AHRC large research grant: The Fabrication of Three Dimensional Art and Craft Artefacts through Virtual Digital Construction and Output

Contents

Introduction – page 2 - 5
Research Methods – page 6 - 7
Aims and Objectives – page 8
Surveys – page 9 - 15
3D Printed Ceramics – page 16 – 43
  - Introduction and Background, p.17
  - Experiments, p.22
  - Summary, p.41
Case Studies – can be found in the online Annex at http://www.uwe.ac.uk/research/cfpr/research/3D/Research_Projects
Exhibition and Workshops – page 45 – 52
Papers and Articles – page 52 – 56
Summary of Research Findings – page 57 – 59
Introduction

**Grant Title:** The Fabrication of Three Dimensional Art and Craft Artefacts through Virtual Digital Construction and Output

**Awarding body:** Arts and Humanities Research Council

**Awarded to:** Professor Stephen Hoskins

**Research Team:**
- **Principal Investigator:** Professor Stephen Hoskins
- **Co-Investigator:** Dr Paul Thirkell
- **Research Fellow:** David Huson
- **RCUK Research Fellow:** Dr Peter Walters
- **Project PhD Student:** Brendan Reid

**Project duration:** 01/01/07 - 31/12/09

---

**Background to the Research**

In many ways this research project follows the natural progression of an underlying theme that has been present in much of the CFPR’s research to date; namely the relationship between technology, ideas and making in the arts and crafts. Two previous projects set the scene, the first investigating digitally assisted 2D print for artists, and the second, examining the possibility of adapting a bas relief imaging technique for the photographic decoration of glazed ceramic tiles. Each of these projects reflected on the field, identified past precedents, tested them in relation to the scope of new technology and pursued possibilities that would enhance their integration for fine art practice. The latter project also supplied valuable insights into 3D software and output through its focus on the creation of bas reliefs that was to feed into this project. As well as the expertise in modifying and manipulating technologies gained in the previous projects, one of the main catalysts in undertaking this research has centred around the increasing availability of the RP technology and the recognition that the field was on the cusp of change.

The Fabrication of Three Dimensional Art and Craft Artefacts through Virtual Digital Construction and Output project sought to practically assess whether it was possible to
expand on some of the recent developments and to use them for the fabrication of unique artefacts.

One such route relating to the area of ceramics had revealed promising results through pilot tests run in anticipation of this project. This involves the possibility of substituting the powders used in a Z Corp 3D printing system with a complete prepared ceramic body, comprising of a mixture of plastic clays, fluxes fillers and modifiers. This body is mixed using a conventional process and then spray dried and ground to produce a powder of specific particle size distribution and properties. By utilising the Z Corp process a physical ceramic object could be produced that is not subject to the limitations of conventional ceramic forming techniques. No moulds or machining would be involved and a direct translation could take place between the virtual object designed on the computer and a physical artefact.

It was anticipated that by further development of this method a completely new form of digital fabrication for ceramic objects may be possible allowing a ‘green’ ceramic article to formed, glazed and decorated in one process leaving only the final firing to be completed.

This would have important implications in the area of Art/Craft ceramics allowing the production of unique works and limited production runs to be achieved without the costs of modelling and tooling.

Introduction to 3D Technologies
3D computer aided design is a relatively new visualisation tool that has served to assist many aspects of modern industrial production. It has also become increasingly evident that these technologies hold enormous potential as a tool for the creation of artefacts by artists and crafts people. However as observed by Aitkin in 1999 ‘a minority of makers have had the opportunity to investigate the benefits of new digital media...’** This situation he noted was on the cusp of change due to the rapid advance of technology.

The development of rapid prototyping technology has already seen several phases; the first being purely a virtual visualization tool for assisting conventional fabrication, the second a means of visualizing and outputting 3D objects using both stereo lithography and subtractive, numerically controlled modelling techniques. The most recent however, enables 3D computer rendered objects to be created using a far more user friendly digitally driven output, especially through the additive 3D printing process.
While the subtractive and now the additive processes have fed both general and specialist industrial needs, high equipment and access costs have impeded the development of their potential for art and craft use, the new generation of relatively low cost (office, or in the case of the artist-studio friendly) rapid prototyping systems, have now become available. This allows -more than ever before- the full scope of the process to be accessed and explored by the creative practitioner. Not only can its potential for art and craft use be speculated and tested, a hands-on skill base for this particular sector can also be finally developed.

As suggested by the title “Rapid Prototyping”, the technique in industrial terms has become a means of creating prototypes for the visualization of an actual product, or in many cases a source for creating moulds to fabricate production line products. Previously, subtractive and additive processes have needed a certain amount of extra manual finishing to prepare smooth surfaces and coloured finishes. In 1998 Rees predicted “Full photo–resolution colour models would be able to contain colour and pattern with as much variety as a 2D printer, and could have notes photographs, patterns and solid colours printed directly on the model. Developing colour may yield other important results. As materials are selectively applied in areas of the model to make different colours, the same mindset could imagine materials applied selectively towards greater strength characteristics and variations of material characteristics.” **

This era has now begun to dawn with the resolution of systems such as the new ZCorp 3D printers which allow the production of a relatively finished surface without the need for external intervention. Significantly, in addition to this the technology is now moving towards the production of printed objects with photo quality colour.

This new more finished output, when viewed from the perspective of art and craft practice (especially in relation to the traditional ‘one off’ and ‘limited edition’ paradigm) marks the emergence of a unique possibility. As observed by Dr Ian Gibson in 1998 ‘As RP (rapid prototyping) processes become more refined, so the prospect of functional prototyping extends into mainstream fabrication. Already in some cases we don’t just use these machines to make prototypes but to make real products. CAD systems also have greater capability for realism which we want to transfer into physical forms with relative ease.”***

However, in considering the objectives behind the manufacture of this technology and the formulation of its output, the transient properties calibrated specifically for facilitating a range of industrially derived purposes hold little in common with traditional art and craft materials. In assessing possibilities in art and craft terms, these existing modes may prove to hold new value for creating certain types of artefacts, however, by comparison with traditional analogue fabrication methods their colour and longevity at this point of development may be seen to be lacking.

As this technology gains maturity and its user base expands it becomes increasingly evident that there are many opportunities for incorporating a further art and craft dimension to the process. A similar possibility has recently been echoed in the field of inkjet printing with several new generations of printer capacities being developed and expanded to accommodate artist quality archival papers and permanent pigmented inks. In the case of 3D printing there are a wide range of similar areas to be examined relating essentially to the permanence, colour and material qualities of output for the production of one-off bespoke artefacts or limited edition, 3D originals.

*THE INTEGRATION OF NEW MEDIA TECHNOLOGY IN CRAFT PRACTICE Taking Crafts into the Millennium P Aitken B.Sc, Research Assistant; Dr K Bunnell, Project Advisor; I Pirie DA;
Research Methods

In order to fulfil the aims and objectives of the project a number of strands of research were employed:
- Data searches and surveys to build an overall picture of the emerging field,
- Practical research to assess the value of existing technology for addressing the research question,
- Experimental research to modify and refine existing technology to reflect needs identified within the art and craft sector,
- Evaluation of methods identified and developed through the research by the production of artefacts from a diverse selection of arts & craft practitioners,
- The ongoing dissemination of findings to facilitate a loop of dialogue between art & craft practitioners, industry and the findings of the research.

Although the overall research aim was broad, it was envisaged that the pursuit of the problem principally from a ceramic building perspective would provide a model which will have and imply possibilities for other areas of art and craft related needs. Also through linking virtual 3D digital modelling directly with the output of objects embodying art and craft values, it was envisaged a new knowledge base for the sector would be developed. This ultimately has the potential to feed back into industry as well as enrich contemporary art and craft practice.

The project has sought to identify routes that may be taken by creative practitioners through accessing the tools of the current generation of CAD – CAM and rapid prototyping technologies for the production of objects.

