual testing of product design and analysis of bottle geometry.



Traditional component-focused CAD/CAM/CAE compared with system-focused virtual prototyping

It is also known as simulation-based-design, refers to the iterative design refinement of a designed product using a computer-based functional physical simulation(s). VP is rapidly gaining importance as the engineering practice of choice to aid rapid product development and shorten the design cycle. The enabling trends for the adoption and rapid proliferation of the VP methodology include: (i) ubiquitous availability of low-cost PC-based parametric simulation/analysis tools and (ii) integration of multi-physics simulations into a unified environment.

The principle of virtual prototyping-aided design



Today, computer simulation may now be used to compute/calculate the geometric, kinematic and dynamic responses of a system (within the computer), and the results visualized in a 3D interactive graphical virtual environment. This has set the stage for this new phase in engineering enabling the designer to quantitatively evaluate the performance of a proposed design completely in software minimizing the expense of multiple intermediary physical prototypes.

Further, VP can now permit a wide variety of test suites to be run on computer models without running the risks of over-testing (and possibly wearing out components) thus aiding in the process of redesign to achieve the desired performance. Virtual prototypes can additionally facilitate the involvement of management, sales personnel and consumers early in the design. Thus, VP has gained acceptance as the method of choice for design of mechanical system products in several leading manufacturing industry sectors (automotive, aerospace, rail, medical device design and general machinery).

While there is a significant demand from industry for students trained in this methodology (and undoubtedly tremendous benefit to be derived in terms of enhanced productivity), there are also numerous issues. Currently, there may not be significant room in engineering curriculum to permit widespread adoption in the lecture-based classroom. Other debilitating factors could includ (i) the significant learning curves (due complexity of these tools); coupled with (ii) t lack of an audience-specific structured learni frameworks (for inexperienced users).

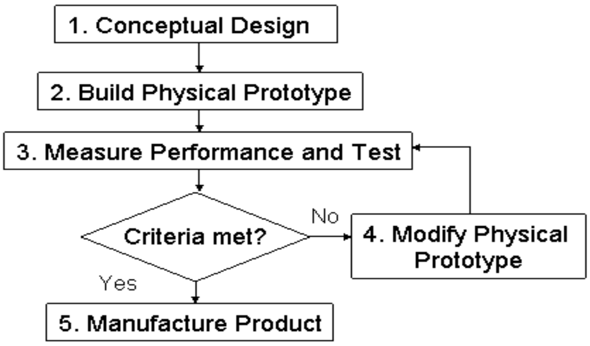
Currently, considerable numbers of Comput Aided Design (CAD) software and technolo tools are commercially available to suppo simulation-based design-refinement of mechanic systems. Many of these tools not only allow a us to geometrically model mechanical devices in a 3 virtual environment, but also permit the simulati and testing of product functionality virtually.

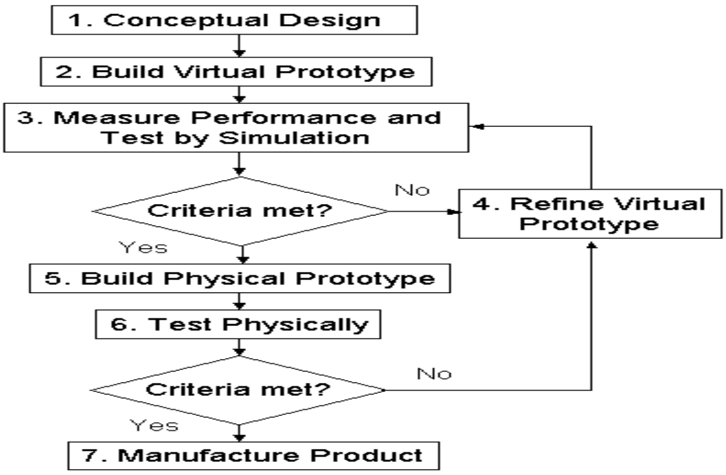
Figure 1 compares the conventional approach wi the VP approach in an engineering design process. In the conventional approach, the iterative creation and modification of a physical design prior to manufacture can be expensive and time consuming. VP approaches derive their many advantages by eliminating the need for an intermediate physical prototype for the design refinement stage. Two trends that have favored the adoption and rapid proliferation of the VP approach are:

(1) the availability of low-cost PC based parametric simulation and analysis tools; and

(2) the capability of integrating multiple functionalities into a unified environment.

