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INNOVATION THE LONG WAY ROUND: TRANSFERRING RAPID PROTOTYPING TECHNOLOGY INTO FASHION DESIGN

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ABSTRACT
Engineering processes often leave little space for exploration of new materials or production methods. In particular complex engineering processes are risk averse and goal focused. Innovation does occur mainly when it is driven by a need that can not be met satisfactorily by an existing technology and approach. Artistic design domains and in particular fashion design, have a very different attitude towards innovation. Designers are constantly on the look out for new ideas or new techniques. They embrace innovations from a variety of different fields and explore how these can be applied in their own work. While they might not develop new technologies, they explore the scope and potential of existing methods in a very playful and supportive way. This paper reflects on innovation in engineering and fashion design and reports on two cases where the creative opportunities offered by Rapid Prototyping (RP) technologies, and in particular Laser Sintering techniques, are explored and pushed to the limits in fashion and textile applications, to illustrate these very different cultures of innovation.

Keywords: innovation, rapid prototyping, comparison between design domains.

1 INTRODUCTION
Many engineers are immensely curious about new technologies and new ways of making things. Many were attracted into the profession by just that. However, in their professional practice there is often little space to explore new technologies or new ideas. Engineering products are designed to tight budgets and deadlines and companies do not want to incur unnecessary risks. Process improvement initiatives, such as six sigma or process excellences are creating a culture of repeatable process in development projects, where innovation is brought in from R&D or research facilities once it has been proven. This is causing concern about an engineer's ability to be creative [1] . While engineering companies need to innovate to stay competitive, there is often very little scope for exploring new technologies as part of highly competitive product development processes. Unless enthusiastic individuals step out of their processes and put additional work into learning about these new options, little exploration takes place. New production technologies or new materials are therefore often only selected when there is a real need to do so, because existing approaches do not meet new requirements, so that innovation is often carried out under considerable pressure. It is difficult for many engineers to find out about new technologies unless they manage to go to trade fairs or have the time to read trade magazines. Even there it might be difficult to spot the potential of new approaches because examples of its application are often hidden within competing products or products outside the range of what designers usually would look at, so that the attention of the designers is not drawn to new approaches.
This is very different in artistic design domains, such as fashion design, product design or graphic design, where designers have much more freedom to explore the potential of new materials or approaches by creating conceptual pieces which have no practical application, and may be constructed from non-conventional materials associated with that particular discipline. These domains have a culture of looking for new ideas and new techniques as part of their routine activities and allow themselves time to explore in a playful manner. This enables them to push the boundaries of what is technologically feasible. While these designers might not engage in need-driven innovation as such, they take up new opportunities and explore them, thereby developing an understanding of the

strengths and weaknesses and evaluating the tools with which to interact with these new technologies. In the case of computer systems that are newly launched, they will often require a period of use to even out difficulties with the handing of the system. As users push a system to its limits, the developers learn what needs to be improved and how to direct their own research and development. Companies require quick feedback from multiple customers to modify their systems and make them more user-friendly.

The drivers for design are different in artistic and technical design processes. Engineering design processes have much clearer and specific requirements than artistic design processes [2] . In fact many engineering design problems are over constraint, when artistic design problem are under constraint [3] . All designers engage in a combination of problem solving and solution seeking behaviour [4] . While engineers might typically more engage in problem solving and artistic designers in solution seeking [2] , both groups are opportunistic and are driven by the structure of their tasks [3] . Engineers engage in exploration and solution seeking when the opportunity arises and artistic designers solve tightly defined problems when needed. Artistic design processes are typically on a small scale with only a single designer or a small team involved in the design of the object so that most artistic designers engage in a number of different type of activities in the design process by contrast many engineering processes are carried out by very large teams of hundreds of people most of whom are highly specialised.