With the assistance of AHRC project funding, and an additional UWE, SRIF 3 allocation, a research lab was equipped for the project with a broad spectrum of 3D equipment. This range sought to cover each phase of the potential working process from data capture, data processing through to output. The technologies were chosen to reflect routes that were either already being accessed by, or those that soon may be accessed by creative practitioners. An additional resource lay in the CFPR laser cutting facility through which it was anticipated there may be crossover and complementary functions that could be used to enrich the scope of the project’s aims, see Artist case study: Brendan Reid – ‘Bone and Skin’ Manta)
While software remains the main tool for designing and constructing objects for output, the possibility for sampling real world objects was anticipated through the acquisition of two different types of scanner. Currently there are a number of sophisticated 3D scanners on the market such as the GOM scanner which represents a pinnacle in current 3D scanning, however, both the high price and the awareness that the technology in this field may not yet have matured, led to the consideration of lower quality cheaper options that may be more easily accessed by the artist. After some consideration in terms of art and crafts accessibility, the combination of a Microscribe arm with a Microscan head and the Z Scanner 700 appeared to cover a wide base with complementary capabilities.

The Z Scanner – hand held scanner was found to offer the crucial range of flexibility that was required for scanning the detail of complex shapes whilst the Microscribe arm with a Microscan head offered a means of more readily capturing and tracing smaller shapes.

To assist the 3D rendering and construction, a survey of software revealed that the 3D programme ‘Rhinoceros’ appeared to be one of the main current standards. To complement this, and assist with the cleaning up and processing of scanned material a further software package – ‘Geomagic Studio ’ - was obtained to work in tandem with Rhinoceros.

In order to render the files built or processed through the software, three additive style printers and a subtractive, 4 axis CNC milling machine were purchased. These were a Z Corp monochrome printer, a Z Corp colour printer, an Objet polymer printer and a Roland 4 axis milling machine.

Each machine was thoroughly tested in relation to build values, and assessed in relation to strengths and weaknesses in creating objects that could be presented in a fine art gallery context. Other types of 3D output were surveyed by sending test files to a number of facilities and manufacturers including Envisiontec and Stratasys. In addition to the assessment of build values, an assessment of colour qualities – specifically in relation to the Z corp colour printer was made and supplemented with the creation of physical, colour look up charts. (See paper: 3D Printing in Colour: Technical Evaluation and Creative Applications).

As well as testing the function of current printer output and standard materials, the research sought to examine the use of alternative, more conventionally accepted permanent materials that would move the function of output from prototype to permanent object. This concept was addressed through the substitution of powdered ceramic material for the standard plaster and starch powders normally used (see tests).
Aims and Objectives

Aims
In light of the current level of quality achievable through the new generation of 3D printers and the enormous potential of this tech for art/craft production this research aims to:

Theoretically define and practically consolidate routes which can assist in incorporating the creative flexibility of digital 3D rendering with the material and tactile qualities intrinsically associated with art and craft practice. The research will specifically focus on the direct output of finished objects produced through the additive, 3D colour printing process.

Objectives

- To survey the field of industrial and craft use of 3D prototyping in order to map the creative potential from an art and craft perspective including software & hardware.

- To evaluate the strengths & weaknesses of additive 3D printing methods in relation to subtractive methods such as CNC milling.

- To investigate the possibilities for substituting the various powdered materials developed for the present scope of 3D printing with those that may facilitate the production of a permanent original rather than a temporary prototype.

- To pursue the possibility for printing and firing clay bodies to create ceramic artefacts.

- To investigate how permanent colour can be incorporated at the object printing stage especially in relation to ceramic decoration.
Surveys

This section outlines insights gained from surveys of the field of 3D practice carried out to provide a series of baselines for the research. Three overviews are included. These outline the current technologies, assess the material qualities surface and form in rapid prototyping and a rationale for the selection of equipment tested and modified for development in relation to the projects aims.

Overview of current 3D printing technologies

Extracted from 3D Printing for Artists: Research and creative practice Rapport Journal of the Norwegian Print Association No. 5. 2010. Walters, P., Davies, K.

A 3D printer is a computer-controlled machine which can fabricate physical objects by depositing or solidifying materials in layers. Each 3D printed layer corresponds to the cross-sectional shape of the object being built. One layer is printed on top of another, and each layer is bonded to the next, creating a continuous, monolithic object. Designs to be produced by 3D printing are created using 3D CAD software. Common software used for this purpose includes, for example, Rhinoceros (Robert McNeel and Associates, Seattle, WA), SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) and Alias Design (Autodesk, San Rafael, CA). Models created in 3D animation software such as Maya (Autodesk) can also be exported for 3D printing. Model files are saved in a polygon mesh format (.stl). 3D printing software “slices” the model and transmits this slice data to the printer, each slice becoming a 3D printed layer. A widely-recognized benefit of 3D printing is that complex objects can be fabricated in this way, including 3D forms which would be difficult or in some cases impossible to make by traditional workshop processes such as machining or casting.

A number of different 3D printing processes and materials are available, and these will now be described. Stereolithography (3D Systems, Rock Hill, SC), in which a light-sensitive polymer resin (photopolymer) is solidified by a laser beam. Selective Laser Sintering (3D Systems; EOS Electro Optical Systems, Munich, Germany), in which a thermoplastic powder is fused together by a laser beam. Metal Laser Sintering or Selective Laser Melting (3D Systems; EOS; MTT Technologies, Stone, UK) in which metal powder is sintered or melted together by a laser beam. Fused Deposition Modelling (Stratasys, Eden Prairie, MN) in which a filament of molten thermoplastic is extruded from a nozzle, and solidifies as it cools. Powder-Binder 3D Printing (Z-Corporation, Burlington, MA) in which plaster powder is bonded together by an inkjet-printable liquid binder. Photopolymer Jetting (Objet Geometries, Rehovot, Israel) in which a liquid photopolymer is deposited through an inkjet print-head, then cured by ultraviolet light. Digital Light Processing-based modelling devices (Envisiontec, Gladbeck, Germany) employ Texas Instruments DLP projector technology to selectively cure a photopolymer resin, including a wax-like resin, which is suitable for use in “lost-wax” metal casting applications. More detailed information about these technologies and their application can be found on the manufacturers’ websites.

Extending beyond prototyping applications in engineering and industrial design, where the technologies are most commonly employed, practitioners in the creative arts have exploited 3D printing as a means to fabricate one-off and limited edition artworks and design artifacts. For example, for her work entitled 1:1.96 (2002) the German artist Karin Sander employed 3D scanning and 3D printing to create a large number of replica figurines of visitors to the Staatsgalerie in Stuttgart*. The rapid prototyping company Materialise (Leuven, Belgium) have used 3D printing to produce a range high-value, designer lighting products**.
Overview of available 3D printing machinery

One of the main aims of the project The Fabrication of Three Dimensional Art and Craft Artefacts through Virtual Digital Construction and Output was to investigate the use of digital fabrication methods by creative practitioners for the production of art and craft artefacts and to investigate the creative opportunities created by 3D scanning and reverse engineering technologies. At the start of the 3D project a broad investigation was conducted into the technologies and equipment available on the market, and to the equipment requirements that would allow the stated aims and objectives of the project to be met. Download full report here

Fine art values in 3D: Material qualities, surface and form in rapid prototyping

In the fields of fine art and design we are often confronted with the idea that - materials can bring life to an object; or indeed (as noted by Ashby & Johnson 2002, p14) create an product’s (or objects) personality. However, with 3D Rapid Prototype Printing - and other forms of digital output - the medium or material on which the virtually manipulated object or image is to be rendered is frequently designed to carry information about the personality and character of other materials that have been virtually manipulated and constructed. For this reason they are ideally designed to mimic (in hardcopy) digital information with out overtly imposing any of their own material qualities.

Although in RP terms, the build materials largely serve to convey a concept that is ultimately intended to be built in other materials, it was decided in the context of this research, to consider the material qualities of the raw output medium as an entity in itself as well as its capacity for imitating others. Where possible it was intended to use these insights to develop new possibilities for extending the capacity of Rapid Prototype output as a means of creating more permanent, aesthetically focussed forms of output.

