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Making it real: virtual tools in 3D creative practice

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Abstract

FutureFactories is a design research project exploring the creative possibilities afforded by digital design and manufacturing technologies. A specific aim of the project is mass individualisation; the industrial scale production of one-off artefacts. Tangible products would 'printed' direct from virtual meta-designs using additive manufacturing (Atkinson 2003). Distinct from mass customisation, where the product is configured to a specific consumer need or desire, individualisation involves introducing elements of random variance similar to the idiosyncrasy seen in natural forms.

In the initial research a computational design approach was adopted in which computer scripts were used to 'drive' parametric CAD models (Unver 2003). A barrier to the adoption of such systems however, is the level of programming involved. Methodologies were developed to simplify the task such a Constructive Solid Geometry, CSG, building block approach (Dean 2009) whereby complex geometries are 'assembled' from pre-defined primitives. In spite of this development programming remained a significant burden. A commercial desire to simplify further had to be balanced against an audience demand for ever more dramatic changes in geometry.

A potential solution came from looking outside of object centred product design to the virtual realm and to digital visualisation and simulation tools developed for diverse industries such as cinema and applied mechanics. This paper explores, through a series of case studies, the adoption and adaption of virtual modelling tools in 3D creative practice. Functional product design outputs are examined along with the practicality of the methodologies used to create them. As the transition between the digital and the real becomes increasingly simple, the virtual realm is set to become an ever more fruitful creative playground for 3D design and craft practitioners.

KEYWORDS
Additive Manufacturing, Digital Manufacturing, Mass-Individualisation, Mass-Customisation, Computational Design, Augmented Reality

1.0 Fluid dynamics

Film and game industry techniques for recreating the world around us are becoming ever more effective and detailed. Despite their focus on the virtual realm, these systems offer significant potential as 3D design tools. The droplet lamp series is a collaboration between the author and Dr Ertu Unver an expert in digital animation and visualisation techniques for the design industry at the University of Huddersfield.

Methods for the animation and rendering of natural phenomena, such as fluid, fire, smoke, bubbles, cloud and non-Newtonian flow are increasing in power and sophistication to meet the leisure industry's demand for ever greater photo-realism. In this research computational fluid dynamics and physics based animation techniques have been employed to generate 3D form and to create individualised design iterations. The complex and seemingly random behaviour of water, real or modelled, offers significant potential for creating variation within a theme. Moreover, given the ubiquity of water and the role it plays in our daily lives, it is something everyone can relate to.

Computational fluid dynamics is a branch of physical science concerned with the modeling of fluid mechanics problems using computers. These techniques have become increasingly adopted by computer graphics disciplines for visualisation. Given a virtual 3D scene, an initial condition and a set of fluid behaviour parameters, a simulation package will model a dynamic liquid body forward in time based, at some level, on physics algorithms. Fluid behavior is complex and multi-scale; small splashes and foams may play on the edges of much larger bodies. Realistic representation requires fine resolution and there is a trade-off between the authenticity of fluid motion and the time and computational power required for simulation. In computer graphics industry the sophistication of experience required can vary from the Hollywood movie to real-time games played on hand-held devices. Unlike their fluid engineering counterparts, which may for example consider subtleties such as the temperature difference between the air and the water, graphics applications require only a plausible depiction of the phenomena. Almost everyone however will have experienced a wide variety of fluid behavior from crashing waves to pouring milk and will have and appreciation of what to expect. Pouring milk was cited by Dreamworks partner Jeffrey Katzenberg as “the hardest shot” in the film Shrek (Hiltzig 2001). Katzenberg goes on to decry realism stating” "Photorealism holds little or no interest for me. To me, the reason to animate something is to push it further from a realistic human character. If you could photograph somebody, why would you animate them?"

Finite Element Analysis (FEM) has been common in engineering computation since its invention in the 1950’s. In FEM a continuum is divided into discreet elements for computational purposes and these individual elements connected together in a topological mesh. The mesh ensures stability but places limitations on the form modelled. A more recent alternative approach is to divide the continuum into a set of nodal points or particles without mesh constraints (Shaofan 2002). In fluid modelling applications this arbitrary location of elements allows effective and realistic representation of liquid behaviours such as splashes and foaming. Smoothed Particle Hydrodynamics (SPH), initially developed in astrophysics, “smoothes” the properties of nodes over the distance between them and is increasingly common in fluid simulation.