This paper will use RP technology to illustrate how a much more playful exploration of the medium can take place outside of engineering by discussing a highly innovative project to produce textile like structures using laser sintering of nylon, and to produce a heel using laser sintering of titanium. The textile like structure project started with body scan data to develop a made to measure glove, built up from meshed but separate links or rings. As a glove is an extremely difficult structure with high degrees of curvature in multiple axes and tiny detail, simpler products can be than produced in the same way. This pushes current rapid prototyping to its limits, in producing a very large number of small but free moving parts with current computer tools. This research on RP is carried out as part of the “Considerate Design” project of which authors are participants, and which investigates how textile consumption can be made more sustainable while remaining economically viable through adapting products to the tastes and body measurements of users[5] The paper has arisen through ongoing discussion between the authors, as the first author has seen the rapid prototyping project, carried out by the second author, evolve; and was reminded of the remarkably different cultures of nurturing innovation. This is complemented by on-going research on comparisons between different design domains, which has drawn on workshops [6] and observations of the design practice (e.g. [6] [7]).

The paper discusses the current culture of innovation in engineering companies in section 2 and contrasts this with the much more playful innovation culture of fashion textiles in section 3. This will be illustrated in section 4 with two rapid prototyping projects as case studies, before reflecting over the different cultures in section 5 and drawing conclusions.

2 INNOVATION IN ENGINEERING

Innovation is vital for most companies to stay competitive [8] . Innovation can take place on different levels, from small incremental changes to the product to radical changes in the business model. Christiansen differentiates in [9] between disruptive innovation, which introduces new products to new customers and eventually takes over from established products in established markets and sustaining innovation aiming for better products in established markets. Markides argues in [10] that disruptive innovation to business models are different to radical product innovation, while in the former the product can remain the same, the mode in which it is sold is different in an innovative way, radical product innovation brings a new product to a new market.

Innovation occurs continually in engineering. However, innovation in engineering is localised in the design process. Contemporary engineering processes, such as the diesel engine design process described in [11] are highly incremental. New technology, developed outside the project, is selected by a small team of experts before a specific project is launched and introduced into the design process. In this case study in innovation had occurred in the parent company’s headquarters and universities. A large team of specialists design specific components to given design, production and use requirements. Besides planned innovation from the beginning of a project, innovation occurs when designers run into unexpected problems late in the design process, where only an innovative solution can save an agreed schedule [12] . In these situations engineers typically have little time to explore. While significant advances are made in engineering, most engineers are removed from it.

2.1 Risk aversion in complex engineering design

Traditionally engineering risk has been defined as risk to life and limb (see [13] for a review), which arises from a malfunctioning of the product. Increasingly however, engineers are becoming more aware of the financial and business risk arising from project delay [14] and service and warranty claims during product operations [15] . Customers of complex engineering products are often more confident buying tried and tested technology, as illustrated by the surge in orders for diesel engines and trucks before a new generation of engines needs to be introduced due to new regulations. Incremental design and reuse of parts and processes plays a vital part in mitigation against these risks, as the risk associated with known parts and components can be estimated from service data and – at least in theory the development time is much shorter. In practice knock-on effects of changes to other parts in a product can avalanche across a product, leading to very high development costs [7] .

Reuse of components can also lead to reduced production costs through higher volumes and reduced manufacturing costs. Due to the high set-up costs and the challenges associated with finding and selecting suppliers, innovation in manufacturing processes are often carefully considered for products with low volumes, as it is typical in the aerospace industry. While many companies have made significant progress with integrating manufacturing and production issues early in the design process, designers are still often unaware of the details of the manufacturing processes that are used or that could be employed.

2.2 The challenge of technology introduction

In this risk averse climate of people working to tight deadlines and margins it can be challenging to introduce new technology. Unless a company recognises a need, they will not invest in new technology, in particular expensive new technology. Large organizations do have research departments, which develop new technologies, which can then be infused into on-going development projects [16] . These projects must still be persuaded that the new technology is fit to meet their needs. This is straight forward in cases where existing technology does not meet the requirements for key parts of the product, for example when it is known that existing material does not function reliably for the new temperature ranges. However improvement in less key parts, or attempts to save money, might not be embraced so readily.

In the early stages of new technology development there are often a number of different technologies from different vendors, with different computer support systems that are competing. For example in PR, as we will discuss in section 4, there are a number of alternative systems and materials, which each have there own strengths and weaknesses. Even if a company is willing to invest, they would need to understand and try out several different options. The companies need to see that before they invest, that the onus lies with the new technology providers to demonstrate its potential, rather then engineering companies exploring the affordances of new technology.