The material qualities of a typical range of 3D rendered output was therefore assessed in relation to:

a) the qualities of the actual existing build materials b) the capacity of the technology in conjunction with build materials to accurately reproduce elements such as texture and tone and colour

From the perspective of the of the pure build materials, it was found that there was some variance between each of the techniques examined. Materials ranged from coloured plastics, rubber like flexible materials through to plaster and starch materials available from the additive processes. In the case of subtractive processes such as CNC milling, a range spanning from specially formulated milling materials such as foam and resin bonded boards through to any number of conventional materials - through the selective use of the machines sculpting tools - that can be milled.

While traditional artists practice, especially in the field of sculpture has incorporated the mainstays of stone and wood for carving and metal for casting, in Modern and Post Modern times, these have extended to almost any material available, including modern plastics, through to the use of found objects in the form of ready-mades and mixed assemblages. In this respect, it is evident that 3D output covers a range of materials that have already been explored by artists and indeed some that haven’t. One of the questions broadly examined by this research therefore sought to discover whether the material and tactile qualities intrinsically associated with art and craft practice could be faithfully reproduced, used or extended through and artists engagement with digitally mediated RP output?
To begin to answer this question, an analysis of the basic surface qualities common to each current form of RP output was undertaken. This was achieved by assessing those commonly associated with the materials that have been adopted for RP output. As both plaster and plastic are currently some of the main components, qualities such as smoothness, resolution of detail and strength were comparatively examined. Whilst notions of both materials often revolve around smoothness generated through mass produced moulding and casting techniques, it was observed that RP output in these generally had a characteristically rougher, more textured surface, even when the object to be printed had been assigned a smooth surface. One of the main reasons found for this was that each of the additive RP techniques, process and render objects by horizontally slicing and then sequentially building. As a result there is a tendency for a wood grain like contour pattern to be imposed on the final objects surface. Therefore the smooth surfaces we commonly associate with plastic and plaster objects made conventionally through casting often take on a less familiar, rougher quality when created through rapid prototyping.

In the terms of the traditional notion of ‘truth to materials’ and the ‘syntax’ of a process, it could be concluded that these qualities represent something of the essence of the process, and in those terms may be exploited by artists who wish to indicate the traces of production and the natural language of the technology in the their piece. For others wishing to reference the more universal notions of the seamless surface, the material quality of an object may need to be balanced with the capabilities and resolution of a machine. For example whilst a Z Corp 310 Plus, powder printing machine offers a plaster like build material, the quality of the intended surface may be further mediated to coax it from one state to another through the operators tacit knowledge of the printer to reduce interference from the build mechanism. Other machines such as the Objet, Eden350V have a higher resolution build capacity so therefore reveal less of a trace of the production.

As has been suggested by McCullough, it is essential even with new technology such as 3D fabrication to choose a medium whose intrinsic advantages are appropriate to the task at hand. (pp 198 –199, 1998). It is therefore necessary, even at this nascent stage of computer assisted fabrication for the arts, for makers to assess their options in relation to the intended qualities of the final output.
As has been frequently observed, one of the principal differences between computer aided construction and traditional artists making practices is that an engagement with touch - and therefore a sense of ‘cause and effect’ - is missing from the equation. Whilst haptic elements have been introduced to various forms of 3D software, they relate only to generic, virtual interpretations of ‘real world’ materials, but not specifically to the materials through which the object is to be prototyped. This therefore leads to a simulation of the material qualities of one medium being rendered in another (in this case the printers build medium). Alternately, an object may be built without any consideration of real world material qualities and in this case a material quality will be assigned by default at the printing stage.

This separation from cause and effect in rapid prototyping has a tendency to remove the influence of a materials natural qualities from the design of it’s form. Whilst form is freed to a certain extent from the constraints of a material, the fusion of the two elements to provide a functioning whole is somewhat undermined. The naturally transformative element that Ingold (p 7, 2007) connects with human making here is interrupted and instead a digitised series of options are offered. Although these frequently align with the logic of traditional making techniques, under some circumstances, the disconnection can lead to weaknesses in form. These are again very much overcome through the users tacit knowledge of the software, the printing machine and materials used. In other cases the direct disconnection from material values allows objects to be constructed and output that couldn’t otherwise be made any other way. (See example below).

Through either digital software or 3D scanning, a range of textures can be imposed or incorporated on the surface of an object. Although it was found that software for virtual 3D
construction and animation such as ‘Maya’ offer unlimited - but largely unprintable possibilities- the software connected with ‘making’ for RP output is more limited. Generic presets are incorporated, however, for artists and designers looking to extend the possibility of using and applying texture have to look to other routes. In some cases the scanning of texture offers the possibility for capturing and applying bespoke textures to an object, however, due to resolution issues in capturing fine detail, this option has proven to be limited. One of the most effective methods identified for generating texture that could be sampled for use came from the use of photographic imagery. Here through the conversion of images into greyscale and the assignation of heights according to the different tones in the image, sometimes highly complex, printable textures could be created. Another method lay in emphasising and exaggerating the build mechanisms of the printer to generate and mediate texture within an object. Through manipulating tool paths, the project’s PhD student Brendan Reid was able to produce a series of increasingly voxelated forms that demonstrated this possibility.

Whilst form and texture were the only elements that could be considered in relation to monochrome printers used for the project such as the Z 310 Plus and the Objet Eden 350V, the Z corp spectrum 510, offered the additional element of colour. This aspect enabled the material and surface qualities of the printed output to be manipulated even further. Simple transformations such as the imposition of all over colour, or the selective use of colour to decorate different parts of an object could be used. Additionally, the possibility of wrapping complex photographic imagery around the built forms offered new scope for artistic exploration. This element of RP led to the exploration of post print colour and surface enhancement. Both existing methods and possible extensions and alternatives were examined. These included wax infiltration through to the use of resins and other bonding materials. (See survey of equipment). As RP colour printing is an inkjet technology, research was undertaken from a colour science perspective to assess and optimise the colour quality available from the generation of printers used (see paper: 3D Printing in Colour: Technical Evaluation and Creative Applications).
In addition to looking at the creative possibilities for using the existing qualities of rapid prototype output for the creation of fine art and craft based object production, a major strand of the research the project sought to develop new approaches to rapid prototype output. This was done through the modification of a Z310 printer to print clay bodied objects that could be fired to create a permanent ceramic object.

The research into ceramic building involved the possibility of substituting the powders used in a Z Corp 3D printing system with a specially, prepared ceramic body. By utilising the process developed, the prospect of producing a physical ceramic object that was not subject to the limitations of conventional ceramic forming was developed. This has offered important impacts for the area of Art/Craft ceramics allowing the production of unique works and limited production runs to be achieved without the additional costs of modelling and tooling.

As a means of imparting knowledge resulting form the technical and aesthetic explorations of the project, a series of artists including members of the research team have been invited to exhibit artworks that respond to a broad brief devised by the curator of the show. Using both 2D and 3D printing technologies the artists will create artwork that will be exhibited in Scotland and Norway in September 2010 and January 2011.

*Photographs and a description of Karin Sander’s artwork 1:1.96 (2002) can be viewed on her website http://www.karinsander.de/index.php?id=e2**. MGX collection of products by Materialise, Leuven, Belgium http://www.materialise.com/materialise/view/en/2555641-.MGX+Collection.html***The term truth to materials relates to 20th Century direct carving in which the sculptor responds to the nature of the block being carved as much as the
subject.****A visual language dictated by the constraints of a technical process (eg a printing process). See Ivins Prints and Visual Communication.

3D Printed Ceramics

This section outlines innovative research into modifying existing technology to push the current boundaries of 3D output. The following document describes the stages of development for 3D ceramic printing carried out within the project.

A major strand of the research project was to investigate the potential of using 3D printing technologies to directly form ceramic artworks. The intention was to attempt to replace the proprietary plaster based powder in a Z Corporation 3D printer with a ceramic body in powder form. If successful this would allow one off or short runs of bespoke ceramic artworks to be produced directly from a 3D virtual model that had been designed in a 3D computer aided design (CAD) software without the need for the traditional intermediate steps of modelling and mould making.

This report will detail chronologically the route taken to achieve the aims of the project, to develop a viable 3D printing process for art and craft ceramics, from the first trials with ceramic powders through to the final outcomes. It will show the problems encountered on the way and the solutions derived to overcome these problems. To illustrate the process short case studies of artworks developed by Brendan Reid the PhD research student on the project will be used along with test pieces developed by other members of the Centre for Fine Print Research (CFPR) research team.

