Lasers: forming a relationship in the making

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Abstract

Laser and CAD/CAM technology can assist in design decision making and enable a more sustainable practice with its speed and reliability of processing. Many designers have approached lasers however, with a desire to extend their practice and a quest for the 'unobtainable by other means'. Often this has involved delving into the fundamentals of laser materials processing, scientific methods and programming in order to achieve creative outcomes. Lasers are now beyond the stage of novelty – they are widely used in education, and to some extent the concept of making is being reinterpreted. With commercial routes for access and an increased understanding of the relationship between processes, digital fabrication can occur with relative ease. Consequently, it is debatable as to the extent its capabilities will continue to be pushed by way of an empirical design research methodology for outcomes in designed products; the focus has shifted to novel ways of presenting products to be consumed and to users being involved in the creation of products, to democratic and ubiquitous digital fabrication.

Key words: laser forming, process transition, user participation

1. Introduction

As an aspiring silversmith in the mid-1990s, producing large geometrically inspired table pieces in silver, appeared a somewhat unsustainable professional practice. It was necessary to find a way of making folded products more affordable whilst retaining the nature of craft and enquiry. Production methods and technologies that could enable repeatability and reduce the making time seemed worthwhile exploring; and indeed some earlier work incorporating modular folded units had been mitred using a CNC router. The idea of using lasers became a reality after meeting Prof. Steen, the then leader of The Liverpool Laser Group, who said, "You wave a laser over a piece of metal and it will bend" - it was not as simple as that!

2. The laser forming process

Laser forming is a non-contact rapid prototyping (RP) technique that uses the heat of a de-focused laser beam to induce compressive stresses, which in turn causes metal to bend without melting. The metal sheet or tube is moved underneath a laser beam by a computer numeric controlled (CNC) workstation. Laser paths can be created using software, so that 2D CAD is converted into machine code. On a macro scale, the process has future applications in the aerospace and automotive industries for producing body panels, whilst on a micro scale; it is currently used for the alignment of the laser diode that reads the disc in CD and DVD players (Geiger, 2002). Although laser forming is mainly of interest to the scientific community, its origins pertain more to the skills of a craftsman. It evolved from the flame straightening technique that is used for the alignment of metalwork (Holt, 1965). The advantages of laser forming are a more controllable heat source which can be precisely directed by CNC.

During the 1990s, engineering research established three bending mechanisms: the temperature gradient, buckling and upsetting mechanisms. The Temperature Gradient Mechanism uses a small beam diameter relative to the sheet's thickness and a high velocity, so that the heat does not penetrate the bottom of the sheet. This results in a temperature gradient through the thickness and achieves greater shortening in the upper layer. Consequently, the surfaces either side of the lasered line are pulled towards each other, resulting in a bend. A ridge of compressed metal forms on the heated side as there is no loss of material. One straight-line scan of this mechanism produces an angle of up to 3° (Vollertsen, 1998); therefore to form a part of significant depth, multiple passes are necessary.

The Buckling Mechanism can bend metal in either direction. It occurs with a large beam diameter and low velocity where heating is nearly homogeneous. As a result, the bends are rounded but they are also large, up to 15° for a single scan (Vollertsen, 1998). The bending direction is influenced by pre-bend in the material (Arnet and Vollertsen, 1995). Consequently, it seems sensible to coax the sheet to the desired bending direction by hand prior to irradiation.

With the Upsetting Mechanism, as a result of low velocity, heating is homogenous; this results in parallel plastic compression through the thickness, which causes an overall shortening of the part. This mechanism is difficult to attain with thin sheets since a bending direction is likely to result. Upsetting is generally achieved with thicker materials and tubes; it is often used to form parts such as bowls, whereby form is created through the reduction of the surface area. Figure 1 shows the heating scenarios of the three mechanisms and an example of the forming achieved by each mechanism. With the upsetting mechanism an increased wall thickness can be seen in the tube.