This makes it difficult for companies or universities to introduce new technologies in industry. While customers are very much assured to hear that other companies are using the same technology, they are often reluctant to broadcast that they have made use of it themselves, leaving the vendors with little to demonstrate. If the product itself has a long development time, it can take a while, before new design and manufacturing technology becomes visible on the market. The lack of time to explore combined with the risk averse cultures constitute a real barrier to the introduction of new technology in the industry.

2.3 Exploring technology outside of engineering

The question is raised as to how the potential of innovative methods for engineering can be explored and tested without putting a great burden on either the engineering companies or the researchers and developers of the new technologies. There is a need to find other applications in which the technology can be perfected and dominant technologies and CAD systems can evolve. In the case of PRthis could be through applications in product design or fashion and textiles, where the climate for exploration and innovation are very different to those in engineering. In a constant search for something new that differentiates them from other designers and their product, many designers enjoy exploring the potential of new tools and techniques. In these industries designing can be a playful process of exploration, where designers are encouraged to do so.

3 INNOVATION IN FASHION DESIGN PROCESSES

Artistic design domains, such as fashion design, graphic design or product design are driven by novelty and innovation. As products often remains static in their basic functionality, novelty is one of the ways in which need can be generated. Similar drivers apply to product and graphic design, but the processes of innovation and development of products, subject to changing fashions, are best understood for fashion and textiles. In fashion apparel the basic function and form of garments has remained the same for most of the last century, but innovation has been introduced through a multitude of new materials, such as elastomerics and microfibers, as well as new production methods, which have seen a transition from a traditional craft based mode of production, via highly optimized, but labor intensive production processes to current highly automated processes. For example knitwear progressed from being produced in large mills in the Europe, to a largely overseas but still very manual mode of production to a new technology, which now allows knitting whole garments in one piece with all the trims attached to minimize labour.

3.1 Context for innovation

As a culture, fashion designers are trained to continuously look out for new ideas. During their education they are encouraged to innovate, to experiment with new materials and techniques and to explore avant garde ideas. At the same time the fashion and textile products need to fit into the context of other designs that are sold on the market. Fashion design exists in the tension between being sufficiently novel to be interesting, but also being sufficiently in tune with existing products to be worn at the same time as illustrated by Figure 1. Innovation can occur in all parts of this evolving space, as cheap follow-on products are often product with highly innovate manufacturing methods to reduce costs of a once expensive design. However innovation to the product or its materials is usually pioneered in the cutting edge design.

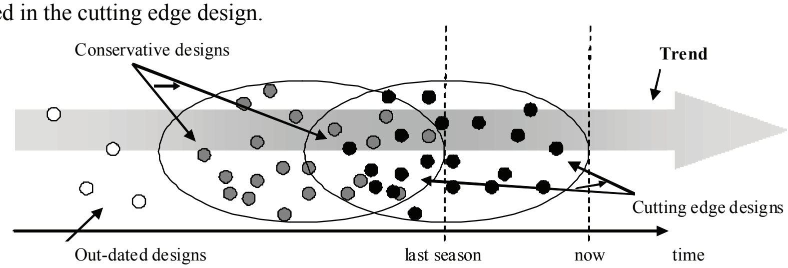


Figure 1 Development of fashion, see [18]