A method of direct printing ceramic artefacts has been successfully developed and extensive trials have taken place. A patent application is being made for the process, at this point in time the team believe that this particular approach to 3D printed ceramics is unique within the field and has the potential to become of real commercial benefit. Discussions are currently taking place to launch a commercial product with a 3d rapid prototyping manufacturer; therefore at this point in time the exact nature of the process is commercially confidential and cannot be published.

Background

The CFPR was first introduced to 3D digital technologies and rapid prototyping techniques during an earlier Arts and Humanities Research Council (AHRC) funded project to investigate photo-ceramic tiles. This project successfully managed to reproduce by using digital technologies a 19C method of generating a continuous tone photographic image onto the surface of a glazed ceramic tile by using a combination of a tinted glaze overlying a relief map of the image. When early attempts to produce the reliefs by using photomechanical techniques prove unsuccessful a method of generating the relief by using a combination of 3D software and a computer numerical control (CNC) rapid prototyping machine was developed. This technique enabled a series of photo-ceramic tiles based on images supplied by invited artists to be produced and exhibited at the City Museum of Stoke on Trent alongside the original 19thC tiles.
The appearance of relatively low cost 3D powder printers from Z Corporation gave rise to the idea that these technologies could perhaps be used to print ceramic artworks and funding was obtained from the AHRC to investigate. Further funding was realised from a UWE SRIF 3 allocation to establish a 3D laboratory and to acquire the additional equipment necessary to fulfil the aims of the project.
Z Corporation 3D printing system

Fundamental to the concept of 3D printing of ceramic powders is the Z Corporation 3D printer, the purchase of a Z 310+ model at the start of the project allowed development work to begin. The Z Corp system uses two moving beds of powder traversed by a carriage consisting of a roller to move a precise thickness layer of powder from the feed bed to the build bed and an ink jet head that moves north and south on the same carriage. The printer software slices a 3D virtual model into layers 100 microns thick and sends each layer to the print head sequentially; each layer represents a cross section of the model. The ink jet head prints binder onto the powder build bed in the pattern of the layer cross section, the build bed drops down by a layer thickness, the roller mechanism moves across to the feed bed which rises by a layer thickness, the roller then sweeps the layer of powder from the feed bed across onto the build bed and the process ids repeated until the model is built, After allowing about one hour for the model to set, the model can be removed from the build bed and the excess powder is removed.

Images: Z Corporation 3D printing process schematic
First experiments with 3D ceramic printing

In conventional ceramic forming processes a clay body is used that is composed of a mixture of different material that react together to form a fired ceramic, an industrial ceramic body for general use will contain clay minerals which exhibit plastic properties when mixed with water and this allows the ceramic body mix to be shaped or formed into mould and provide the green (unfired) strength to the mix. Other components such as feldspathic fluxes are added as they form a glass like structure during firing to bind the materials together, the final ingredient is silica in the form of flint or a ground sand that acts as a filler and is vital to obtain the correct thermal expansion of the fired body to ensure a good glaze fit.

The selection of different types of raw materials and the adjustment of the ratios of these materials in the blend allows the fired characteristic of the final ceramic body to be achieved. Ceramic clay bodies can be bought from suppliers ready prepared or can be mixed from the basic ingredients. In industrial ceramic production one form that be bought is spray dried material, this is a fully prepared and pre-mixed ceramic body that is in granular form. As a starting point for the 3D ceramic printing experiments spray dried material was sourced and introduced into the feed bed of the Z Corp printer.

Some simple geometric shapes were drawn in Rhino 4, a computer aided design (CAD) software package and loaded into the Z Corp printer driver software. The first indications were that although not as good as the native Z Corp material the spray dried body had reasonable flow properties and printed reasonably well, unfortunately on trying to remove the printed forms from the build bed the green strength was seen to be inadequate as they crumbled back to dust. The procedure was repeated but this time much more care was taken in removing the printed forms and prior to handling they were carefully dried to remove any moisture remaining from the binder. After drying the printed forms were fired in a kiln at 1150 deg C and examined, as can be seen from the following photographs some distortion had occurred. The fired forms had a very low density and were quite friable; in some respects they resembled a “ceramic sponge”. Nevertheless the first 3D printed ceramic object had been made.
While it had proved possible to 3D print simple geometric shapes in a ceramic material, because of the poor green strength it would be very difficult to print a more complicated form, to circumvent this problem a two stage firing regime was investigated. The maturing temperature of the ceramic body mix being used was 1150 deg C, it was thought that by printing a more complex form and removing it from the build bed still encased in the unbound powder it would be possible to pre-fire or sinter the ceramic material to a point that the printed model could gain sufficient mechanical strength to retain its form while the supporting powder would be loose enough to by removed from around the model by brushing it away. Firing trials were carried out and a temperature of around 990 deg C was discovered to be the optimum for this particular body.

In terms of ceramic production the unique property of a 3D printing system means that it is possible to produce complex forms that could not be realised by conventional forming methods, freed from the constraints of moulds and tooling, to demonstrate this property a 3D model was constructed in Rhino 4 CAD software of a lattice sphere containing a ball, this model was to be printed out and processed using the two stage firing method.
Image: CAD model in Rhino 4
Images: Ceramic 3D printing of CAD model

Image: Pre-sintered form prior to de-powdering
The two stage firing process combined with the spray dried ceramic body had been shown to be able to be used to form 3D printed ceramic objects but while it had the advantage of the prepared body material being readily available and of the correct thermal expansion, the coarse grain size and the poor green strength which necessitated the two firing approach limited its attraction as a process worth further investigation.

It was decided to investigate a different material to see if some of the disadvantages could be overcome.

Ball clay is sedimentary clay that is used in ceramic bodies for its contribution to green strength, it is highly plastic with a fine particle size and when fired to around 1100 deg C is self fluxing and will produce a dense body. A commercially available ball clay was obtained and a series of printing trials were carried out on a range of models.
Images: 3D ceramic printing with ball clay showing results and problems
Using the ball clay gave a useful insight into how the 3D printing process operated with ceramic materials, because of its high green strength it became possible to print out models that could be remove from the build bed without breaking and could be de-powdered and fired in without having to follow a two firing pre-sintering route. The fine particle size particle size of the ball clay while contributing to the superior green strength also gave a much improved surface finish. On the downside the properties that showed what was needed to solve some of the problems in the original spray dried body system also caused difficulties. The high plasticity that helped the unfired body strength caused problems with cracking of the model when drying (the binder used in the process contains a high percentage of water which is absorbed by the powder) and the same action causes the individual layers of powder to curl and shift causing distortions in the model. From a ceramic point of view using a single ball clay type material is not a viable route to produce ceramic objects as well as the above detailed problems the thermal expansion characteristics means that it would be very difficult to find a glaze to fit. However the ball clay trials were extremely useful in determining the next direction for the investigation.

A widely used ceramic body, particularly in the UK ceramic industry is an earthenware body, a typical recipe for this type of material would be 25% ball clay, 25% china clay, 35% silica and 15% flux, the ratios of the components in this type of body can be adjusted to optimise the characteristics of the body. The standard method for processing these materials would be to wet mix them to and then either to de-water the mix by filter pressing to make a plastic clay body or to spray dry the material for dust pressing. The previous work carried out during the project showed that a fine particle size with sufficient plasticity to provide a reasonable green strength would be essential.

Investigations during the project and research into the details of the Z Corp 3D printing process had indicated that the addition of certain binders and supplementary materials to the powder mix would help to solve some of the problems with the previous ceramic body mixes that testing had highlighted.

It was decided to dry blend a mix of the earthenware ingredients with the addition of binders and catalysts to the powder and to run a series of tests and trials.

