DIGITAL FASHION, MASS CUSTOMISATION & DIRECT 3D MANUFACTURING

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ABSTRACT

The uptake of 3D technologies into the fashion and apparel industries, from bodyscanning and visualisation, to virtual prototyping and seamless 3D fabrication, has the potential to take the established made-to-measure model to a level of mass-customisation which would allow a majority of consumers access to individualised products tailored to fit their bodies and their needs.

This paper presents the background, motivation and current research practice in customised sports footwear as an example that demonstrates the convergence of materials science, engineering, computer science and design. It outlines the motivation and risks in the development of a new design and manufacturing paradigm based entirely in 3D, and gives a vision for the future of design practice that utilises evolutionary design and e-Manufacturing, with potential for a wide range of fashion and apparel applications.

1. INTRODUCTION

In April 2006 Prior2Lever, an interdisciplinary partnership of podiatry and design, established to create functional bespoke footwear launched their first football boot concept, « Assassin », following a 12 month research collaboration with the London College of Fashion, funded by the London Development Agency.

The boot combines a traditional hand crafted leather upper with a laser sintered outsole, designed from an individual footscan and biomechanical data captured using a pedar in-shoe system to optimise the support and energy conservation of the players musculoskeletal system by positioning the studs to minimise peak forces on the foot during play. In the short-term, the manufacturing plugs directly into conventional and existing systems, as the CAD model is created from foot scan and biomechanical data to create a unique last and outsole that may be Direct Manufactured and then closed in a conventional manner to the upper. In the mid- term there is the vision of a potential digital process based on existing technologies from 3D foot scanning via product design and adaptation to control of the manufacturing process. In the long term it is the aim to finally develop these technologies to a cost level that allows their use for “everyone’s”, i.e. Mass-customised products aiming at the same price level as a comparable non-individualised product.

2. CURRENT PRACTICE IN MASS CUSTOMISATION

To take sports footwear as an example, where once the sports shoe performed a single function, that of providing a improved comfort for performance of an athlete during a particular sporting activity. The same product now has to function on many levels for many different users. From the improbable infant trainers bearing brand names which perform no function other than as visible cultural status for parents, to the boxfresh editions and vintage collections of the obsessive sneaker freaks (a ltd edition of Nike iDs recently sold for $14,000 on eBay) which have the same cultural capital as art. But this increasing differentiation of product styles and functions means increased fashion risk for large brands using traditional mass manufacturing routes.

The response to this has been to offer individualized or mass-customised products to the consumers requirements for fit, comfort and style. Mass Customisation, as defined by Davis (1987), states that “the same large number of customers can be reached as in the mass-market of the industrial economy, and simultaneously they can be treated individually as in the customised markets of pre-industrial economies…The ultimate logic of ever-finer differentiation of the market is markets of one, that is, meeting the tailored needs of individual customers and doing so on a mass-basis.”

Over the last decade a number of customisation models have emerged. These include Soft Customisation or “post-production” customisation which may occur in a retail environment or at home. This allows customers to manually customise products once they have been purchased in store, and is easily integrated into existing business models as it requires no adaption of the manufacturing cycle, but adds value in the perception of an ultimately individualised product. The Adidas “Adicolour” range originally released in 1983 has been recently updated in the wake of an increasing demand for personalised sneakers. This time capitalising on an online community created through design competition, by encouraging consumers to become actively involved in their own customisation, they are also being encouraged to discuss and interact with others through the brand site and online forum. This is further developed by Adidas in the F50 Tunit range of football boots, which can be described as “adaptive customisation”, where a standardised product with multiple options allows the customer to customise after purchase in a number of ways from modules supplied with, or integrated into the design. This boot offers variable upper materials, insole and stud configurations for different climate and ground conditions.

Hard Customisation: covers a wide range of customisation options from truly personalised products to online style customisation. Some of these customisation models require new adaptive e-manufacturing approaches, and are more high risk for adoption as a new business model may be necessary for implementation. (eg. MiAdidas)
They can be categorised as:

Style Customisation- which allows the customer to customise a limited number of style choices e.g. Colour, materials, for the individual configuration of an existing product. This can be done online from home (Nike ID, Puma, Converse/One, Vans, Timberland) or in-store as in the case of the Puma “Mongolian BBQ” concept which allows the customer to manually pick components which are then collected and assembled.