Different companies are typically positioned at different relative positions of this moving space, as the high street follows the expensive designer labels and cheaper brands follow the high street [18] . Big fashion trends are typically set by the elite designer labels, showing fashion collections and promoted by celebrity endorsement and through advertising campaigns in the mass media. However, more detailed innovation is often developed by independent designers, who work away from the big labels and therefore the constraints of house styles. Some of these independent designers are picked up by large global brands once they have built up a reputation. For example Stella McCartney and Alexander McQueen are backed by Gucci group as they provide breadth and kudos to their portfolio and can be turned into highly profitable business through licensing for perfume, sunglasses etc. which these large brands are highly capable at. In return the designers get assurance of high quality manufacturing and marketing support, as well as cash flow to sustain the business, which are very difficult to sustain as an independent designer. In a culture where designers are constantly on the look out for interesting ideas and innovative way of doing things, and magazines and “red carpet” events showcase interesting designs. New ideas are disseminated very quickly [19] and a premium is placed on uniqueness and individuality. A large part of the role of fashion is on recontextualising or representing themes which occur in a cyclical form as such that what is seen as highly unfashionable at one point in time may be represented as highly fashionable at another. This has an additional value in that it allows designers to re-evaluate and re-appropriate familiar techniques, materials and processes as well as incorporating new technological advancements so that they may gain new insights and design approaches. This has a reinforcing effect on the consumer, who is able to share the familiarity of the context or language of design which is comfortable to them, while at the same time enjoying the recontextualisation or novelty of the new design or technological elements.

In fashion and there a lively design scene with niche products situated between art and designer fashion, where designers try out and explore new ideas. These designs are often not sold, or sold in small numbers but still receive a huge amount of publicity through sponsorship deals, catwalk shows or the specialist media. Some of this innovation is associated with particular fashion colleges or universities. Another hub of fashion innovation is around the building of textile production machinery or design support software, as they are interested in exploring the potential of tier technology, thus creating a need for their equipment on in the mass market. Again these ideas are disseminated quickly.

Fashion innovation works both top-down through fashion label and respected designers, but also bottom up through "street fashion". Youth culture and the individualisation of fashion products, combinations through styling and modification-user customisation, form a vital part of the fashion system. Independent designers tend to be sited in areas that are culturally important for this type of mélange to happen. For example the more deprived or industrial areas of cities which tend to have high number of artists, musicians and culturally diverse populations who are catalysts for street fashion. Many of them may be fashion students themselves. Global companies know the importance of these "arbiters of taste" as they are not only the early adopters of new trends but also innovators in themselves through reconfiguring and combining diverse influences. Large brands such as Levis, and Nike use international trend scouts to report on these groups as they can be as influential as global design brands through recommendation and networks of influence within the fashion, music and creative industries. The need to industrialize these emerging street looks can be a significant driver for material and production innovation in mass produced fashion.

In this design scene innovation is carried out in a very playful way. Designers explore the potential of materials or technology while at the same time producing products that fit into a currently emerging fashion context or "zeitgeist" with they have often absorbed tacitly. While the designers in large organizations can be quite isolated these independent designers often operate in loose and informal support network of designers, often simply friendship groups, who operate in a similar mode and encourage each other to explore and push their product, material or process to the limits. Exploration in textiles has far less risk then with engineering products, as the products are rarely safety critical. They only require basic functional testing, for which the modes of testing it are fairly well established. The cutting edge of innovation, in particular the use of new materials and processes is on the edge of fashion and art, there the products are not necessarily designed for usability but for conveying the ideology of the designer, and as such may be thought of as art objects, which potentially could be worn.

With the high street being hungry for innovations to provide novelty, the transition between the designers, who generate the original ideas and those of mass market designs are fluid. Sometimes the designers themselves work freelance for the mass market manufacturer, but often the designed products are purchased by the designers of the mass market companies or their images are used as sources of inspiration for their own ideas [18] The culture of inspiration in fashion is very opportunistic, with everybody making use of everything that can give them an interesting idea. The boundaries between innovation and fraudulent copying are fluid and small independent designers rarely have the power or the money to follow up infringements of their own intellectual property. Even the large global brands only protect their significant markets, as the cost of worldwide protection is beyond them, and some copying in developing countries may be seen as beneficial to PR and marketing in some cases.