*Images: ceramic 3D prints in new earthenware body*
With the new dry blended earthenware recipe body the same set of models as in the earlier trials were produced to provide a comparison. The performance of this ceramic body was far superior to the original trials; it was possible to remove the green printed ceramics from the build bed and fire in one process. Adjusting the orientation of the models in the build bed helped to reduce the incidence of layer shifting but did not completely eliminate it. Although the fired contraction, porosity and surface finish were not yet comparable with ceramics formed by conventional processes it was thought that attempting to produce a one off ceramic artwork using the 3D printing ceramic process would be a useful exercise. Brendan Reid, the PhD research student working with the team, had been using 3D CAD
design techniques allied to the 3D scanning of found objects to construct 3D virtual models, by printing these models in the new ceramic powder it would be possible to determine the viability and desirability of the new process.

Image: CAD model in Geomagic Studio

Image: laser 3D scanning wing

Image: scanned wing in Rhino 4
Image: finished CAD model in Geomagic Studio

Image: final concept rendered in Rhino 4
Images: 3D printed ceramic swallows prior to firing

Image: Concept rendered in Rhino 4
Images: Fired and glazed 3D ceramic Dead Swallows

Creating the Dead Swallows concept in 3D printed ceramic material showed that a viable reproducible process had been developed but that it still had serious limitations; from an aesthetic point of view the surface quality and definition of the finished work could be improved. Looking from a technical perspective there were four areas that needed to be improved, these were layer shift, too high fired porosity, too high fired contraction and variable surface quality.

To realise these aims it was decided to take a two track approach, research had indicated that by applying the new powder binder addition and catalyst to pre-processed commercially available bodies it was possible by careful attention to the particle size and the overall particle size distribution to create a ceramic body suitable for the 3D printing process. The reduction in particle size by ball milling gave an increase in green strength that allowed the liquid binder saturation level to be reduced. This had a beneficial effect on the layer shift problem and reduced the incidence of this to acceptable levels. By controlling the particle size distribution the high porosity and high fired contractions exhibited could be reduced to manageable proportions and were starting to approach the figures experienced with conventional ceramic bodies in conventional ceramic forming techniques. Being able to adapt any commercially available clay body by pre-processing and the powder binder/catalyst addition would increase the flexibility of the ceramic 3D printing system in the range of bodies that could be processed and the final fired appearance and characteristics. A commercial bone china body was acquired and prepared for 3D printing.

Although modifying a commercially available body had the potential to give good results it meant that the firing performance of the body was still tied in to a fixed body recipe, the exact recipe and the materials used in commercial bodies are confidential, so a second track was followed that involved using the knowledge gained from the previous trials and experiments to construct a suitable ceramic body for 3D printing from raw materials, again with careful attention to particle size distribution and with the addition of powder binders and catalysts. A porcelain type was blended and prepared for 3D printing. Both of the new bodies were used for case studies to demonstrate their properties.
Using the bone china body a case study was done using a 3D model created by Brendan Reid. Manta was designed in Rhino 4 and intended to be produced in a range of materials at differing scales by various rapid prototyping methods.

To reduce the potential for distortion in the firing process, the ability if the Z Corp Z Print software to form a support structure was used to print a firing setter alongside the model. The
new bone china body demonstrated a much higher green strength and could be handled and de-powdered straight from the build bed. The Manta model was successfully fired and exhibited alongside other versions at the Impact Conference held in Bristol in September 2009.

*Image: bone china 3D print in build bed*

*Image: de-powdering*
Image: de-powdering 3D ceramic print

Image: de-powdering setter

Image: de-powdering 3D ceramic print

Image: 3D ceramic print on setter
Dr Peter Walters, a RCUK Research Fellow based at the CFPR, has been working with the team using a series of CAD generated forms to investigate the material properties of a range of 3D printing and rapid prototyping methods. To demonstrate the capabilities of the 3D ceramic printing process with the porcelain body it was decided to use two of these forms the trumpet sphere and the echinoid. Both of these objects would be impossible to make using conventional ceramic forming methods and would be ideal subjects to demonstrate the capabilities of the ceramic 3D printing process.
Image: trumpet sphere rendered in Rhino 4

Image: echinoid rendered in Rhino 4
Image: porcelain trumpet sphere in build bed

Image: porcelain echinoid in build bed

Image: un-fired trumpet sphere
Image: un-fired echinoid segment

Images: fired ceramic 3D prints
Summary
3D ceramic printing using a Z Corporation machine has proven to be a viable method for the production of bespoke ceramic artworks and has great potential for future use in the areas of Art/Craft and industrially based ceramics.

Development is continuing with both methods of production for a 3D ceramic printing body and refinements have been made to all the relevant parameters, the layer shift problem has been eliminated and green strength, surface finish, fired contraction and porosity have all been considerably improved.

The increased resolution possible with the latest body types have meant that we have now come full circle, it is possible to print a surface relief with sufficient detail to produce a glazed photo-ceramic tile of the same type that that the CFPR originally developed over five years ago at the start of the journey into 3D digital technologies. The CNC milled tiles required up to fifteen hours of machining time to cut the relief into a plaster substrate, then several hours of mould making and slip casting. A 3D ceramic printed tile can be formed directly from a 3D file in less than half an hour, fully realising the potential of this new technology.

The following images are of the latest models made by this technique
Venus 3D model in Geomagic studio
ceramic 3D printed Venus
ceramic 3D printed Venus glazed

ceramic 3D printed skulls
glazed 3D printed photo-ceramic tile
Exhibitions and Workshops

Throughout the project a series of exhibitions and workshops were held to disseminate aspects of the research findings through practical demonstrations and the exhibition of artefacts whose production was assisted by the research. The following provides an overview of the scope covered.

Exhibition - 3D2D3D: Object and Illusion in Print

**Dates:** 11th September - 30th October 2010  
**Venue:** Edinburgh Printmakers Gallery  
**Dates:** 8th - 30th of January 2011  
**Venue:** Norske Grafikere, Tollbugaten, 24 0157 Oslo, Norway

There has long been a close relationship between the second and third dimension in the field of Printmaking. Connoisseurs and printmakers frequently describe how the rich surface qualities of (for example) the etched emboss, the raised trace of the relief block, or the layered impasto of a screen print – serve to enhance the impact of a 2D image, creating something more akin to an object than a mere visual illusion on a flat surface. Many traditional artists printing techniques in fact share similar principles and conventions to those of sculpture for moulding, processing, casting and being produced in multiple.

In recent years new digital techniques for printing have enhanced the printmakers palette, however, prints produced through digital output have remained largely in the 2D realm. Currently a new era is dawning with print based, Rapid Prototype technologies gradually coming within the reach of the fine artist.

This exhibition proposes to investigate the dual possibilities of creatively engaging with digital software and hardware to produce data that can be printed in both 2D and 3D. To explore this new transition, a selection of artists currently working in the field have been selected to produce printed images and related printed objects that reveal new insights into image and object making through print. For the exhibition each artist will produce both a 2D (digital print) and a 3D printed object that in some way sets up a relationship or an interaction between the 2 dimensions.

Exhibition: Inside Out

**Dates:** June 2010  
**Venue:** Object Gallery, Sydney, Australia and De Montfort University (Institute of Creative Technologies)  

Brendan Reid, CFPR research PhD student, will exhibit work created as part of his studies at the Inside Out Exhibition at Object Gallery in Sydney and De Montfort University (Institute of Creative Technologies) on June 5, 2010. Inside Out seeks to provide a significant selection of emerging and established artists and designers, in both analogue and digital mediums, with the opportunity to experience and explore emerging digital design techniques and rapid prototyping tools and methods and to venture outside their usual medium. How they interpret the theme Inside Out is left open to them.

Inside Out begins with the creation of sets of miniature sculptures produced through an exchange programme between art school centres and artist groups in the UK and Australia. Each sculpture will have originated as a 3D computer-generated object and will be capable of fitting in a small box (6cm x 6cm x 6cm). After the virtual models have been created their data
files will then be transmitted via the Internet to the opposite country. The received files will then be ‘printed’ as real objects by the process of stereo-lithography (3D printing) or rapid prototyping in the reciprocal countries. Employing this process obviates the need for shipping the sculptures between the two countries, avoiding a large carbon footprint. In addition, as miniatures, the sculptures will be able to be transported effortlessly as they tour selected galleries in the two countries. Creating virtual 3D objects and then transmitting the files as data sets, before they are actualised, means that the artists involved may not even sight the physical sculptures before they are exhibited.