Puma “Mongolian BBQ”

MiAdidas

Best-Fit-where foot scan or manual measurement data is used to match to a database of existing lasts and components to find the best fit for a consumer. This may also include a style customisation module to increase customisation options. (MiAdidas, Vivavor, Selve)

Custom Fit-where foot scan and biomechanical data are used to create a CAD model from which a personalised last, insole and sole can be created for a consumer. A style customisation option may also be added. (Euroshoe,P2L)

2.1. Co Creation and Open Innovation

New models of consumption are based around the interdependency of consumer, designer and producer , and have emerged from user groups and online communities where “co-creation” and “open source” innovation pioneered in software development are being applied to design.

Co-Creation allows the direct interaction of the consumer with the designer in co-creating a personalised style. This type of customisation is also known as “collaborative customisation” (Pine 1993), and while it may involve elements of style customisation, it goes a stage further than choosing from a range of options to the origination of ideas driven by the consumer.

While the terms are new, the ideas are based on much the same process that existed before the mass manufacturing of ready-to-wear apparel emerged post WWII. It is interesting to compare the methodology behind the retail strategy of Alfred Dunhill, whose motoring apparel store opened in the 1920’s in London, with some of the latest thinking in co-creation

Alfred’s retail strategy has been described in the recollections of key employees :

- He always gave his personal attention to every customer order
- In getting to know his customers he obtained many good ideas from them
- He put no obstacle in the way of worthwhile ideas
- He adopted a relentless determination in quality control
- Individual commissions and designs were discussed between customer and salesman.

“Co-design activities are performed in an act of company-to-customer interaction and cooperation. Without the customers' deep involvement, the manufacturer would be unable to adequately fill each individualized product demand…co-design is the core element that differentiates mass customization from other strategies like agile manufacturing or postponement strategies in the distribution chain. Customer co-design in a mass customization context establishes an interaction between the manufacturer and customer which offers also possibilities for building up a lasting relationship. Once the customer has successfully purchased an individual item, the knowledge acquired by the manufacturer represents a considerable barrier against switching suppliers.” (Piller 2006)

The notion of co-creation is an interesting one from a design point of view, particularly if we consider it in relation to products derived from consumer needs. It is suggested that an FEA model, that is Function, Expression and Aesthetics are inseparable parts of the whole, when considering new product development for apparel, and there is “no reason to distinguish between functional apparel design and fashion design” (Lamb & Kallal 2002). This idea is core to the product development process of P2L, and will be further explored later in the paper.

Open Innovation, described as “the democratization of innovation”(Von Hippel 2005) describes the process of creation being taken “from the hands of the few and given to the hands of many”. That is through the development of online user interaction “toolkits” which allow users to interact with products, and allow designers and manufacturers to understand the interaction which is taking place in order to improve both that interaction, through development of better interfaces, and integration of consumers needs into the product generation lifecycle. These ideas can currently be explored through two modes of online interaction between designer and consumer:

Online design competition: essentially based on style-customisation principles, online users are encouraged to submit their own designs based around a core product. The most popular designs uploaded onto a website where visitors vote for their favourite are then produced.(Threadless, Adicolour, OpenSource Shoes) The significance of these type of interactions is that they are fun, they offer a showcase for designers from which they receive a fee if their design is chosen for production, and they may get offers of further work. There is a commitment from the voter to purchase should their chosen design win, which means reduced fashion risk and less waste due to overstock for the manufacturer, and a constant supply of new design innovation which attracts people to the site.

Online user group: This may be linked to the above, or may be a separate forum, as in the example of “MiAdidas”, who encourage their customers, who may be semi-professional or professional athletes, to give feedback and suggestions for improvements which may then be incorporated into next generation products. The advantages of this type of interaction are in getting good quality wearer trials and feedback “for free” from the user, while the user is getting an improved product offer with the satisfaction that they are contributing to the improvement of the product, which will in turn enhance their comfort and performance, and increase brand loyalty.

