Virtual Prototyping or Rapid Prototyping for Tableware Design Evaluation

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ABSTRACT

The 21st Century is a digital world where modern tools for product development created in the last decade have become powerful and affordable alternatives for industry.

Prototypes are achieved within hours by Rapid Prototyping (RP) machines. Computer Graphics have reached a point where high detail, photo-realistic displays can be achieved. Virtual Reality (VR) is no longer a tool for researchers only. With all these different product development strategies, how can they be best utilised and combined?

Rapid Prototyping is the production of a physical model while Virtual Prototyping (VP) is the analysis and simulation carried with a computer model. The ultimate question to be answered is whether virtual representations can replace or be complementary to physical objects.

This paper will describe and discuss both technologies and investigates their suitability and effectiveness for tableware design evaluation. Tableware is an interesting product for this evaluation as it involves a combination of 3D shape and 2D pattern to make an effective design. The case study will make general recommendations for future application of these tools for this and other sectors.

1 Introduction

During the product development cycle, physical prototypes are frequently required for evaluation to provide feedback for design modifications [1] and yet a short product development cycle is crucial for company survival to enable it to deliver new products to the market quickly. These two requirements can be considered to be conflicting.

Using conventional processes and highly skilled technicians to realise prototypes can be substantially time and effort consuming and consequently expensive. For faster development, new tools have been released in the two last decades that promise to speed up the production of physical models and reduce the number of iterations in a products development.

Rapid Prototyping machines can now make physical prototypes overnight. Computer Graphics have reached a point where highly detailed, photo-realistic displays can be achieved. Virtual Reality is no longer just a tool for researchers but is widely available. The question is could these technologies reduce or eliminate the need of physical mock-ups?

Industrial sectors such as Manufacturing, Process Engineering, Construction, Automotive and Aerospace have recognised the power of Virtual Prototyping [2]. Companies such as Roll Royce, British Aerospace, and Volkswagen are now using virtual environments in their design process.

This paper will demonstrate a case study comparing product validation using Rapid Prototyping and Virtual Prototyping in the Tableware sector of the Ceramic Industry in order to establish if Virtual Prototyping can be useful.
2 Definitions

In order to remove any possible misunderstandings, a set of definitions need to be established in order to differentiate between the different technologies that this paper covers. These definitions will be general rather than specific to the Tableware Industry.

2.1 Rapid Prototyping (RP)

Rapid Prototyping can be defined as a method by which physical prototype models are generated from a numerical description such as Computer Aided Design (CAD) or 3D scan data. These models are built by quick highly automated and totally flexible processes.

Unlike Control Numeric Command (CNC) machines tools, which are subtractive in nature, RP systems join together liquid, powder or solid materials to form complex parts, even parts which cannot normally be made in one piece by traditional processes (Bearings, Chains…).

The principle of RP systems relies on building models layer by layer. RP machines fabricate plastic, paper, ceramic, or metal objects based on thin horizontal cross sections created from the 3D model. There are many different processes including Stereolithography (SLA), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), 3D Printing, Solid Ground Curing, Ballistic Particle Manufacture (BPM) and others [3]. Each of these processes has strengths and weaknesses that make them more or less appropriate for different applications.

2.2 Virtual Reality (VR)

Virtual Reality is a term that is widely used but often misapplied. The reason for this is that VR is a term that can be widely applied and can be interpreted by different people and in any number of ways.

Is a photograph virtual reality? Clearly a photograph is a representation of a real place or object and since it is not in the original location it could be argued to be virtual. However most people would accept that a photograph is not VR even if it is displayed digitally on a computer screen.

One of the fundamental requirements for VR is the definition of objects in 3 dimensional space (3D). This is one area where the photograph fails the VR test. So a CAD system that defines products in 3D would pass the 3D test but is it VR? Most CAD systems represent models on the screen using the most basic (but fast) algorithms that clearly give an impression of depth but do not attempt to represent the real appearance in anything but colour. So shadows, reflections and textures are usually ignored in the search for speed. The appearance of reality is limited. Moreover CAD Systems allow only one transformation (rotation or translation) at a time, and they are not intuitively obvious.