It is intended that Inside Out should encourage further debate on issues surrounding future rapid prototyping technologies: environmental, aesthetic and conceptual issues currently being investigated via research and practice. The Inside Out exhibition is, in effect, a visual documentation of new practices across the three dimensional spectrum in art and design and a signpost of future directions.

The Inside Out collection will tour Australia and England.

Exhibition: Medals of Dishonour, The Hutton Award included in 'Richard Hamilton'
Place: Serpentine Gallery, London, Kensington Gardens, London W2 3XA
Dates: 3 March - 25 April 2010
URL link: Serpentine Gallery Richard Hamilton

Dr Peter Walters and Professor Stephen Hoskins helped to create a Medal called 'The Hutton Award' in collaboration with renowned artist Richard Hamilton exhibited at the Serpentine Gallery London 3 March - 25 April 2010.

To create the three-dimensional form of the medal, colour photographs were first converted into black and white tones representing the depth of relief. The tones were then transposed using Photoshop tools so that the white produced the highest relief - the tip of the nose - and black the background; bump map simulations of the three-dimensional object were rendered in Lightwave to check progress. The researchers used 3D Modelling software to generate a 3D displacement model from the 2D artworks provided by the artist. A 3D printing processes under investigation at the Centre for Fine Print Research produced regular wax and photopolymer relief trials and a master was milled in resin to cast the edition.

The medal was commissioned by the British Art Medal Trust, a registered charity dedicated to the making and study of medals from leading contemporary artists.
3D Printing Research - symposium and exhibition

Dates: 9th December
Times: 10.30am-4.00pm
Venue: The Blue Room, Tobacco Factory, Raleigh Road, Southville, Bristol BS3 1TF
Programme: See the Annex to download speaker presentations and biographies

The research team are coming to the end of a three year AHRC funded research project which aimed to investigate and exploit new 3D Technologies, including 3D scanning, CAD modelling, 3D printing and CNC machining, within the context of the fine and applied arts and crafts. The research team at the Centre for Fine Print Research has a well-established track record in practice-led research within fine art printmaking and print technologies, supporting the creative activities of leading artists, as well as working closely with scientists, technologists and manufacturers within the printing industry. In light of current developments in 3D printing technologies, extending our enquiry to encompass emerging 3D media was a natural progression for the Centre for Fine Print Research. Research staff within the 3D printing laboratory come from a broad range of backgrounds, including printmaking and digital art, sculpture, ceramics technology, industrial design and prototyping technologies. Our ongoing research interests are also wide ranging: developing appropriate methodologies to support art practitioners in the creative use of 3D technologies; the development of a new process for the direct 3D printing of art and craft artefacts in ceramic materials; 3D fabrication of smart sensors and actuators for robotics applications and interactive artworks.

3D Rapid Prototyping Demonstrations and Exhibition at IMPACT 6 International Printmaking Conference
Wednesday 16th September – Saturday 19th September 2009

Location: Bristol Council House and The Centre for Fine Print Research-UWE, with exhibitions at venues across Bristol. Presented by Dr Peter Walters and David Huson The Centre for Fine Print Research, UWE, Bristol

In September 2009 the Centre for Fine Print Research UWE, hosted the 6th International Multi-disciplinary Printmaking Conference. The first Impact conference was hosted at UWE in 1999 in association with the Royal West of England Academy and the Southern Graphics Council, USA.
The conference was attended by over 400 delegates from more than 20 countries with presentations of academic papers, workshops, print process demonstrations, exhibitions and lectures on a multitude of contemporary and historical print practices. Dave Huson, Peter Walters and Brendan Reid - conducted a rolling demonstration of the Objet and Zcorp 3d printers.

**Medals of Dishonour, The Hutton Award - by Richard Hamilton** "A Major exhibition of historic and contemporary medals at The British Museum"

**Research Association:** AHRC large research grant: The fabrication of 3-dimensional art and craft artefacts through virtual digital construction and output and RCUK Fellowship: The Application of Digitally Assisted 3D Construction for the Arts and Crafts

**URL link:** British Museum, Medals of Dishonour Exhibition

**Place:** British Museum, Great Russell Street, London, WC1B 3DG

**Dates:** 25 June to 27 September 2009

**Photography by:** Peter Walters

Print experts, Dr Peter Walters and Professor Stephen Hoskins, from the University of the West of England, have helped to create a Medal called 'The Hutton Award' in collaboration with renowned artist Richard Hamilton for the Medals of Dishonour exhibition at the British Museum.

Medals of Dishonour is an exhibition that features medals that condemn their subjects rather than celebrating important figures or heroic deeds. The Museum's collection of satirical and political medals from the 16th to the 20th centuries will be displayed alongside recent work by leading contemporary artists including Jake and Dinos Chapman, William Kentridge, Grayson Perry, Ilya and Emilia Kabakov, Richard Hamilton, Mona Hatoum, Ellen Gallagher, Langlands and Bell, Cornelia Parker, Michael Landy, Yun-Fei Ji, Steve Bell and Felicity Powell. 'The Hutton Award' is a two faced medal depicting Tony Blair on one side and Alistair Campbell on the obverse. The satirical potential of placing a pair of familiar faces in a different context recalls a seventeenth-century medal showing Oliver Cromwell and Thomas Fairfax as a devil and a fool.
The medal relates to the Hutton Inquiry, set up by the British government to investigate the circumstances surrounding the death of the government scientist David Kelly in July 2003. Just eight days before he died, Kelly was named as the source for claims broadcast by the BBC that in the run-up to the invasion of Iraq earlier that year the government of Prime Minister Tony Blair had ‘sexed up’ a report on Iraq's military capability. In his report published January 2004, Lord Hutton strongly criticised the BBC, leading to the resignation of its chairman and director-general, but his exoneration of the government resulted in several newspapers describing the report as a 'whitewash'.

To create the three-dimensional form of the medal, colour photographs were first converted into black and white tones representing the depth of relief. The tones were then transposed using Photoshop tools so that the white produced the highest relief - the tip of the nose - and black the background; bump map simulations of the three-dimensional object were rendered in Lightwave to check progress. The researchers used 3D Modelling software to generate a 3D displacement model from the 2D artworks provided by the artist. A 3D printing processes under investigation at the Centre for Fine Print Research produced regular wax and photopolymer relief trials and a master was milled in resin to cast the edition. Professor Hoskins said, “This commission confirms the regard in which the Centre for Fine Print Research is held and highlights the way that we are pushing the boundaries in 3D rapid prototyping techniques. It’s great to work with Richard Hamilton who is such a well established contemporary artist and this reflects on the CFPR as being renowned for working at the cutting edge of digital technology.” The medal was commissioned by the British Art Medal Trust, a registered charity dedicated to the making and study of medals from leading contemporary artists. The Trust has presented an example of each of the newly commissioned medals to the British Museum for its permanent collection. Reviews of the exhibition: The Times GQ Andrew Graham Dixon This is London

'Committed to Print' Exhibition, London - An Exhibition Celebrating Digital Art'

Location: London Print Studio, 425 Harrow rd, London W10 4RE
Curated by: Paul Thirkell
Funded by: Arts & Humanities Research Council
Images: Peter Walters, 3D Printed Bodies

This exhibition featured a selection of work from leading UK artists - produced as digital prints - in collaboration with the Centre for Fine Print Research, Bristol. An extraordinary set of images and even 3-D prints emerge as Britain’s artists stretch our understanding of print in
a series of bold digital experiments. Artists taking part include: Richard Hamilton, Paul Hodgson, Susan Collins, Charlotte Hodes, Peter Walters and Paul Sandameer.

'Committed to Print' Exhibition, Newcastle

Location: Northern Print Gallery, Stepney Bank, Newcastle Upon Tyne, NE1 2NP
Dates: Exhibition from 22 August – 25 October 2008
Curated by: Paul Thirkell
Fund by: Arts & Humanities Research Council
Images: (above from left to right) Glastonbury Tor series, pigmented inkjet print by Susan Collins; Untitled, pigmented inkjet print with laser cutting by Charlotte Hodes; Portrait with Smoke and Steam, pigmented inkjet print by Paul Hodgson.