3. THE CASE FOR 3D DIRECT MANUFACTURING

The motivation for this project was in the potential offered by new and emerging Direct Manufacturing techniques arising from Rapid Prototyping (RP) technologies that enable functional parts to be produced directly from a 3D CAD model without the need for tools or moulds, utilising an additive layer by layer build process, in this case laser sintering of Polyamide 12.

3.1 Rapid Prototyping

There are many Rapid Prototyping technologies that allow the direct fabrication of 3D parts from a 3D CAD model. These include (Selective) Laser Sintering, Stereolithography, Fused Deposition Modelling, Layered Object Manufacture and 3D Printing. However not all of these technologies are suitable for producing functional parts, due either to the robustness of the parts produced, or the stability of the materials used.

Laser Sintering describes the process of bonding sand, plastic or metal powders with laser energy in an additive, layer-by-layer build process directly from a CAD model. The technology was developed for Rapid Prototyping and helped to reduce development times and cost significantly, especially in the automotive industry during the 1990’s. The resulting reduction in both time and cost for rapid product development translated to savings of up to 90% compared to traditional prototyping routes.

3.2 e-Manufacturing

Today, Laser Sintering is also associated with “Rapid Manufacturing” which is “the direct production of finished goods from a RP device”(Wholers 2003), where highly variable functional component parts and assemblies can be produced to satisfy variable customer requests without the need for tooling. The term Rapid Manufacturing however emphasises two aspects, “Rapid” also in association with Rapid Prototyping and “Manufacturing”. Both aspects are true, but lose sight of a significant aspect of laser sintering for mass customisation. This aspect is expressed in the term “e-Manufacturing”, the fast, flexible and cost-efficient production of parts directly from electronic data. (Junior & Shellabear, 2003)

The fact that the machine control information for the laser sintering process can be automatically derived from the 3D CAD description of the product fills in one important step on the way from the data generation with the help of foot scanning to the fully customized finished product.

In an individualised product, such as custom fitting sports footwear, laser sintering offers the means to use existing materials (PA12 based) that have the potential to serve as a basis for football boot outsoles.
Current mass-production methods such as injection moulding offer the ability to build outsoles with variable performance characteristics using multiple assemblies of

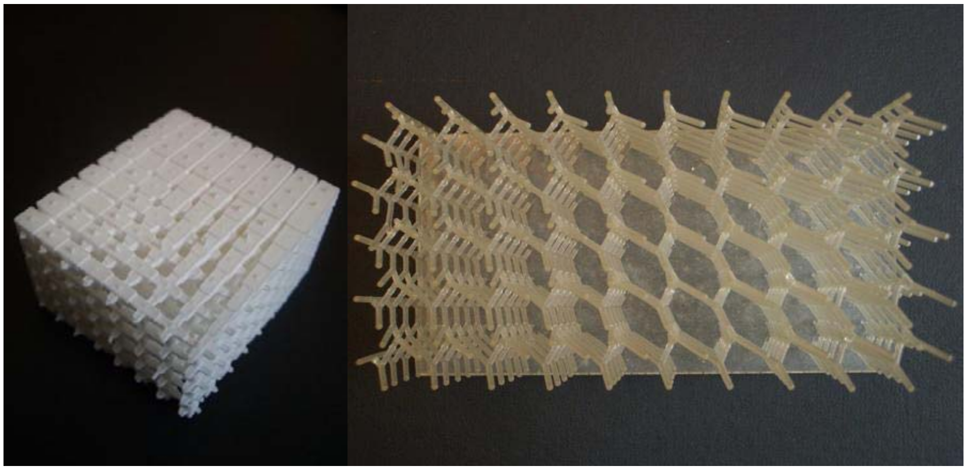
materials with different characteristics, however the constraints remain within “Design For Manufacture”, as the designer must take into account the wall thickness, flow of materials into the mould etc. and it is often necessary to modify the design of the product over several iterations to meet the constraints of the materials. “Manufacture For Design”, on the other hand offers the designer the freedom to produce parts of any complexity, geometry or wall thickness as there is no link between complexity and cost. The only cost implications are in the build volume and the time taken to generate the CAD. The higher the functional integration into one part (i.e. the more parts that have to be moulded separately and mounted afterwards are subsidised by one integrated layer manufactured part), the higher the economic advantage for laser sintering technology. (Junior & Shellabear, 2003)