3.2 Innovation in the design process

Innovation and exploration is an inherent part of all fashion and textile design processes. This applies to designers at all positions of the market, where the processes are remarkable similar for all products of one type [19] . As the products are much simpler then engineering products, designers produce a large number of designs in the course of years and typically have different designers going through at the some time at different degrees of maturity. They are always on the look out for new ideas or new trends, whereby they both notice what recurs very frequently, but also what is really new. They notice

innovation quickly, because they routinely look for new ideas in the places where it is typically written up or presented. Fashion designers also allow themselves to look at ideas and to play and explore with new ideas. Finding out what can be done with new materials, for example, is an integral part of design process. Of course this is not unlimited, but all designers understand that a certain amount is necessary otherwise their designs become formulaic and they loose their design edge.
Fashion design is very hands on. Designers feel their materials. They physically manipulate the shapes of their prototypes. Their design is only partially analytical, and in many ways very tacit, as they hone in their perceptions to the style and feel of a season, to understand in a holistic manner what a new design needs to be.
Like in engineering design a certain amount of innovation is generated though the detailed design of garments or fabric, partly due to the inadequate modes abstract representations for many fashion and textile products, but also due to the experimental nature of the development and inspiration process. As garments rarely have very tight requirements, designers often embrace "surprises" in the design process. It does not matter whether a design is what they had intended it to be, as long as it is better then what they have planned for it to be [20]

3.3 The playful culture of innovation

Whereas engineering is risk averse and in many ways anti-innovation, fashion designers enjoy innovation and aspire to it. Even if in practice engineers are often extremely innovative and fashion designers are highly derivative, their mind sets are different. In particular for independent designers there is a desire to explore and to play and not to let go before they have come up with a new idea that excites them and their peers. Rather then following explicit requirements, which can be objectively evaluated, a large aspect of fashion and textile design is about creating delight for the user, about making something that excites people.
This generates a culture which embraces innovation and looks outwards for ideas to bring into their own field, but also makes people willing to experiment. The following section will describe exactly this behavior for the example of using RP technologies in textiles, which is both driven by the desire to generate unusual objects, but also to find new ways to producing and selling fashion and textile products.

4 CASE STUDIES: LASER SINTERING FOR FASHION & TEXTILES

Fashion and textile designers are interested in a number of new engineering technologies, such as nanotechnology, integrated sensing or "smart" fabrics and wearable electronics. There is also a growing recognition that the increasing demand for more agile low volume production is driving a move away from mass manufacturing to mass customisation. Even mass produced fashion and textiles typically have fairly small runs of less then 1000 garments, which are offered in a range of sizes. Personalisation of fashion or textile products is becoming more widespread, as body scanning technology makes measuring much easier then previously and an aging population demands better fitting products. Production is still typically craft based, for example cutting and sewing. Even components are rarely bought in large number as stockpiling costs can not be absorbed by low piece costs. Current digital manufacturing technologies for fashion are generally subtractive, in the sense that 2D materials are cut and sewn together, with the exception of 3D knitting which is the closest to additive manufacturing, along with felting which is probably the oldest 3D manufacturing technology for clothing. The uptake of additive manufacturing technologies would be a particularly attractive mode of manufacture for fashion and textiles as it would allow individualized made-to-measure products to be produced without the associated waste [22]. It would also allow the potential for integrating multiple materials, electronics etc within the build, and would significantly reduce the components and logistics of the complex supply chain associated with the manufacturing of clothing. The long term vision is that designs could be downloaded and printed at home or locally [25], and this would enable on-demand production.
This section illustrates the innovation potential of fashion textiles through to examples using RP techniques, where the second author has pushed the available technology to its current limits.

4.1 Rapid prototyping so far

There are a number of 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.

Unlike many other processes, Laser Sintering is self supporting during build and does not require a support structure to be built in addition to support the object in the build chamber, which adds significantly to time for finishing. 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 product development times and costs 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. Today, Laser Sintering is also associated with "Rapid Manufacturing" which is "the direct production of finished goods from a RP device" [21] , 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 emphasizes two aspects, "Rapid" also in association with Rapid Prototyping and "Manufacturing". The technique has little wastage as powders can be recycled and the need for additional components, such as moulds is removed.