An exhibition of digital prints from the Centre for Fine Print Research UWE is opening at Northern Print’s gallery. Curated by Paul Thirkell, the exhibition is funded by the Arts & Humanities Research Council, and features the work of Richard Hamilton, Susan Collins, Charlotte Hodes, Paul Hodgson, Jo Lansley & Neeta Madahar.

The CFPR has been active in working with a broad range of innovative and cutting edge artists and approaches to fine art print for well over a decade. This exhibition represents some of the work produced by artists from its staff and those it has worked in collaboration with. The exhibition seeks to address the question - does digital artwork have its own stand alone aesthetic or does it seamlessly engage with others? To frame this in relation to the many activities that fall under the umbrella of digital art, the exhibition seeks, through its title ‘Committed to Print’, to focus on work that has been committed to an end product or fixed output i.e. a print or print related object.

An exhibition of work from the CFPR’s AHRC funded 3D Printing research project was featured in the exhibition.

For more information about the gallery, visit www.northernprint.org.uk

‘Committed to Print’ BristolRoyal West of England Academy, Bristol. Group exhibition by the Centre for Fine Print Research, University of the West of England, June - July 2007.
Sharples and Winterstokes Galleries
The Royal West of England Academy, Bristol
Curated by Paul Thirkell
Photography by Paul Laidler
3 June - 22 July 2007

The Centre for Fine Print Research (CFPR) at UWE is a fine art based facility dedicated to the research of a broad range of print issues that emerged with the invention of photography in the nineteenth century, and continue to the present.

This exhibition features prints and print-related artefacts resulting from some of the Centre’s many research projects. It includes artworks that explore the possibilities of several almost forgotten high quality nineteenth century printing processes through to the latest cutting-edge digital printing techniques. One of the over-arching themes of much of its research involves the integration of the best of the old with the advances of the present to facilitate new and increasingly comprehensive means of expression for artists.

As well as work exploring the possibilities of combining digital imaging techniques with rare old processes such as collotype, printed enamels and an obscure photo ceramic printing technique, the exhibition aims to reveal the potential of some of the newer imaging technologies that have recently emerged.

Through its research activities, the Centre has attracted collaborative ventures with a number of internationally important artists. One such artist, Richard Hamilton (the founding father of the British Pop art movement), produced a major work ‘The Typo Topography of Marcel Duchamp’s Large Glas’s in collaboration with the Centre in 2003.

Besides work from its diverse projects and collaborations, this exhibition features prints commissioned by the CFPR from five artists especially for this show. Working in conjunction with researchers from the Centre, the five artists: Susan Collins, Charlotte Hodes, Paul Hodgson and Neeta Madahar and Jo Lansley - selected for their innovative work with new forms of digital imaging - all produced a series of ambitious prints that, along with the other pieces in the exhibition, reveal some of the exciting new horizons in print currently being explored by contemporary artists.

Papers and Articles

This section holds conference papers, journal articles, panels and symposia that present findings and issues generated by the research project.

Impact 6 International Multi-Disciplinary Printmaking Conference

**Venues:** Bristol Council House and The Centre for Fine Print Research-UWE, with exhibitions at venues across Bristol

**Dates:** 17 - 19 September 2009.

Professor Stephen Hoskins directed the conference and chaired the Technological Advances Panel which presented a series of views encompassing these new technologies and will debated the future for digital technology with papers from Dr Peter Walters ‘3D Printing in Colour: Technical evaluation and Creative applications’ and Brendan Reid ‘The relationship between the surface and sculptural qualities of 3D printed rapid prototypes’.

3D Printing in Colour Technical Evaluation and Creative Applications (see Annex for full paper)

The conference was attended by over 400 delegates from more than 20 countries with presentations of academic papers, workshops, print process demonstrations, exhibitions and lectures on a multitude of contemporary and historical print practices.

3D Printing Research - symposium and exhibition

**Date:** 9th December 2009

**Times:** 10.30am-4.00pm

**Venue:** The Blue Room, Tobacco Factory, Raleigh Road, Southville, Bristol BS3 1TF

The research team are coming to the end of a three year AHRC funded research project which aimed to investigate and exploit new 3D Technologies, including 3D scanning, CAD modelling, 3D printing and CNC machining, within the context of the fine and applied arts and crafts. The research team at the Centre for Fine Print Research has a well-established track record in practice-led research within fine art printmaking and print technologies, supporting the creative activities of leading artists, as well as working closely with scientists, technologists and manufacturers within the printing industry. In light of current developments in 3D printing technologies, extending our enquiry to encompass emerging 3D media was a natural progression for the Centre for Fine Print Research.
Research staff within the 3D printing laboratory come from a broad range of backgrounds, including printmaking and digital art, sculpture, ceramics technology, industrial design and prototyping technologies. Our ongoing research interests are also wide ranging: developing appropriate methodologies to support art practitioners in the creative use of 3D technologies; the development of a new process for the direct 3D printing of art and craft artefacts in ceramic materials; 3D fabrication of smart sensors and actuators for robotics applications and interactive artworks.

(See the 3D symposium Annex for a full programme, speaker presentations, sound recordings and biographies)

3D Symposium
Date: 25 June 2008
Times: 10.30am-4.00pm
Venue: School of Creative Arts, Bower Ashton Campus, UWE

In June 2008, the Centre for Fine Print Research at the University of the West of England hosted a symposium focussing on new 3D technologies and their creative application within the Arts and Crafts. The event took place at the University’s School of Creative Arts, Bower Ashton Campus.

The Centre for Fine Print Research is currently engaged in a research project which aims to investigate and exploit new 3D Technologies, including 3D scanning, CAD modelling, 3D printing and CNC machining, within the context of the Fine and Applied Arts and Crafts. This research is funded by a large grant from the Arts and Humanities Research Council, and Research Councils UK. The Centre has a well-established track record in practice-led research within fine art printmaking and print technologies, supporting the creative activities of leading artists, as well as working closely with scientists, technologists and manufacturers within the printing industry. In light of current developments in 3D printing technologies, extending our enquiry to encompass emerging 3D media was a natural progression for the Centre for Fine Print Research.

The aim of the symposium was to develop an open dialogue with researchers and practitioners, to share ideas centred around the use of 3D digital technologies from an arts and crafts perspective and beyond.

Delegates attending the conference were academics, research staff and students, from the Royal College of Art, Edinburgh College of Art, University College Falmouth, University of the Arts London, National College of Art and Design, Ireland, and University of the West of England.
The following speaker presentations and biographies can be downloaded from the Symposium Annex:

The fabrication of 3dimensional art and craft artefacts through virtual digital construction and output speakers David Huson and Paul Thirkell University of the West of England

Creative Boundariesspeaker Stephen Bottomley Department of Jewellery and Silversmithing, Edinburgh College of Art


Anatomy of an Instrument: Diagnostic Imaging as a Research Tool and its relation to Rapid Prototyping speaker Andrew Folan, National College of Art and Design, Dublin

3D Printing: Some practical examples in art and design speaker Peter Walters University of the West of England

Conference Papers


‘Pictorial Information as Transcribed by the Artist or Designer’, Hoskins, S. Electronic Imaging Science and Technology Conference, San Jose, California, USA, 20-22 January 2009


‘An untruth to materials’, Reid, B. Chelsea College of Art, 16th May, 2008


‘3D Printing of Bespoke Ceramic Artworks’ Conference paper, IS&T International Conference on Digital Fabrication Technologies, 6-11 September 2008, Pittsburgh, Pennsylvania


**Journal Articles**

'3D Printing for Artists: Research and creative practice' Walters, P., Davies, K. in Rapport: Journal of the Norwegian Print Association No. 5.