Piller, Möslein and Stotko (2004) discuss the advantages of mass customized market approaches using the term “economies of integration”. This describes the potential benefit for producers based on the advantage of information about the customer and the products needed leading for example to lower stock, reduced fashion risk or higher customer loyalty. However, the high level of specialisation in manufacturing, and extremely low costs for high quality products due to the traditional mass manufacturing approach of high volume, low cost, create a highly competitive benchmark. In the case of football boots it may be worth mentioning that the market price of today’s football boots including all the costs for development, manufacture, transport, sales and marketing as well as manufacturing and the retail margin, compare to the full labour cost of a CAD designer for between half an hour and half a day. Thus it is easy to see that the cost of labour for individual service and adaptation of products asks for additional cost saving potential in order to achieve the cost target.

A solution to this conflict has been offered by the approach of Klotz (1999) in his discussion about the influence of information technology on products and production. In traditional mass manufacturing the cost reducing effect called “economies of scale” is achieved by repeating the production of a fixed geometry, typically using tools. In terms of IT, the economies of scale can be achieved by repeating processes rather than fixed geometries, as the individual adaptation of geometries is delivered “for free” if it is described by electronic data. Emerging CAD software is offering a route to deliver this individualization from a core design using a “modular” approach eg. A sole unit design can be quickly customized to an individual last using global shape modeling (GSM) to automatically morph the design to fit.

3.3 Evolutionary Design

New developments in computer science utilising genetic algorithms may also have significant impact on the generation of CAD in a more time efficient process, where “manufacture for design” is being implemented, as these systems design materials(or material microstructures) from the bottom up ie. Design driven by application, or “design for design”. This means that the iterative trial and error associated with new product design may be significantly reduced and an optimized product produced at once. This offers the potential for products which are better suited to application, use less materials and can exhibit properties previously unattainable. In the case of laser sintering it offers the potential to add heterogenous characteristics to homogenous materials by the use of variable microstructuring and/or power-variable laser scanning.



Microstructuring of laser sintering (left) and sterolithography (right). Complex Matters

For the football boot outsole, this offers the potential to automate the process of personalization for the individual based on the 3D scan and biomechanical information to distribute forces. As we have already discussed, laser sintering offers the automation of manufacturing from 3D CAD, and this generative approach has the potential to automate the process from 3D data and biomechanical capture, to generating the individualized 3D CAD information. If this can be successfully integrated then the long-term objective of Mass Customisation may be achieved.

3.4 Aesthetics

The relationship between the industrial or manufacturing process, or rather the reaction against industrialisation by the use of these RP technologies has been compared to the Arts & Crafts movement of the late 19th Century, and that the parallels between mass customisation and art may well revive the ornamental approach to design which was marginalized through mass production techniques resulting in a situation that could perhaps be dubbed the renaissance of applied art – or art customization" (Gros, 2004).
Traditionally this approach to ornament has been the preserve of luxury goods, the fine arts and crafts such as jewellery and ceramics, where the high costs were perceived as acceptable for a unique piece that reflects the taste and status of the patron. The notion of art customisation could now be the preserve of the co-creator or "prosumer" (Toffler 1980), the consumer who is a willing and active participant in the style customisation of a product.

In the case of sports men and women who are already used to a highly individualised product offer through sponsorship deals and endorsements, it is envisaged that the potential for high levels of personalisation, both in terms of performance but also of individual expression and identification of a personal brand may be positively received.
The exploration number of surface finishing strategies was a key focus of the joint research project between LCF and P2L, in order to resolve the look, feel and performance of a laser sintered outsole. The "Assassin" uses a spray coating system derived from the automotive industry, which gives the required flexibility, look and media resistance required from the raw part. But to further develop the options for co-creation a 3D printing system was investigated for the potential to offer individual style –customisation for the outsole.