To enhance the perception of 3D it is possible to use additional hardware to view the scene stereoscopically. The viewer can wear special glasses and/or use projection systems to create a picture with a sense of depth. Most people accept this as being an important aspect of VR.

Take such 3D models and use high quality rendering software and faster computers to enable more realism to be added to the scene so that the model looks like is in a real environment and the idea of virtual reality is coming closer. The best exponents of this work are film companies that can generate movies that are so believable in terms of appearance that it is ‘difficult to see the join’. But is this virtual reality? Since the viewer is passively watching the scene unfold and is not able to interact with it directly most people would accept this is not virtual reality. VR requires the ability to interact in a natural way with the scene.

In summary VR requires some or all of the following:
### Increasing Virtual Reality

<table>
<thead>
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<th>Feature</th>
<th>Description</th>
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<tr>
<td>3D Computer generated model</td>
<td>Real time low latency generation of computer images.</td>
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<td>High quality rendering to show realistic features such as textures, reflections, shadows etc.</td>
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<td>Stereoscopic presentation giving an immersion into the scene.</td>
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<td>Interaction with the scene to allow the viewer to move around, pick up objects and interact with other people similarly immersed.</td>
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<td>Tactile feedback to the operator giving indication of forces and weights in the simulation.</td>
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### 2.3 Virtual Prototyping (VP)

Garcia, Gocke, and Johnson [4] define a virtual prototype as “a computer-based simulation of a system or subsystem with a degree of functional realism comparable to a physical prototype”. Their definition of Virtual Prototyping is “the process of using a virtual prototype, in lieu of a physical prototype, for test and evaluation of specific characteristics of a candidate design”.

Virtual prototyping aims at using the CAD data of a product in combination with virtual environment technology to offer designers the ability to visualise, interact and simulate what-if scenarios to assess various product life cycle issues and communicate design ideas to others.

Virtual Prototyping uses VR technology, therefore referring to the previous section where virtual Reality was defined, a virtual prototype has to be a 3D model, ideally viewed stereoscopically, high quality rendered and interactive. This means that viewing on screen or printer a flat ray traced picture cannot be considered as a method of VP in this instance.

### 3 Design Validation in the Tableware Industry

#### 3.1 Product Shape Design

Well known names such as Wedgwood, Spode, Royal Doulton, Portmeirion, Denby and others have now recognised the potential of CAD implementation in their design studio. This was mainly due to the fact that they recognised that the CAD system opens doors to other technologies such as RP and VP for design purposes and subsequently in CNC Machining for rapid tooling as well. The long-term goal is therefore the integration of design and manufacturing (CAD/CAM). Small companies have recognised the value of CAD too, but financial constraints mean lower adoption rates.

Shape modelling for tableware mainly consists of freeform surfaces. Tableware models are designed with the ceramic industries standard CAD system DeskArtes. This surface modeller offers many advantages to the ceramic designers and includes the ability to facet the models into a mesh of triangular polygons, which can then be exported as STL files suitable for RP.
3.2 Shape Prototypes

3D Systems developed and published the STL format in 1987 for converting the CAD models for use in their Stereolithography Apparatus (SLA), which was the first commercial RP machine. An STL file is a polyhedral representation of the part with triangular facets. It is generated from a precise CAD model using a process known as tessellation, which generates triangles to approximate the CAD model. Triangular facets are described by a set of 3 coordinate values (X, Y, Z) for each of three vertices and a unit normal vector to indicate the side of the facet that is outside the object [5].

