

# An Investigation into the Capabilities of a Virtual Workshop

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## Abstract

The last ten years have seen major advances in design technologies, with Computer Aided Design (CAD), rapid prototyping and haptic feedback modelling evolving to perform operations that were unthinkable before the advent of affordable high speed computing. These technologies have now moved from commercial applications to higher education, and with the widespread use of three dimensional (3D) CAD in the secondary curriculum, it is not unreasonable to predict that the uptake of such technologies will follow suit. As the potential for a virtual workshop draws ever closer, this paper provides an overview of rapid prototyping and haptic feedback modelling through product design cases studies for a garden trimmer and toaster. The limitations and merits of these technologies are identified and the paper serves as a discussion document for those involved in the development of the secondary design and technology curriculum.

## Keywords

Virtual workshop, rapid prototyping, haptic feedback.

## Introduction

New design technologies have a habit of being expensive, as software developers and manufacturers seek to capitalise on their investment in research. Over time, as the market becomes saturated, educators benefit from incentives to introduce these technologies to their students. The secondary design and technology curriculum has now benefited from this evolution with powerful 3D CAD software and computer aided manufacture (CAM) now in widespread use.

The use of 3D CAD opens up opportunities for use in a variety of applications associated with design activity, and whilst CAM is the most obvious choice within the secondary design and technology curriculum, its use for the efficient production of components must be questioned. In contrast, rapid

prototyping has the capacity to directly translate 3D CAD geometry into physical components in one operation. In effect, the shape that the designer sees on the screen is what they receive as a rapid prototype component.

Unfortunately, the use of 3D CAD and rapid prototyping removes the ability of the designer to shape both the virtual component (as CAD geometry) and physical component (as rapid prototypes) by hand. This is not of course the case in a conventional workshop environment, where the designer manipulates material using a variety of machinery and hand tools. In an educational context this experience contributes not only to the development of craft skills and understanding of material properties, but the development of form through direct tactile interaction (similar to sculpting).

The increasing use of digital design methods can be seen as a threat to the learning experience afforded through craft activity, but this may be redressed by the emergence of the haptic feedback device. If successful, the introduction of the haptic feedback device has significant implications for the workshop environment, as replicating the shaping of physical material by hand and machine in a virtual environment has significant resource implications. This arises from the nature of the new working methods that facilitate a scenario where the virtual component is defined through touch (using a haptic feedback device) and 3D CAD. The design outcome can then be translated into a physical component through rapid prototyping. This would lead to a design environment that is largely comprised of computers, haptic feedback devices and rapid prototyping machines.

As the debate on the way new technologies are integrated within design activity at all levels continues, this paper provides an overview of the capabilities and limitations of rapid prototyping and haptic feedback modelling through the use of design case studies. Its aim is to inform on the status of design tools that

extend and enhance the use of CAD, and serves as a discussion document for those involved in curriculum development at a time when the emergence of a virtual workshop appears increasingly viable.

### Research Methods

In evaluating the capabilities and limitations of rapid prototyping and haptic feedback modelling, extensive use was made of case studies. Case studies have been described as an approach to research as opposed to a research method (Moore, 1983), with a capability, "to describe and understand the phenomenon 'in depth' and 'in the round' (completeness). In this role, case studies serve a useful purpose, since many important issues can be overlooked in a more superficial survey." (Birley, 1998 p36) In addition, the way in which data is collected and analysed "implies the collection of unstructured data, and qualitative analysis of those data" (Gomm, 2000 p3). The principle of an in-depth investigation into the integration of rapid prototyping within industrial design practice through the use of case study methods forms the core of this study.

In focusing on specific methods applied as part of case study research, Moore (op cit), Gomm (op cit) and Cohen and Manion (1980 p178) identify action research as a valid approach. Action research has been defined as an on-the-spot procedure designed to deal with a concrete problem located in an immediate situation. This means that the step-by-step process is constantly monitored (ideally, that is) over varying periods of time and by a variety of mechanisms (questionnaires, diaries, interviews and case studies, for example) so that the ensuing feedback may be translated into modifications, adjustments, directional changes, redefinitions, as necessary, so as to bring about lasting benefit to the ongoing process itself.

The cyclical nature of action research has been identified by Birley, who sees it as being conducted by a practitioner with the aim of bringing about an improvement in

practice (op cit). Action research was therefore considered particularly appropriate in meeting the objectives of this project, as it represented a recognised method for the facilitation of improvements in the execution of design and make activity.

### Rapid Prototyping

Rapid prototyping is a relatively recent technological development, with the publication of research in this area starting in 1982 and the first commercial system launched in 1989 (Kochan 1993 pv). Rapid prototyping has been defined as "the creation of three dimensional objects directly from CAD files without human intervention" (Wood 1993 p1), although it is necessary to extend this to acknowledge that it is an additive, layer-based process. The layer-based build process arises from the fact that the 3D geometry of the CAD component is converted into a series of layers that are then translated into the build material by the rapid prototyping machine. A significant feature of rapid prototyping is that as an automated process, the costing of components is based on volume and not complexity.

