# The effects of Rapid Manufacturing on Virtual and Physical Prototyping

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ABSTRACT: Rapid Manufacturing is starting to have an impact on the way designs are formulated and then on how parts are produced. This paper discusses the wide variety of impacts on the Virtual and Physical Prototyping that is being undertaken and will be in the future. Many changes will need to occur in both of these areas with Physical Prototyping becoming less important and Virtual Prototyping become paramount.

## 1 INTRODUCTION

### 1.1 *Definition of Rapid Manufacturing*

For this paper Rapid Manufacturing (RM) is defined as the direct production of finished goods from an additive process. The technique uses additive processes to deliver finished parts directly from digital data and this then eliminates the need for tooling.

In the future RM technology may develop and the layer-based approach may be combined with subtractive (machining) operations or replaced by additive processes that use a multi-axis approach instead of a layered process. However, the definition of RM above will continue.

### 1.2 *Benefits of Rapid Manufacturing*

Rapid manufacturing offers many benefits in a number of areas such as in reduction of tooling costs, reduced lead times and product cost, design freedom, heterogeneous materials, custom products, just-in-time production, and decentralization of production (Wohlers, 2004). However, this paper will concentrate on the two areas of Virtual and Physical Prototyping.

## 2 EFFECTS OF RAPID MANUFACTURING ON PHYSICAL PROTOTYPING

The effects of Rapid Manufacturing on Physical Prototyping will be both positive and negative.

The positive effect will be a greater acceptance of the prototype as being representative of the manufactured part because they will both be made on the same machine. Conventional manufacturing processes often involve expensive tooling and so there have arisen a number of processes developed as an intermediate stage. This can be easily seen in the area of plastic parts where prototypes may be made by one of the Rapid Prototyping processes but the end-user part is to be injection moulded in a completely different material. In this case both the material and the manufacturing process are different. This will therefore lead to a reduced need for many secondary prototyping processes such as vacuum casting of urethanes and so a whole section of industry could suffer as a result of this. The best option for companies in this area is to invest over the next 10 years and migrate to small lot manufacturing with Rapid Prototyping machines.

Another positive benefit will be the greater complexity of parts which can be prototyped (Hague et. al., 2003a). This ability to produce both prototypes and production parts by an additive process will mean that parts could be much more complex than before. This could be greater complexity in geometry and/or greater complexity in material composition. However the material complexity may be a problem as discussed later. At the moment, we have the ability to produce very complex parts by Rapid Prototyping but the intermediate processes like vacuum casting or the final processes such as injection moulding are very limited. The use of Rapid Manufacturing will ensure consistency from generation of concept to delivery of product.

A negative effect of Rapid Manufacturing will be the reduced need for tooling and machining and so some of the more traditional companies will suffer due to this.

However, having discussed the advantages and disadvantages above, the question should be asked whether prototyping will be really needed? This really depends on the quantities that will be manufactured by additive processes in the future. Existing work has already shown that the current Rapid Manufacturing processes are economic for tens of thousands of parts (Hopkinson & Dickens, 2003) and clearly in this case it makes sense to manufacture a physical prototype and test it. However, where parts will be made on an individual basis it will not make sense to produce a prototype and then physically test it to be followed by a single part which is sold. In this situation Virtual Prototyping will become much more important and so the majority of this paper will concentrate on this subject.

## 3 EFFECTS OF RAPID MANUFACTURING ON VIRTUAL PROTOTYPING

With the reduced investment costs involved in prototype tooling and production tooling then it is likely that there will be more entrepreneurial designs. Many good ideas are currently not pursued because of these investment costs so there is likely to be a growth in product variety and small companies established to exploit an inventor's idea.

However, there will be a need for more imagination from current designers to exploit the possibilities of more complex geometry. In some ways the current designers have been trained into producing simple designs which are not optimal. This is simply because manufacturing engineers have pushed the concept of having designs that are simple and easy to produce. There is also the likelihood that products will be much more integrated in terms of functionality and aesthetics due to part reduction and greater complexity. Ultimately, a hybrid designer may emerge—one that is skilled in aesthetics and mechanical design as well as Rapid Manufacturing techniques (Hague et. al., 2003b).