Defects such as holes or cracks, non-manifolds, overlapping facets and incorrect normals frequently exist in STL files. DeskArtes allows unifying and flipping triangle normals to ensure the integrity of the model. Moreover, during the faceting, the software reports any gaps found and minute gaps can then be repaired. This process is essential to ensure the integrity and quality of the final models produced by RP systems.

After assessing different kinds of RP machines, the 3D printing system from Z Corporation has been identified as the most suitable for Tableware. Different reasons have given rise to this decision. Firstly the speed of the machine is attractive; you can grow a typical teapot in 5 hours for instance. The accuracy of Z-Corp prototypes is relatively low but tableware pieces do not such require the tolerances of more typical engineering parts! The Surface finish of Z-Corp models is fair but the prototype is easily polished and can be sprayed with a white glossy paint to simulate porcelain material. Perhaps the most important reason is the material used by the process – plaster. This is a material already widely used in the industry and it is possible to use the rapid prototype model to directly produce moulds for short run production. Figure 1 shows a RP teapot from the Z-Corp machine.

3.3 Artwork Design

The Ceramic Industry has been using digital tools for artwork well before integrating CAD system for shape design. This is due to the requirement to produce complex arrangements of colour-separated artwork for print houses to produce decals that will be placed on a wide range of porcelain shapes.

Artists create hand drawings or paintings of decorations, which are then imported into a computer by scanning. These artworks are afterward edited and retouched to fit on different kind of tableware shapes, using tools such as Adobe Illustrator and, Photoshop and the Typemaker product Platescribe.

3.4 Artwork Prototypes

There are two main different ways used for validation of artwork. The first is using a module in DeskArtes named ExTrace. This module allows the assignment of material and texture onto the geometry as well as defining the lighting environment before being ray traced. It produces a complex image in timescales that range from a few minutes to several hours. The acceptance of these 2D non-interactive photo realistic prints relies very much on the designer’s capability to realistically define and light the scene. Figure 2 shows a ray traced teapot produced on the DeskArtes CAD system.

The second technique consists of printing the decoration onto a decal that will be applied directly to the RP model. This removes the problem of interaction with the product just mentioned. This technique also permits testing whether the shape of the decoration fits correctly onto the product surface. However this technique is only used towards the end of the design cycle because of the time taken in the production of the 3D parts assuming they are actually available. Figure 3 shows a photo of an RP model with a decal applied.
3.5 Discussion

The RP model provides an interactive model to manipulate and test; however it can provide only relatively small or scaled-down parts. It gives just a single limited physical model that is unlikely to be made from the intended material which means that material properties cannot be simulated (reflection, shine of the porcelain and mass).

To remedy this problem, ray traced images are used in addition to these RP models for validation of design. However these images are unable to convey the quality of a design since they are limited to 2D and are not interactive. In the marketing sense they are equivalent to a photograph of the finished product - useful but not as good as being able to pick up and interact with the actual product. The combination of these rendered pictures with a rapid prototype model can be a powerful tool for describing design intent to clients.

These two tools (RP and Ray Traced pictures) improve design visualisation, product functionality, verification, iterative development and testing for optimisation of the product but they can still require a significant amount of time and money.

4 Design Process integrating Virtual Prototyping

4.1 Product Shape Design and Artwork Design

We have seen previously that in the actual design process digital tools are used to create shapes and decorations. Therefore, all the data is ready and available to be integrated in the VR software. The interface between CAD and VP is directly equivalent to that between CAD and RP since VR software uses polygonal representation of the models. However the decoration needs to be applied to these geometric models. This technique is called texture mapping.

In its basic form, texture mapping lays an image (the texture) onto an object in a scene. The texture is then applied to the polygon mesh by assigning texture coordinates to the polygon's vertices. These coordinates index a texture image, and are interpolated across the polygon to determine, at each of the polygon's pixels, a texture image value. The result is that some portion of the texture image is mapped onto the polygon when the polygon is viewed on the screen. Different kinds of projection are used according to the geometry to limit distortions due to applying a 2D picture onto a 3D surface.