Kai and Fai have identified the generic operating principles of rapid prototyping systems, categorising them as: liquid-based, for example: stereolithography (SLA) and solid ground curing (SGC); solid-based, such as Laminated Object Manufacture (LOM) and Fused Deposition Modelling (FDM); powder-based, such as Selective Laser Sintering (SLS) (1997 p11). In addition to the operating principles, the material properties have led to a distinction between the more robust components of production rapid prototyping systems (SLA, FDM, SLS) and the concept modelling systems that are more suited to design iteration than prototype applications (for example: Thermojet and Z-Corp).

The most widely used rapid prototyping system is the SLA process manufactured by 3D Systems. This process involves the hardening of a photo-curable epoxy resin by a scanning ultra-violet laser. When the

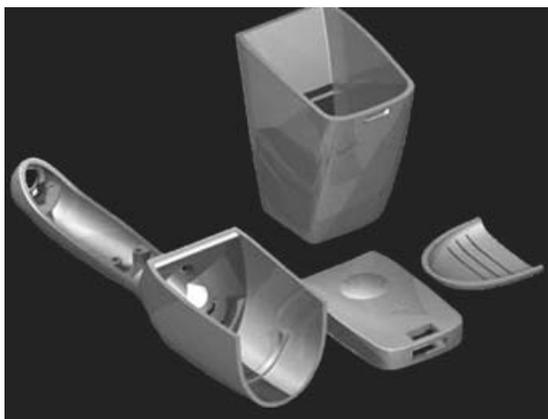
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surface layer of resin has been scanned and hardened by the laser, it is lowered to allow liquid resin to re-coat the surface. The laser then scans the next layer of the component and the process is repeated. The complete component emerges from the vat of resin when all layers have been hardened. To help prevent the build up of stress concentrations the laser only partially hardens the resin, so an ultra-violet light box is used to complete the curing process.

Other rapid prototyping processes involve the laser cutting of paper (LOM), the fusing of polymer granules by laser (SLS) and the extrusion and fusing of a heated polymer filament (FDM).

### Rapid Prototyping Case Study

The capabilities of rapid prototyping were evaluated through a product case study that involved the design of an innovative battery operated garden trimmer in which the motor was housed in the handle to improve ergonomics. Following concept generation and design development, all components were modelled using 3D CAD. This geometry was then converted into the .stl file format that is generally required for rapid prototyping. A rendered image showing some of the CAD components for the line trimmer can be seen in Figure 1.



**Figure 1: Rendered image of 3D CAD geometry used for rapid prototyping.**

The .stl files for each component were imported into the SLA rapid prototyping system and a complete set of components produced. The rapid prototype component

build took ten hours with another hour required for full hardening in an ultra-violet light box. It was also necessary to rub down the outer surface of each rapid prototype part to remove the stepped surface finish that results from the build process. This required two-and-a-half hours of workshop time to complete.

The rapid prototype parts were to be used to produce an appearance model that looked like a production item but had no working components. Testing for the fit for the SLA parts can be seen in Figure 2.



**Figure 2: Evaluation of fit for SLA components.**

Having removed the stepping and checked the components for fit, they were then primed and painted to give the appearance of production injection mouldings. This required a further three hours of workshop time followed by two hours for assembly. Detail of the cutter guard for the finished appearance model can be seen in Figure 3.



**Figure 3: Cutter guard on appearance model produced using rapid prototyping.**

Having produced the appearance prototype with considerable efficiency and confidence that it was an exact reproduction of the 3D CAD geometry (within tolerance), it was apparent that its use could be extended to appearance prototypes where the exterior form of a product is integrated with functionality: it looks like a production item and also works. This arose from the fact that wall thickness could be included at no extra cost, providing of course that it was specified in the 3D computer geometry.

A second set of components was therefore produced and internal components added for example: motor, drive mechanism, battery and switch. Figure 4 shows the integration of the flexible drive and universal coupling into the cutter head.



**Figure 4: Inclusion of working components into the appearance prototype.**

Following a period of testing and adjustment, the appearance prototype was used to evaluate the ergonomics and performance of the product as it represented an extremely close representation of the intended production item. Whilst no appearance prototype was produced using conventional workshop-based fabrication techniques, it was predicted that such a product would have taken five to six times longer to produce than one employing rapid prototyping.