RealFlow by Next Limit Technologies is dedicated particle-based fluid simulation software compatible with a number of 3D design software packages: RealFlow in conjunction 3DS Max design software was used in this research. The idea behind the project was to generate the form of a lamp shade by pouring virtual liquid over a sphere. Individualised design iterations would be generated by either materialising different frames of the animation or re-running the animation with different parameters. An animated sequence was created with a water droplet hitting a sphere and spreading around it while being trapped by a hidden outer boundary sphere (the outer boundary proved necessary to force the creation of a hollow form). After the scene is created, the simulation software allows adjustment of physical characteristics such the number of particles, compressibility, gravity, buoyancy and surface tension each of which contributes to the behaviour of the dynamic fluid body. Particle numbers for the water droplet were set at around 20k and the event duration to 10 seconds (Figure 1). At any point in the simulation the particle behaviour can be captured, meshed as a 3D body (or set of bodies in the case of droplets) and exported to a 3D modelling package.

Figure 1
An animation sequence of a water droplet in motion

The resulting 3D models included numerous detached bodies representing spray and droplets. These bodies required manual attachment to allow the spherical form to be built as a rigid part. This manual process might be seen to detract from the authenticity of the simulation. The product designer's skills were vital at this point to maintain the 'natural' aesthetic whilst ensuring an appropriately rigid structure. A similar methodology was used in the creation of a trophy for the 2012 De Montfort University Alumnus Award (Figure 2). In this design the simulated water droplet impacted on a concave rather than a convex surface and the secondary invisible barrier was dispensed with. The form of the barrier surface used was similar to that of an egg cup which was also the approximate size of the manufactured piece. The simulated impact would cause the virtual fluid to form a wall of plumes rising up the sides of the vessel and shooting foaming droplets over the edge. In practice the surface generated would only fill a segment of the cup and several iterations were overlaid to create the 360 degree geometry printed for the trophy. Separate droplet bodies once again required manual CAD manipulation to attach them to the main body. An additional modification of the generated form was the addition of the stem which was modelled manually and attached in a Boolean operation. Abandoning the hidden secondary boundary allowed a much more natural looking form. It should be noted however that the double surface face in the previous example was required to produce the hollow shell of a technically more demanding,functional lighting object. The trophy is merely a sculptural artefact; although cup-like in form it could not retain liquid. The cup section of the award was 'printed' using Selective Laser Melting (SLM) in stainless steel and the plinth by Selective Laser Sintering (SLS) in polyamide. The plinth was hand finished and painted.

Figure 2
De Montfort University Alumnus Award

2.0 Computer graphics, animation and augmented reality

In many of the author's creations, the animated meta-designs stimulate as much interest as the real-world production pieces they generate. These virtual 'performances' are to some extent lost in the physical object purchased by the consumer. The proliferation of web-enabled devices, in particular smart phones, potentially allows a ready link between virtual concept and physical artefact through an augmented reality experience. T-Rex Versus the Gorilla is a jewellery ring collection created around such an experience.

A recent joint research project between De Montfort University, UK, Loughborough University UK and Vaal University of Technology, South Africa facilitated collaboration between the author and an experienced digital sculptor for film, Philip Van der Walt. The idea was to examine alternate workflows and software tools associated with diverse forms of 3D practice. Direct digital manufacturing has diminished the significance of 'design for manufacture' bringing product or industrial design closer to more empirical art and craft disciplines. A common digital platform coupled with increasingly easy translation between software packages allows a cross fertilisation of techniques and practice. Digital sculpting software such as Z-Brush and Sculptris allow the rapid development of 3D characters using tools that mimic manual techniques such as the sculpting of clay.

T-Rex Versus the Gorilla is inspired by 60's science fiction movies. The design centres on a fight sequence between monster characters. These figures wrap around opposing sides of the finger to form a ring with the gorilla gripping the T-Rex's tail on the underside (Figure 3). The fight sequence exists as a virtual animation with the protagonists exchanging blows and with a precious stone employed as a weapon.