Current mass-production methods such as injection-moulding offer the ability to build parts 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. "Manufacture For Design" [22] 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. The higher the functional integration into one part (i.e. the more parts that have to be moulded separately and mounted afterwards are subsidized by one integrated layer manufactured part), the higher the economic advantage for laser sintering technology, this is emphasized by the term "e-Manufacturing" ([23], [23] [24]

At present the techniques offer relatively limited scope for surface finishes and can only produce parts of homogenous materials. However, it is expected that heterogeneous characteristics may be applied to the materials through CAD modelling and optimisation, or by power-variable laser scanning. Recent developments have seen the possibility for graded functional materials and multiple material builds using 3D polymer inkjet. Finer resolution can be achieved at the cost of higher printing time, and emerging systems such as 3D Laser Printing based on existing toner printing technology may offer much higher resolution parts with greatly improved aesthetic properties such as color at much higher speeds. Where current systems fall down is in the materials properties required for RM, however for non-engineering applications this may not be so critical, and so the creative application of the technologies may actually be some of the first to capitalize on them.

4.2 Laser Sintered Titanium Shoe Heel

During discussion with a technology vendor who provides laser sintering hardware and materials, and who has supported creative use of their technology through sponsorship to designers-it was agreed to test the use of new titanium sintering technology to support a footwear masters student at London College of Fashion (LCF) for the building of several heel prototypes. With the technical support of the staff of the Digital Studio at LCF several designs were developed which demonstrated the potential for such technology in the footwear market, these are:

- New design freedom which allows complex designs which would be difficult or impossible to build using traditional casting techniques.
- Use of materials which allow lightweight yet strong designs to use less material than traditional techniques.
- New approaches to manufacturing, using a one piece heel and shank which plugs in to a nylon sintered sole to reduce the number of components in the shoe, by integrating several components which would have had to be assembled to be produced in one piece.

The process began with a design tutorial with the student who was having difficulty in modeling a complex heel using traditional metalworking techniques, and was interested to find out if RP techniques could provide an alternative. From her sketches for heel two designs were selected for development and she was assisted in the CAD modeling stages of the heel. This process was rather intuitive and based entirely on the aesthetic requirements of the student, without any dimensional or mechanical consideration. Several physical prototypes were made in plaster on a 3D printer to check for pitch and fit to the last prior to sending the CAD file to be built in titanium. It took several attempts to build successfully but was a valuable exercise for both technology developers and designer alike. Strength tests were subsequently undertaken and the heel was found to be capable of supporting more than 400 kg, which was well beyond any expectation, but this was not a consideration at the design stage.

The outcome is that the first design prototypes have been successfully made into shoes and exhibited in the student degree show. As a result the shoes have been shortlisted for 2 design awards and the technology suppliers have an interesting case study which demonstrates the potential for this material process in new markets, and useful marketing prototypes which can be used for trade shows and promotional materials. The playful nature of the design process and aesthetic considerations were the drivers without constraints of cost or mechanics. However the actual cost which would be around $2000 is still acceptable in the couture market, so that the product is potentially viable, and alternative materials are also now being tested which would reduce costs and make larger volume production possible.

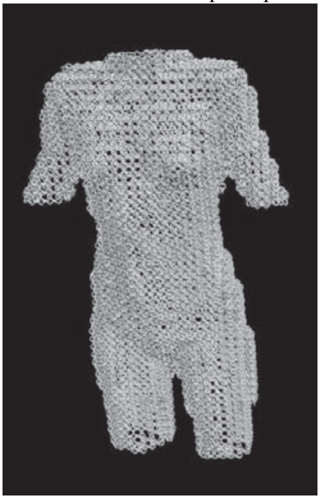
Figure 2 Rapid prototyping model of the heel, final shoe and sketch above

The heel displayed in Figure 2 is not just a test piece for this the rapid prototyping technology, it is also a fashionable item, which keys in with current cat walk fashion for interesting shapes in heels. The shapes are organic and flowing. The design of these heels is interesting as an art object, just as much as as an example of a new technology. During the design process observers reacted to the visual

quality of this organic and praised the emerging design for its aesthetic qualities. In this sense the design was a success even before its structural qualities were tested.
This is an example of the fact that in fashion, a design does not necessarily have to meet all its requirements. Sometimes it is enough to meet some very well. This example is aesthetically successful, structural sound, but not economically viable. By contrast an engineering design that does not meet a key requirement is typically seen as a failure.