### Haptic Feedback Case Study

The rapid prototyping case study demonstrated how a design progressed from virtual CAD model to physical components with no tactile interaction during the virtual and physical modelling phases. It was only during finishing operations that working by hand was employed, but by this time the design had been finalised. The shaping of material by hand has been at the core of design education since the founding of the Bauhaus after World War 1 (Heskett 1980 pp101-102, Whitford 1984 pp29-30) and the efficiency gains afforded through the introduction of new technologies should not be used to justify the removal of this key activity. The use of a haptic feedback device was therefore identified as an interface that would allow a designer to undertake tactile interaction whilst modelling in a virtual environment.

A case study for the design of a domestic toaster was devised to evaluate the capabilities of the SensAble FreeForm/Phantom haptic feedback system. This involved the comparison of two analogous modelling strategies that were intended to produce the same outcome. The first strategy required the development of the design through the manipulation of a physical material (Styrofoam). The second strategy employed the use of the SensAble FreeForm/Phantom haptic feedback system to manipulate a virtual material followed by the production of rapid prototype components using a concept build system. The SensAble/FreeForm system employs a 3D cursor that enables

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the operator to experience resistance when it comes into contact with 3D geometry. The FreeForm/Phantom system can be seen in Figure 5.



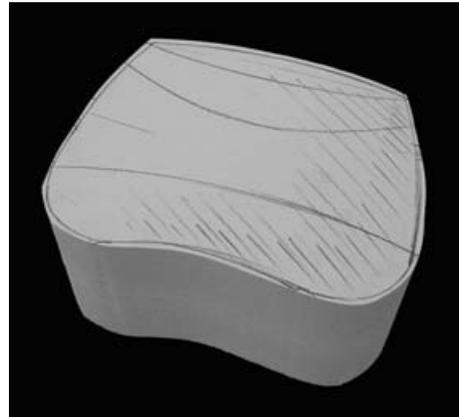
**Figure 5: The SensAble FreeForm/Phantom haptic feedback device.**

The evaluation of the workshop-based shaping of a material by hand involved the modelling of the toaster design in Styrofoam. Styrofoam is widely used by designers for the production of physical models as it can be shaped extremely quickly using basic workshop equipment. In translating 2D information to the 3D Styrofoam, the first phase required a block of material to be cut to size and drawings bonded onto the sides (see Figure 6).



**Figure 6: Orthographic sketches bonded onto Styrofoam block.**

In the second phase the cross-sectional shape was produced using a bandsaw and sanding disc (see Figure 7).



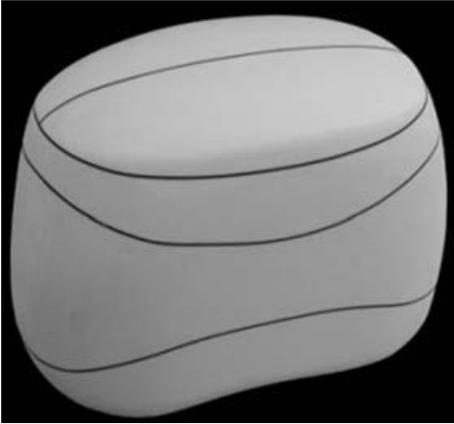
**Figure 7: Approximation of form using a bandsaw and sanding disc.**

The third and final phase employed abrasive pads and papers to precisely define product form through fine tactile interaction (see Figure 8).



**Figure 8: Definition of form through tactile interaction.**

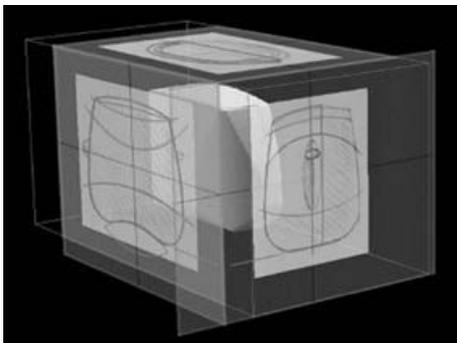
Tactile interaction took over from the 2D sketch information as a guide for the shaping activity and enabled the design to evolve in much the same way as sculpting. When the basic form had been defined to the satisfaction of the designer, split lines were added using black tape. The final sketch model can be seen in Figure 9.



**Figure 9: Styrofoam sketch model produced by hand in a workshop.**

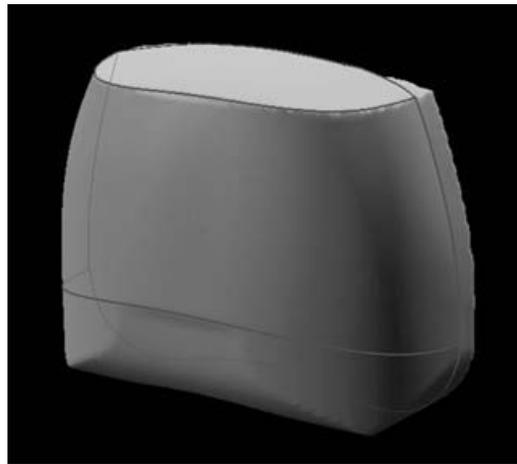
Having arrived at the required form through the tactile manipulation of material, the techniques used in the workshop were transposed to the FreeForm/Phantom haptic feedback device.