Useful Links

Autonomic Research Group, University College Falmouth - http://www.autonomic.org.uk/
Objet Geometries Limited - http://www.objet.com/
Bristol Robotics Laboratory - http://www.brl.ac.uk/
Heart Robot - http://www.heartrobot.org.uk/
Ceram Research - http://www.ceram.com/
Summary of Research Findings

Although 3D rendering and output technologies have been on the market for some time, their presence as a unified means of creating and outputting fine art objects has only recently begun to be explored by artists. While 3D technology has been used from an engineering perspective to assist the technical production of ambitious sculptural pieces in varying degrees since its development in the 1960’s and 70’s, it is only in the last decade or so that artists have begun to adopt it as a new, accessible means for both exploring and creating sculptural space. Pieces such as Anthony Gormley’s 1999 ‘Quantum Cloud’ perhaps represent something of a culmination of this new form of artistic engagement. Other key works such as Karin Sanders 2002 work ‘Sculpture 1:96’ however, embody a potential scanning and Rapid Prototype output route that holds many similarities to those offered a decade or so previously with digital printing for artists. Through the development and broadened accessibility of 3D scanning, CAD software and object output devices; a similarly expansive area of artistic exploration has now emerged.

A seminar held at the beginning of this research project revealed how the accessibility of such technology was beginning to foster a broad range of creativity from UK artist, designer makers and crafts practitioners. The presence of artist accessible scanning methods and the increased user friendliness of 3D software revealed a common thread between the different disciplines however, for all, there appeared to exist a series of challenges at the output phase for realizing the objects output potential. A number of possible solutions from the production of casting matrices, laser cutting to Rapid Prototype output were presented at the seminar. Each revealed much promise and many areas for further development.

Through focusing on the potential of Rapid Prototype (RP) output and CNC milling, the project was equipped with a range of technology that was gauged to represent some of the typical devices (from input to output) that have recently become increasing accessibility for artists. To explore potential in relation to a continuum of practice, research was undertaken to practically consolidate routes which could assist in incorporating the creative flexibility of digital 3D rendering with the material and tactile qualities inherently associated with art and craft practice. At first the research specifically focused on the direct output of finished objects produced conventionally through the additive, 3D colour printing process. These revealed the current scope of material and build parameters intrinsic to the area of production. Data searches and surveys were also used to build and assess an overall picture of the 3D field. Practical research carried out to assess the value of existing technology was subsequently used as a basis on which experimental research to modify and refine existing technology for creative use. Additionally, the facilitation and evaluation of methods developed through the research for the production of artefacts were applied and documented in the form of case studies. These were done in relation to the creative needs of a diverse selection of arts & craft practitioners.

Setting the baselines of practice and 3D output

To set baselines of 3D practice and output, surveys of the field of industrial and craft use of 3D prototyping were used throughout the project to map the creative potential from an art and craft perspective. A rational for the equipment to be purchased for the project was made in relation to a detailed survey of the current 3D market. Decisions for this were centred around the factors of cost, flexibility and potential for use in an art and craft context. A range of complementary object capture, object processing and output devices were subsequently selected and installed for testing and production purposes at the CFPR. These included 2 scanning systems, a range of software for interface with rapid prototyping systems, a
subtractive RP CNC milling machine, an additive polymer resin printer and two additive 3D powder printers one for colour output and one for monochrome. In addition to equipment-based surveys, contextual surveys of the field were carried out. This included historical reviews of the antecedents of rapid prototyping, a critical context in relation to technology and creativity, a review of the technologies used by artists and designers and a survey of key practitioners in the field. The results of these findings were published in the Journal Artefact and reveal how new creative synergies, resulting from interdisciplinary practice that is innovative both in process and outcomes are being explored by a range of artists, makers and designers.

Throughout the project strengths & weaknesses of a broad cross section of 3D technologies were tested. These included additive 3D printing methods and subtractive methods such as CNC milling. As is evident from a number of case studies carried out during the research, various strengths and weaknesses of the different technologies emerge for artists on a case-by-case basis. This depends on the intentions of the artist and often revolved around the varying emphasis of the elements of the piece. In the case of the Richard Hamilton’s Medal of Dishonour, the fine detail intrinsic to CNC milling was found to be most appropriate for producing mould that could be cast in silver. Another case study, this time involving the casting of glass favoured the softer detail of additive Z Corp output over CNC milling to produce the master. Whilst the output of the Objet machine also produced highly detailed polymer resin objects, many of the artists preferred the less detailed but more tactile option of plaster output from the ZCorp machine rather than the plastic like finish of the Objet. The option of colour from the ZCorp printers also provided a unique fusion of object and image that was not possible with any of the other technologies. This aspect inspired a number of unique explorations incorporating colour and form that were documented among the case studies. An assessment of the current scope of colour quality offered by Rapid Prototype machines revealed weaknesses in relation to the sophistication of inkjet colour. To optimise the colour capabilities of the ZCorp machine used for the project a series of colour look up charts were produced to enable a more predictable choice of colour to be made by the user. Whilst these were based on the generation of three colour machines (CMY + a neutral binder), a new generation of four colour (CMYK + binder) have recently been released promising even more scope for colour enhanced object printing. To gain the best possible colour quality from the printed objects a range of coatings from the standard wax immersion methods recommended by the manufacturers to other non standard methods were tested. One of the most promising revealed through the research was a crystal resin coating method that was found to hold similar properties to ceramic glazing and had along with its colour intensifying capabilities the potential for adding strength to the printed form.

The Development of a unique ceramic building technique through rapid prototype output

In relation to a primary objective of the project, possibilities for substituting the various powdered materials developed for the present scope of 3D printing with those that may facilitate the production of a permanent original rather than a temporary prototype were explored. This was done through the modification of a Zcorp powder printer. Initial tests revealed great promise, however, to develop the concept towards being a viable option for use by artists or aspects of industry for that matter, required a considerable investment of time to consolidate a number of factors. While the possibility of this approach being used to print decorated, glazed objects in one printing that only needed a single firing to make them permanent was envisaged through the projects objectives, the need to refine the initial tests in printing with a raw ceramic powder excluded the possibility of enhancing the innovation with the addition of a glazed element.
For the fourth objective, the possibility for printing and firing clay bodies was continued to create ceramic artefacts. Using a ZCorp machine, a viable method for the production of bespoke ceramic artworks has been developed that demonstrates great potential for use in the areas of both art/craft and industrially based ceramics.

Development continues and problems encountered along the way such as layer shift, green strength, firing contraction and surface porosity have all been considerably improved. Additionally the increased resolution possible with the latest body types developed through the project has meant that an aspect of our research has now come full circle - it is now possible to print a surface relief with sufficient detail to produce a glazed photo - ceramic tile of the same type that that the CFPR originally developed over five years ago at the start of our journey into 3D digital technologies (see photo ceramic relief project). The CNC milled tiles originally produced required up to fifteen hours of machining time to cut the relief into a plaster substrate, then several hours of mould making and slip casting. Whilst the new 3D ceramic printing method has proven to be capable of creating a broad range of forms, it is perhaps significant to note that it now enables a 3D ceramic tile to be printed (with similar qualities to the CNC method described above) directly from a 3D file in less than half an hour. An application for a patent for ceramic printing has been filed as a result of the projects work.

Collaboration as a result of this project

The last of the research objectives in promoting ongoing dissemination to facilitate a loop of dialogue between art & craft practitioners, industry and the findings of the research has been fulfilled through a number of channels. An initial seminar brought together major arts based makers in the UK field to speak about their work and discuss the possibilities of new technologies was used to establish a forum. These links have been ongoing and have resulted in the current exploration of collaboration between Autonomic, University College Falmouth and CFPR. During the project relations were established with several university groups including the Engineering Department at the University of Washington, Seattle, Birkbeck College, Edinburgh College of Art, Bath Spa University, Aberystwyth University and the National College of Art and Design in Dublin.

Other potential collaborators as a result of this project include Bristol City Museum and Art Gallery, The British Museum Conservation department. An ongoing dialogue with schools is taking place, recently CFPR has started to collaborate with the John Cabot Academy in Bristol to develop a series of training courses for teachers.

CFPR has submitted a patent application for 3D printed ceramics as a result of this links have been established with a range of related industries including 3D print manufacturers, the Boston based Z Corp, Roland Digital Group and Bits from Bytes who make the RapMan. In addition, through the CFPR’s links with Hewlett Packard a potential research and development strand has emerged. CFPR has also undertaken some commercially confidential proof of concept work with Aardmann Animation.