Today, computer simulation may be used to compute and calculate the kinematic, dynamic and FEA-based responses of prototype completely within the computer and the result can be visualized within a 3D interactive graphical virtual environment. Further, the ubiquitous availability of low-cost personal computer processor with accelerated graphics hardware coupled with the ease of availability of the tools for such platform has set the stage for this new phase in engineering, enabling the designer to quantitatively evaluate the performance of a proposed design completely in software.





**(a)**

**Comparison between (a) conventional approach and (b) VP approach in design process.**

The trend of integrating different modules and packages has permitted users not only to create the geometry for the mechanical devices of interest, but also to test the product by functional simulation within the virtual environment and ultimately to iteratively refine the design based on the result of such multi-domain simulations.

While there are undoubtedly tremendous benefits to be derived in terms of enhanced productivity, there are also numerous issues. Currently, there may not be significant room in engineering curriculum to permit widespread adoption in a lecture-based classroom. Additionally, a well-structured educational course and a considerable amount of hands-on practice would be necessary for the students to effectively learn to use these tools.

Therefore, we are developing this series of web-based self-paced VP tutorials with the target audience being the students of the course MAE 412: Machines and Mechanisms II at the State University of New York at Buffalo. The goal is to reinforce the ideas and concepts originally presented in the course by paralleling the course material with these tutorials. The overall desired outcome includes improving the overall understanding of mechanisms by the students and accelerating their learning experience without increasing the lecture hours.

## The Need for Virtual Prototyping

Virtual prototyping lowers the risks associated with machine design by improving the understanding of customer requirements, speeding up the design process, and streamlining debugging. Without a virtual prototype, you would have to build the entire physical prototype before you could obtain tangible customer feedback on the product’s operation. By using virtual prototyping, you can show a digital representation of the mechanics of the machine to the customer and get feedback more quickly and easily before actually building the machine. This ensures that customers are more involved in the design process and prevents you from having to wait until it is too late in the prototyping process to get customer feedback.

Additionally, you can shorten the time to market of your product by creating a virtual prototype. This type of prototype helps you conceptualize and iterate on a virtual design, so that when you start to build a physical prototype, you get it right the first time. By being able to connect control software to a 3D CAD model, you can more easily find and fix problems that you do not normally catch before building the physical prototype. You can write motion control code such as 2D and 3D motion profiles and see the result of the code on the 3D model. So if a part is so large that it might cause a collision or if you want to look at the difference between a contour move and a linear move, you can fix the problem and view the difference with virtual prototyping. Compared to the traditional design approach, virtual prototyping helps you make key design decisions earlier in the process.

Another way virtual prototyping can save time and money is by reducing the number of physical prototypes you are required to build. Traditionally, you had to build several physical prototypes because you could not foresee future mechanical challenges. The advent of CAD and simulation software changed the game by dramatically improving visibility through the design process. Now you can build, test, and verify a design in software that previously required building a physical prototype. When you digitally simulate and validate the real-world performance of your product's mechanical design, you save time and money by significantly reducing physical prototypes.

And, finally, virtual prototyping can help increase the quality and efficiency of a machine or device. In the past, you often had to choose motors based on limited information and potentially even over-engineer mechanical designs to add security margins. With virtual prototyping tools, you can simulate the dynamic behavior of the whole system, including the motors, control algorithms, and physical structure, in advance and collect all the necessary information to propose an efficient and effective design.

## Conclusion:

Rapid prototyping is preferred to VP for kinematic simulation, assembly, fit and interference checking. As a physical part, RP allows the user to gauge the size of the prototype. It is also used for ergonomic and tactile evaluations. Rapid prototyping parts are also used for manufacturing input, usually for a cross-functional team where representatives from all disciplines evaluate the prototype from their own specialist requirements. Most RP parts suffer from mechanical property drawbacks. SLA components are brittle and prone to war page. The need to build supports in some RP systems also creates problems. In addition, very thin parts cannot be build by some RP systems.

Virtual prototyping provides a quick iterative design process, where problems can be rectified immediately wherever indicated from analysis. Solving the problems in the VP domain helps reduce physical prototyping costs and time. Virtual prototyping has high initial investment costs in hardware and software and demands skilled and experienced operators to extract the full benefit from the software. Transfer of data between differing VP systems is poor and vendors often recommend total reconstruction of parts.

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