4.3 Laser Sintered "Evolving Textiles"

The aim of this project has been to develop and extend on the work done in rapid prototyping textiles, by using 3D body scanning and genetic algorithms to generate novel linked textile structures and create a 3D textile mesh conformal to the scan surface. This will demonstrate the capability for textile and clothing products to be manufactured directly in 3D from raw materials in much the same way as engineering or consumer products are now being produced using these techniques. At the same time the project set out to question the design process and associated CAD software which currently bridges the gap between design and production processes.
The uptake of 3D body scanning technology into the clothing and fashion industries [26] is beginning to have an impact in the area of made-to-measure and mass customization [27] . However only limited incremental changes have come about in recent years in clothing manufacture, and the sewing machine remains the principle means by which fabric is joined together to make the finished garment.



This project has explored the potential to use linked structures to fit around a personalized body shape. Laser Sintering was selected as particularly suitable as it is self supporting during build, because it would have been extremely challenging and time consuming to build a support scaffold for a delicate chain link structure.
The potential to not only create concept models, but to directly manufacture functional parts using this technique has more recently emerged, enabling the capability to build complex geometric shapes and assemblies of components which would have been impossible to create using traditional tooling or moulds. Increasing use in industry combined with improved build speed and size allows for greater flexibility for production of custom and bespoke products. Some examples already commercialized include custom fit hearing aids, automotive components, lampshades and sunglasses. Freedom of Creation, a product design company, have shown proof of concept for rapid prototyping techniques to be applied to textile-like linked structures, and these have long term potential for clothing applications[28] .

Figure 3 Chain Link Structure for whole body scan

Limitations of the current RP hardware which has the capacity to produce objects near to, but not at full body size, are recognized. Figure 2 shows a computer model of a potential whole body fit. Experiments with software which allows collision simulation suggest that there is the potential for deformation of the textile structures so that they can, in effect, be compacted and produced in a smaller space than they would occupy if they were on a body. This also offers a potential saving on time and space, as well as possibilities for producing pre-packaged products in a single manufacturing process[28].

At this stage of the project it has become clear that currently available materials for PR have been developed for engineering, medical and tooling processes and so considerations such as drape, softness and wearability have not yet been considered. For this project we chose to test several materials which have potential for more flexibility (TPEs) and are much lower cost materials than currently available. The current market is driven by high cost materials which are only available from a very limited number of suppliers. Machine producers make significant revenue from consumables and there are few 3rd party producers currently due to warranty and servicing constraints. It is foreseen that once the market opens up significantly that much lower cost and more varied materials will be available. Perhaps to consider specific requirements for clothing may mean that organic materials as well as polymers may be available, and that materials developed for medical uses ay also have design and fashion applications. It also has the potential for multiple materials such as clothing with integrated sensors, electronics and power supplies that could all be printed into the structure of the textile.