As with the workshop-based techniques using Styrofoam, the first phase of haptic feedback modelling required orthographic sketch views to be transposed into the virtual modelling environment. This was achieved by scanning the original drawings and importing them into the virtual modelling environment using the 'sketch planes' functionality of the FreeForm software. This functionality also enabled the transparency of the drawings to be adjusted to suit the particular modelling operation (see Figure 10).



**Figure 10: Sketch elevations imported into the FreeForm/Phantom virtual environment.**

As with conventional workshop-based techniques, the second phase of the haptic feedback method required the basic geometric form to be roughed-out. This was achieved using the 'wire cut' and 'smoothing' functionality of the FreeForm software. As the design had a line of symmetry, the modelling operations focused on the definition of a quadrant of the design that was copied and mirrored to produce the complete component (see Figure 11).



**Figure 11: Basic form defined using FreeForm/Phantom.**

As with the production of the Styrofoam sketch model, the third and final phase of the digital design strategy required a high degree of control over the emerging shape to enable the final surface geometry to be modelled through tactile interaction (touch). Whilst using the FreeForm/Phantom system, this activity proved to be far from straightforward as it was relatively difficult to achieve a smooth finish over the entire surface. However, by using some of the smoothing operations and adjusting the hardness of the virtual material an acceptable result was achieved, although concerns existed on the suitability of the surfaces for high definition rendering or manufacture as they lacked the surface continuity that is possible when using 3D CAD. The virtual sketch model produced using the FreeForm/Phantom system can be seen in Figure 12.



**Figure 12:** Final form defined using CAD-type functionality of FreeForm/Phantom, not haptic interaction.

Having completed the final phase in the definition of form, the virtual model was translated into physical components using the Z-Corp concept modelling rapid prototyping system. When assembled, the Z-Corp model became analogous to the Styrofoam model as a 3D physical representation of design intent in which the design had evolved through the tactile interaction with form.



**Figure 13:** Z-Corporation concept model produced using FreeForm/Phantom geometry.

Having approved the design through the use of relatively simple physical models, the toaster was rendered using the functionality of the CAD software. The final design can be seen in Figure 14.



**Figure 14:** CAD rendering of the final toaster design.

### Conclusions

The two product design case studies illustrated both the capabilities and limitations of rapid prototyping and haptic feedback modelling.

The line trimmer case study demonstrated that following the rapid prototype build, considerable workshop-based effort was required to produce the level of finish required for an appearance model or prototype. This was due to the time and effort required for the removal of the stepped surface finish and painting operations. Despite this, the SLA rapid prototype components were extremely robust and represented exact copies (within tolerance) of the geometry produced using 3D CAD.

Within an educational context, where students are required to produce products that actually work, the capability to economically produce components that closely resemble production items (with accurate wall thickness) would be a significant development. However, such practice raises issues in terms of the learning outcomes required of the design experience. Specifically, what is the significance and balance between designing and making. Whilst the use of rapid prototype components still necessitates assembly and possibly finishing, the higher levels of skill needed to produce similar components using fabrication techniques would no longer be

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required. This can of course be seen as liberating in terms of designing, as the student is no longer restricted by what they can make but what they can design and model using 3D CAD.

The use of the FreeForm/Phantom haptic feedback device introduced the missing tactile link that exists between 3D CAD and rapid prototyping. In fact, it could equally be identified as the missing link between 3D CAD and CAM should a decision have been made to machine or rout the sketch model from foam. Whilst the FreeForm/Phantom system represents the first generation of fully supported desktop haptic feedback devices, its capabilities were impressive as it provided an opportunity to sculpt and feel virtual geometry. However, when attempting to undertake fine finishing through tactile interaction, its ability to produce smooth forms with surface continuity was somewhat limited in that it was always slightly rippled. Despite its limitations, the FreeForm/Phantom system does make a contribution to design modelling that was previously unavailable, and whilst surface continuity may be an issue within higher education and professional practice, this is not necessarily the case within the secondary curriculum where exposure to new technologies and a more open exploration of form may be more appropriate.

If the use of rapid prototyping and haptic feedback modelling impact on the curriculum in a similar way to 3D CAD and CAM, the nature of the school workshop is destined to change as more products are designed within a virtual environment and remotely translated into physical components. Evidence from the line trimmer and toaster case study indicate a continuing requirement for craft skills as haptic feedback modelling still requires workshop skills as rapid prototype components are translated into finished products. As costs continue to reduce and availability increases, it is not unreasonable to predict that these technologies will impact on the school

workshop environment. The hands-on workshop will therefore continue to exist, but the nature of the "hands-on" experience will change considerably.

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