Figure 3
Character sketch by digital sculptor Philip Van der Walt

Using the animation industry technique of rigging the characters were moved through a choreographed action sequence that was first explored using human actors in costume. The use of actors was a further technique derived from the film industry; this process added valuable realism to the poise and balance of the virtual creatures (Figure 4). Skeletal frames were constructed within polygon meshes derived from digital sculpting in Z-Brush. The rigged monsters were then moved through a series of key strike positions previously established using the actors. A key frame animation was then used to extrapolate between these orientations creating a seamless animation. The idea is that five of these key frame poses will be materialised into a set of ring designs. The ring designs are to be cast in silver from printed waxes and the gorilla distinguished from the dinosaur using black Rhodium plating.

Figure 4
Acting out the action sequence

The skeletal rig is best applied to the creature mesh in a "Da Vinci" pose with limbs slightly splayed (Figure 5). This orientation facilitates the distinction of limb and body and allows movements to be confined to appropriate areas of the mesh. Creased areas such as arm-pit and crotch can cause particular difficulty. Even with a well modelled mesh and a carefully constructed skeletal rig character manipulations are likely to distort the underlying geometry; the more extravagant the movement the greater the risk. The effect of such inconsistencies might go unnoticed in as rendered animation but would be unacceptable in a manufactured artefact. Aside from the aesthetic aspect, problems such as self-intersecting surfaces, whilst they might render on-screen, will prevent the successful export of production data. This meant a two stage process. An animated sequence was created by manipulating the rigged 3D characters through the strike poses identified by the actors. The character meshes at these key points were then exported separately and any areas of inconsistency, visual or geometric, reworked manually in CAD. A stated aim of FutureFactories research is the automatic computer generation of variants avoiding creative input after the meta-design has been defined. Greater skill, tools and resources applied to the rigging and animation could reduce or eliminate these mesh problems and allow the automated output of 'clean' data. This is a trade-off between the level of initial CAD investment and post-generative manual work. The pros and cons of such 'mapping' processes have been reported previously (Dean 2005). This design was conceived as a set of five pieces rather than an extended run of variants; hence an element of manual finessing was acceptable.

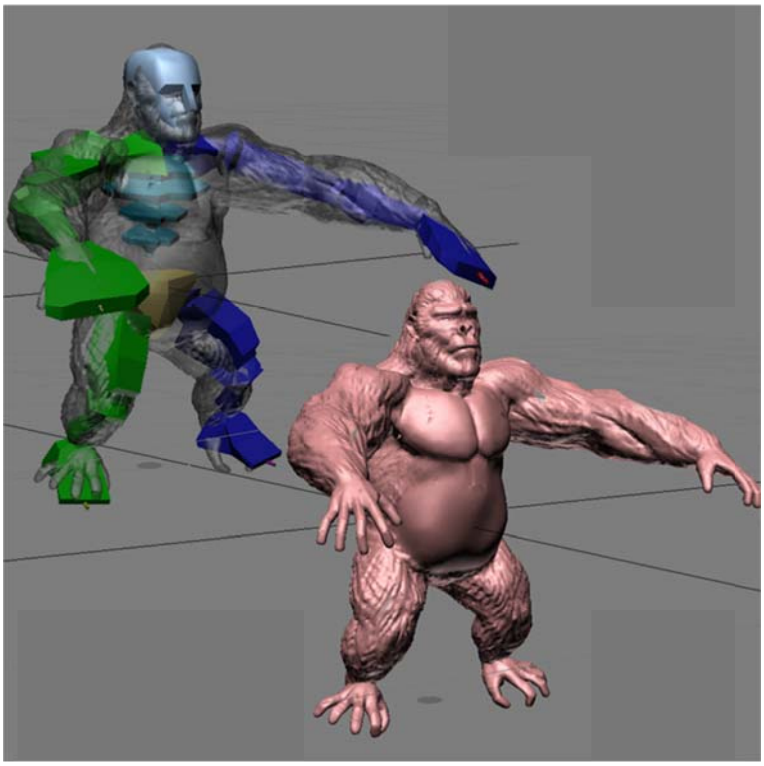

Figure 5

The rigged gorilla in a Da Vinci pose

The animation is a fundamental part of the design and its potential allure to the buying public. It is important that this video clip can be seen alongside the isolated pose that each physical ring represents. The solution was to include a Quick Response (QR) code on the underside of the ring and for this code to facilitate access via a suitable mobile device, to the animation posted on the internet.