One area that will require less Virtual Prototyping will be concerned with interfaces as parts will be more complex and there will be fewer parts to model. It is often the interfaces between parts where the greatest difficulties arise in modeling because the surface properties may be different from the bulk properties. With more complex parts there will be fewer interfaces requiring fasteners, seals, adhesives etc.

The current CAD systems are very good for modeling solid and surface geometry but they will not be appropriate for more complex parts. For example, some CAD systems cannot tolerate topologically incorrect models such as a Kline Bottle. They are also unable to model textures, porosity and material composition, all of which have the possibility of control using additive processes. In some situations we will need to wrap textures over CAD models and this texture could be variable (Sachs et. al., 1994). The same variability could apply to porosity and material composition. Some of these areas are being addressed by TNO (Knoppers et. al., 2004)) for graded materials and by Hague (2004).

A serious deficiency at the moment is concerned with the area of Reverse Engineering for custom fitting products. For example, if a grip is to be designed and manufactured for a customer then it is possible to capture the geometry of the hand. However, what is required is the geometry for the hand to fit into that gives the most comfortable and effective grip. As the customer grips an object then the soft tissue deforms so there has to be some intermediate geometry between the geometry of the soft tissue and that of the bones. A Virtual Prototyping system is required that will take both sets of geometry and produce the grip geometry that gives the best fit.

As the number of Rapid Manufactured parts and products will be much lower than those from conventional processes and in some cases this will be a single unit the need for Virtual Prototyping will increase and this will have an impact on the type approval process to obtain CE marking (European Commission, 2000). As many of the initial applications appear to be in safety equipment then there will need to be some work to understand the implications in this area as products may be covered by the Personal Protective Equipment Directive (European Commission, 1989). If Virtual Prototyping is to replace physical prototyping then there would need to be great reliability in the results. In this area then Virtual test standards become very important to replace or augment the existing physical test standards.

In general there will be a much greater need for Virtual Prototyping and there will be much more of a need for design optimization of structures, airflow etc. This will also lead to simultaneous optimization (Sobieszczanski-Sobieski, 1996) where for example the strength of a Formula 1 fairing is being optimized at the same time as the air flow in CFD.

There will be less need for some aspects of virtual prototyping such as assembly and clash detection due to the reduced number of parts and therefore the smaller chances of interference.
Much of the existing Virtual Prototyping is associated with consumer products, automotive, aerospace etc. However, there will also be a need for a wider range of modeling capability in other areas and an example of this could be in the modeling of bone ingrowth into implants.

Of course all of this modeling is impossible if the properties of the materials are unknown and so it is important to obtain accurate material property data from the RM processes. To date there has been limited work in this area except for recent work to investigate the long term properties of Stereolithography resins and Laser Sintered nylon (Hague et. al 2004). One of the main problems here is that the materials are still developing and being replaced at a rapid rate. By the time the data is obtained for a material it is often replaced by a new version!

There is also the issue of how the customer will interact with the design process in the future. With mass produced products the customer is either canvassed before for opinions or takes part in product assessment clinics. Therefore, the customer input is either opinions based on general likes and dislikes, or is opinions based on seeing the product. To have customer input for customized products then it is likely that they will have to be involved more in the actual design stages. If this involves CAD then we will have a major problem. CAD systems are not designed for this type of activity and require an extensive skill level to be operated efficiently. Even if we had a 'customer-friendly' CAD system the next issue would be how the interaction would take place? There are a number of possibilities:

- Customer uses the CAD system to design a product
- Customer uses a design system on the web
- Customer goes to local 'Customisation Centre'
- Customer goes to the company

Each of these possibilities will have a major effect on the way companies do business.

Another effect of Rapid Manufacturing will be that more resources will switch from prototyping to design and manufacturing. At the moment the early design stages account for a small proportion of the total cost. With Rapid Manufacturing and Customization there will be a very great increase in resources to the design process and possibly a small increase to manufacturing.

One of the potential problems of Rapid Manufacturing will be the use of graded structures/mixed materials. We are currently developing a number of processes that can combine materials into complex structures. However, taking them apart for recycling will be a major difficulty. This will become even more of a problem with the end of life directives for cars and electrical products.

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