3D Printed Outsoles from P2L launch exhibition

3.5 Materials Properties

Currently the most significant advances being made are in the development of new materials for laser sintering. Biocompatible materials such as cobalt chrome, stainless steel and even gold have been successfully sintered, in addition to a number of ceramics and polymers. Increasingly specialised new technologies are developing the production of specific types of materials, with added functionality through the enhancement of existing materials with Nano particles (added strength, flexibility, temperature and chemical resistance), by the use of biomimicry to replicate the functions of naturally occurring materials and properties, or even, as suggested by the "Rep Rap" project at University of Bath, self-replicating RP machines able to exponentially reproduce themselves along the lines of John Von Neumann's "Universal Constructor" from a range of simple materials which we may, in the not too distant future, buy alongside our groceries at the local supermarket.

3.6 Sustainability

The nature of Laser Sintering being self supporting i.e.-The powder supports the structure as it is built, means that there is very little waste material, and a significant proportion of the powder may be recycled. Also homogenous parts are simple to recycle in comparison to injection moulded, multi-component parts. As all the tooling is eliminated, the physical iterations of prototyping are replaced by CAD and virtual prototyping, and with the ability to ship digital information around the globe rather than physical objects; the impact on the environment of the e-Manufacturing model is significantly reduced. The old adage of "think local, act global" may now be reversed to "think global, act local" as the movement of data rather than materials to highly adaptive rapid manufacturing units local to the consumer-in the future perhaps even in the home of the consumer, where fabricators may produce products on demand (Gershenfeld 2005).

4 HOW P2L ADDRESSES THE RISKS OF MASS CUSTOMISATION

Since today highly flexible manufacturing systems and processes tend to be cost intensive, their use in the manufacture of individualised products can only be justified by the outstanding value of the product delivered. There must be a perceived benefit in paying a premium for an individualised product, which can be identified in the field of athletics and professional sports, where rewards for improved performance are quantifiable. But key questions arising are whether the range of options offered to the consumer by mass customisation may actually be detrimental, and lead to “mass confusion”(Teresko 1994, Piller et al 2003) due to burden of choice, lack of support and uncertainty of consumer satisfaction with an untried product that they must pay for in advance.

In case of high performance footwear the burden of choice is minimised due to the fact that the player has simply to decide than whether he wants this type of footwear or not. Subsequently most of the decisions that have to be made are a consequence of the foot dimensions, the skeletal structure and the biomechanics.
Apart from the choice of minor individual adaptations like name and squad number, the individual choice is limited to leather type, colour and outsole appearance.

The core work with the customer to define the optimised footwear performance for their individual requirements also gives room for consultation on the pro’s and cons of the different choices. Athletes in performance sports are already used to a high degree of personalisation, which reduces the burden of choice on them as the consumer, and the perceived advantages negate the added cost issues-it is already well proven that the perceived added value of competitive advantage has a premium. A personal level of service through direct offline consultation with the athletes/clubs/teams aims to bridge the information gap in providing the assurance of a product which will be supported through a service contract which will allow for development of products to suit the athletes needs over a period of time.

5. CONCLUSION

The work done by P2L, which has pioneered the integration of new 3D design and manufacturing systems into a traditional bespoke product, has the potential to develop Mass Customised sports footwear not only for football, but for a range of athletic and sporting activities, as well as for orthaepedic and protective footwear. It also points to a new design and manufacturing paradigm that integrates 3D data capture, design and manufacture without the need to translate from 3D-2D-3D. Research into the direct “one step” production of shoes is already established with the CEC-Made Shoe project under a consortium of EU partners, which is investigating a number seamless production concepts.

Whether laser sintering, or similar emerging 3D manufacturing processes will offer the solution in terms of speed and functional materials remains to be seen, but it is through the integrated solutions outlined in this paper that the potential for the gap between consumer and producer to be bridged, and for better designed, sustainable products based on the needs and desires of the consumer to offer a viable alternative to current mass-manufacturing practice.

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