3.0 Topological optimisation

In the context of a population increasing in both weight and age, walking aids are becoming increasingly important. In performance terms, these devices have developed significantly from the walking stick with specific consideration of mechanics, materials and ergonomics. Topology Optimisation is a research specialisation that identifies the best material distribution within a fixed boundary, under given loading scenarios. This methodology effectively 'strips away' unnecessary material to create more efficient mechanical structures. Working in collaboration with the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing the author explored concepts where there might be an opportunity for innovative aesthetics as well as an advantage in enhanced engineering performance. From a structural standpoint, the objective was to minimise the weight of the part in relation to the yield stress of the titanium material used. A density based method of topology optimisation was utilised whereby material across the virtual part model was selectively added or removed over time. Over a number of iterations the weight is gradually reduced whilst constraints placed on the mechanical performance of the part remain satisfied resulting in a topologically optimal design (Figure 6).

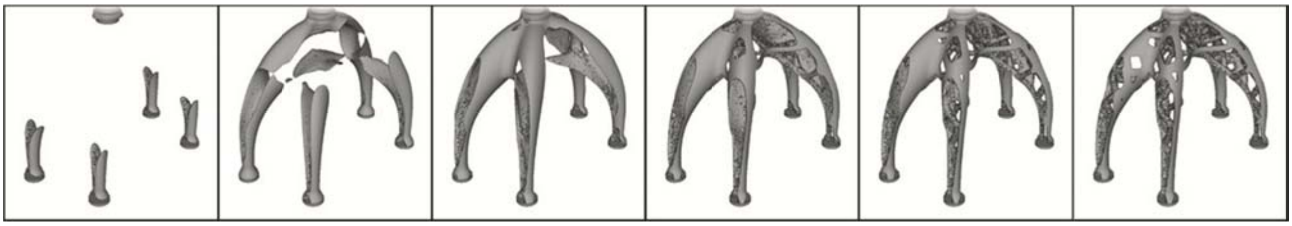

Figure 6
A sequence from the topological optimisation process

This process would suggest an iterative refinement toward a single optimal design solution based on mechanical performance. The use of topological optimisation often results in striking, and counter-intuitive aesthetics. It can also however yield outcomes that, whilst mechanically optimal, are visually unremarkable. A monocoque structure in a curvaceous part can be an excellent mechanical solution: Altair Optistruct, the topological optimisation software used in this research, can often revert to this option. Visually the monocoque is indistinguishable from a solid part. By adjusting the loading conditions it proved possible to steer the optimisation process. In this way a part could be created that was both visually striking and that, at the same time, offered extremely high, if not literally optimal, mechanical performance. The resulting design is eccentric. It is difficult to imagine arriving at such an outcome without the use of digital tools, certainly not without compromising rather than optimising the mechanical performance. This is an example of how the use of specialised technology could help suggest novel forms, yet retain and enhance the functional constraints of the project. The walking aid was 'printed' in titanium via SLM with a carbon fibre laminate shaft (Figure 7).

Figure 7
A walking aid produced using Topological Optimisation

4.0 Conclusions
Common digital platforms increasingly offer a democratisation of specialist technologies and processes. Often the rationale behind such software tools centres on benefits of productivity and efficiency with understandably little regard given to the creative potential they might offer. The case studies illustrate the potential creative benefits of interdisciplinary (applying the methods from one discipline to another), multidisciplinary (combined skills from various disciplines) and transdisciplinary practice.

Product design is a sector often aligned with formalised and established modes of practice or 'workflows'. In the search for creativity, designers must harness the potential of digital technologies beyond designated disciplinary domains. The transition to an information based economy affords artists and designers the opportunity to reassess and re-invent their practice. University research and teaching needs to embrace these developments and respond to the cultural and not only the technical challenges (Marshall 2007). As it becomes harder to better products in performance terms (Dormer, 1990), what we chose to build matters just as much as how well it can be made to operate (McCullough, 2004). The context surrounding a design may as important as the object itself. The Augmented Reality experience of T-Rex Versus the Gorilla is an indication of how conceptual ideas and physical objects could become closer linked. In his 'Shaping Things' thought experiment (2005), Bruce Sterling asserts that;

"The modelling arena is where I shape my things. The physical object itself has become mere industrial output" (Sterling, 2005).

As illustrated by the case-studies, the manufacturing freedoms afforded by additive manufacture allow additional value to be "designed into" artefacts. Design investment however, should be matched by materials of quality and permanence (Dean 2012). In the short term the palette of materials afforded by additive manufacture is limited and appropriate finishing remains a challenge.

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