4.2 VR Integration

Transfer of data between the VR and CAD software is poor and usually demands a customised exporter. DeskArtes did not have an integrated exporter suitable for VR. None of the current output formats wrote geometry files with embedded texture coordinates and material properties. Collaboration with DeskArtes has lead to the development of such an exporter for this project. The models were then exported as polygons to the VR software with their proper texture and mapping for decoration information.

A virtual environment was required to accommodate these models. These environments representing dining room were thus populated with the models placed on the table.

4.3 Visualisation

To simulate the navigation within the dining room, a Hand Controller tracked by a Polhemus Fastrack has been set up to allow walk through of the scene. The use of this 3D joystick gives a stronger feeling of being immersed, rather than 2D basic pointer devices, which do not allow up and down or rotational movements without using a keyboard shortcut or software commands.
Further interactions between user and virtual objects have been developed such as pickup, examine and replace items. Replacement of the complete dining set or just object texture is also provided to allow the user to compare different ranges of products see Figure 4.

A team of people conducts product development and validation, thus it is more convenient to display the VE on a large format projection screen viewable by everyone simultaneously. The projection is stereoscopic to give a sensation of depth. Stereoscopic display systems give users the impression of true spatial perception of computer-generated three-dimensional images.

4.4 Discussion

The main drawback of VP is the lack of touch interaction. Imagine having modelled a new handle shape for a teapot, how can you check on the screen that the design is correct and satisfactory for holding the product? Devices such as data-gloves and cyber-gloves are under development and may in the future address this problem but for now they are too expensive and unreliable.

However, since design is an activity that has no bounds, virtual prototyping enables designers to explore how things could be done versus how things are done. Virtual prototyping allows the exotic and unconventional designs to be prototyped, rapidly and cost-effectively.

Collaborative work means that people working on a project may be geographically dispersed. VP brings a solution to this scenario since the files can be sent via email or network to the remote workplace to discuss the design.

5 RP against VP?

Both RP and VP models can provide beneficial sources for simulation and validation of new products. It is difficult to state categorically which one performs better than the other one since they are in fact simulating different aspect of the design. The conclusion is that the recent development of VP will not make RP redundant. VP provides a source of computer graphics that removes the limitations of ray traced pictures and, combining these graphics with RP produces the most powerful prototyping combination.

We can differentiate Virtual Prototypes within two main groups: immersive VP and analytical VP. Analytical VP usually uses standard computing technology (mouse keyboard and screen) and is more widely developed in the simulation fields. Industry such as Automotive, Manufacturing, Aerospace and others use these analytical prototypes for different purposes such as kinematics simulation, assembly, fit and interference checking. These prototypes are poorly graphically represented since their purpose is more mathematical than visualisation of the product.

However often industries prefer RP to VP as a physical part for ergonomic and tactile evaluations, RP allows the user to gauge the size of the prototype. This demonstrates the importance of touch and this will remain a fundamental issue for the Ceramic Industry. Moreover, some companies maintain that they have noted a 15-25 percent reduction in tooling cost when a toolmaker uses an RP model.

Immersive VP is more likely to check shape than functional design, automotive developers use it to visualise car interiors for example. In this last example, we can obviously see how money is involved with creating a physical mock-up. These virtual mock-ups are used to gain a general feeling and often the degree of realism is average. Lighting and Shadowing are not pushed to their best. So they combine this VP with photo realistic rendered prints out.
It is not that expensive to create an individual physical prototype for a porcelain ware, but when you know that new range comes onto market every 6 months and this can comprise up to a hundred pieces per range you can see that we are talking consequentially of exigent time and money. Moreover, the shape design could receive ten different decorations meaning that you would need to create ten physical mock-ups to visualise them with the different patterns. Because of all these problems, the Tableware Industry use highly realistic rendered scenes of their ware with different backgrounds. They combine these photos with a few physical prototypes. They have adopted this process but are aware of the limitation of these rendered pictures that were discussed earlier in the paragraph 3.4.