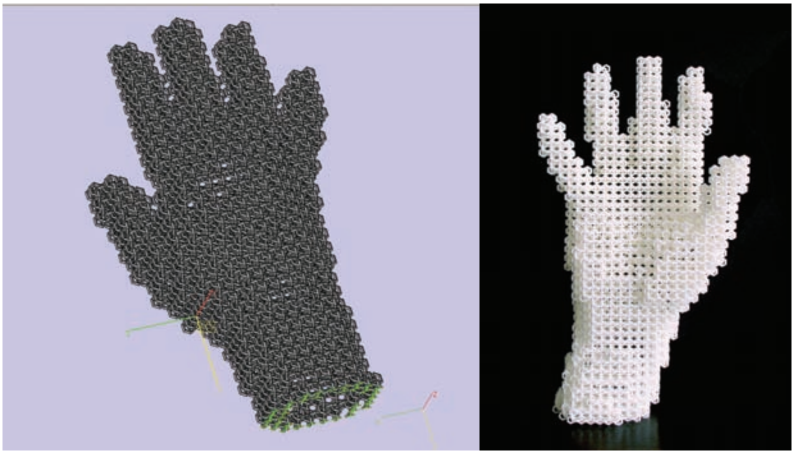


Figure 4 Chain Link Structure for a Glove

A hand scan was selected as an example, to construct a glove around, because it was small enough to be produced in a standard laser sintering machine, while posing the greatest challenged due to its high degree of complexity, curvature and mobility. Figure 4 illustrates some of the challenges of generating a chain link structure, which would provide the wearer with the flexibility to move their thumb unrestricted. While it is possible to think of applications of such a glove, for example in safetywear, the development is not motivated by a specific need. Rather, a glove is an intuitively understandable example something challenging to prove. A convincing a glove will inspire others to produce other highly flexible products. The glove will be displayed in project workshops and exhibitions. So far designers, who attended project workshops, were observed to pick up the glove and play with exploring its flexibility. As the glove becomes increasingly more flexible, the participating designers become increasingly more positive. So far it still has not reached full mobility, but the feedback has continuously been positive.

4.4 The innovation potential in fashion of rapid prototyping

The ability to produce and store digital products rather than physical ones gives a new potential for products not only to be produced on demand, but to be open to innovation processes previously described in our discussion on fashion innovation. That is by making digital products available to others they can be shared, adapted, customized and updated. This is already having an impact on the fashion industry through the use of virtual prototyping for design communication and marketing, thus reducing the number of physical prototypes that must be made. More interestingly there is a new market emerging for fashion which exists entirely in the virtual-as more people engage in Massive Multi Player Online Games (MMPOGS) such as Second Life, Home, Habbo etc a new market for virtual fashion products is being stimulated as the inhabitants of these virtual worlds desire the same individuality of style that they would in the real world. In this environment the design of the heel could instantly be deployed. It is easy to see that in the near future we will be able to chose and customize virtual products which can then be sent to “fabricators” either in local manufacturing centers or in our own homes. Indeed this type of online community of design is already being tested with companies like Philips introducing “Shapeways” beta site [30] . This online design and manufacturing site offers simple 3D design tools to allow users to design products which are then uploaded to the site. The user can then choose from a number of materials to have their design manufactured using a range of RP technologies and the finished product is then shipped to the designer. More importantly all the designs created form a catalogue which other users can choose to purchase, or with the originators permission, to modify for themselves.

The significance of these new models of design/manufacture and interaction for 3D manufacture of clothing described in this project are that they offer the potential to dramatically change the mode of consumption of clothing. Currently the fashion industry is very wasteful with a third of all clothing produced ending in landfill due to a number of factors including poor fit, over production of similar goods and bad forecasting [31] . This waste could be significantly reduced if a proportion of clothing was produced on demand, particularly if it was produced using such an additive manufacturing process.

5 CONCLUSIONS

The two case studies of rapid prototyping projects illustrate the spirit of innovation in fashion textile domain: a playful exploration of the technically possible. Without tightly defined success criteria at the beginning of the project, partial success is encouraged and rewarded by the peer group. These projects did not invent new manufacturing technology, but they pushed existing technology to its limits and suggested new ways to do it. Once the ring links in the glove provide full freedom of movement for the thumb the same solution approach can be applied to other application, which require a ring link structure. The model of the glove will be displayed and published, so that other designers can draw inspiration from it. In a culture where publically being seen to be first to have come up with an idea counts very highly, ideas are shared freely with those who want to follow, within the limits of companies and individuals protecting their know-how. This contrasts strongly with the innovation culture in engineering, which is very risk averse and often plays down the novelty of designs. Engineering design is highly creativity, but this creativity is often hidden from view rather then publicised widely. It comes through when there is a real need. In the tightly constraint environments of engineering projects, engineers often have little opportunity to explore new techniques or play with new materials. Engineers, in particular later down a process are discouraged by their managers from exploring and coming up with new solutions, as these introduce potential risks and costs. Engineering companies occasionally manage to set up a similarly innovation friendly culture through sunk works or special projects, but these are very much the exception.

Looking at these differences in cultures and in modes of working, it becomes apparent that there is potential for collaboration or cross fertilization between fashion and textile designers and engineering designers. Fashion designers are already looking at engineering in as much as they have access to, but engineers might to think to look at fashion products for general engineering. Collaboration between textiles and engineering is already happing in the automotive industry in innovative industrial textiles. However for other industry sectors, totally non competitive situation could provide a great opportunity.

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