The challenge was to create VP for this Industry, by producing a believable product with pieces fully interactive to the user. Porcelain, Glass, Gold and Silver are materials having properties, which are complex, such as reflection and refraction. These properties were often the reason people gave up with Virtual Reality because of the difficulty of achieving a good mimic of the representation of these properties.

The most useful function of VP is in the visualisation of the product within its intended environment (for instance a dining room in the case of tableware). Often in Virtual Prototyping, only the model is rendered without caring about its surrounding world. Having the piece in its natural environment changes the way you see it, more practical reflections can be carried out this way.

VP and RP are then considered complimentary and work well in association with each other but only if employed correctly. This statement is valuable and really applicable to any Industry. VP certainly reduces the number of physical prototypes during the design of products but RP models are still essential for ergonomic and tactile evaluation, assembly, fit and function checking. However the best scenario will be to create a single physical prototype at the end of the design cycle when the majority of iterations have been completed with virtual prototypes. Solving the problems in the VP domain helps reduce physical prototyping cost and time since mistakes are made in the computer rather than on the physical prototype.

6 Conclusions

Currently 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. However development is being undertaken to bring Virtual Prototyping applications to high-end PC’s rather than expensive supercomputers. Moreover, other ongoing development of computer technology (Graphic cards, Processors and others) means that complex VR system will work in real time even on a common personal computer. However, RP models are not cheap either, a typical price for a teapot prototype ranges from £400 for a Zcorp model to £1600 for a SLA version. Now bearing in mind that a range for a tableware can have on average 100 pieces, prototyping costs can have serious consequences. All the money spent on iterative physical prototypes can have been in the most of the cases saved by using virtual prototypes. This means that the return on the investment in Virtual Reality could be quicker than expected.

Developments in the Rapid Prototyping field is making machines faster and offering new capabilities. New types of material are emerging, providing pieces with different properties such as surface finishing. Zcorp has launched a new machine printing in 24bits colour, capable of printing the decoration directly on the tableware prototype for example but obviously the material has not the properties of porcelain (light reflection, shine…). So here again we can demonstrate that there is not competition between both technologies, they are definitely complementary.
Virtual Prototypes open the doors of 3DWeb integration. This is another application of great interest with the potential to integrate virtual product on web sites either for commercial sales or for marketing/research exercises. The use of 3D product representations on the web is very much in the embryonic stages but should not be underestimated. As the restriction of narrow Internet bandwidth is removed 3D VR models will be the normal means of presenting product on the web.

This Virtual Reality system offers new opportunities in sales support. This gives an illusion of the reality while just designing even before any physical product has been developed. Other business processes such as marketing and sales can benefit from VP. In the traditional retail environment, stores simply cannot hold sufficient stock, or indeed may not have enough display space, for customers to be able to try out all the products and make their decision. A full range of high end dining room products could easily include 50 different pieces. By complementing a small display of actual product with an in store point of sale computer, customers could click on those products they are interested in and actually view them in a virtual environment. The same scenario will be used during an exhibition or launch of new ranges of products.

Our vision of developing a virtual prototyping tool to allow designers to consider the whole life cycle early in the design phase, to produce quality products and reduce development time and cost have been well received by the Tableware Industry. The team is currently developing such a tool for Wedgwood.

Wedgwood as well have launched a new range last February, which was created with digital tools from the design stage to tool making. We consider this as a big step towards the digital world of our vision and we are confident that others in business in this Industry will follow on.

The main ongoing research themes include techniques for enhancing the physical realism of the virtual prototypes such as reflection of porcelain, shine of paint-applied materials (platinum, gold). Human Computer interfaces are being developed and tested as well, to achieve intuitive interaction with these virtual prototypes.
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2. http://www.vrac.iastate.edu/research/prototyping/index.html. And other applications