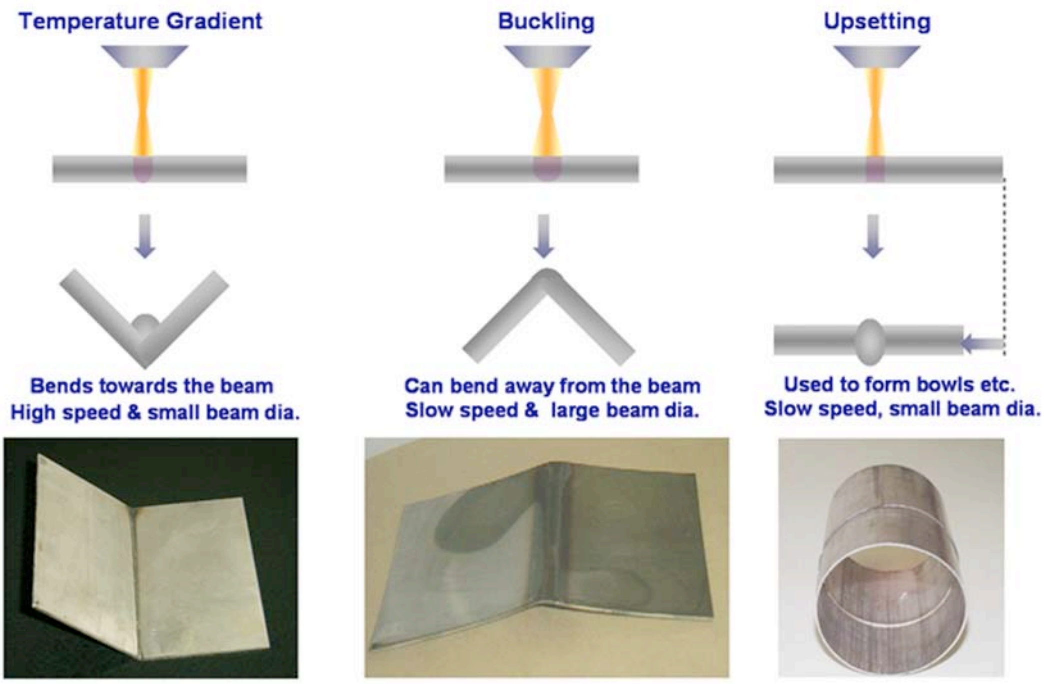

Figure 1: The heating scenarios for the three laser forming mechanisms.

3. Researching laser forming for silversmithing objects

The culture of an engineering lab gave exposure to new ways of working; in particular the rigour of scientific experimental methods, metrology and Finite Element Analysis. Technical information on laser forming was gleaned from an extensive literature review; the most common kinds of papers at that time were parameter explorations for specific engineering materials, which involved plotting reliable results from straight line folds. Little work had centred on the capability of the process to produce three-dimensional forms. The most advanced work at the time that had potential aesthetic quality and functionality had been undertaken by the Kielce University in Poland and the University of Erlangen in Germany. Frackiewicz had extensively investigated achieving ridges and contours in tubes and formed archetypal bowls (1992, 1996). The German product orientated investigations included net folding bowls and lamp housings, and the laser cutting and forming of spoons (Geiger *et al*, 1994).

The intriguing aspect of laser forming is that it bends metal without external forces. The process shapes metal by compression and cannot stretch it. As with traditional metalsmithing, it requires thought as to where you want the material to go. There is a relationship between the 2D CAD, or laser path, and the 3D form. It was this relationship that needed to be given some definition in the course of the study. Given the seemingly open-ended nature of the exploration, the data available and the experimental procedures did not seem wholly suitable to the project. Yet to proceed purely by an empirical methodology could also be seen as fanciful and be potentially fruitless. Initial experimentation began with creating straight folds and simple examples such as those shown in Figure 1 in order to have a handle on the mechanisms for the materials under investigation. It was a strange experience to treat materials as if they were paper, rather than proceeding through a design process to a final object. The project then focused on developing a series of heating strategies for 3D forming, in effect creating a ‘dictionary’ or ‘handbook’ as reference for creating artefacts (Silve, 2004).

This had its own constraints; it was necessary to start out with ideal forms to be achieved and success of the outcomes seemed more measurable in terms of being able to control the process if the forms were symmetrical. The experimentation proceeded systematically through potential geometries and heating sequences for a given form. To expand on this, each line in a laser path can be executed from either end, and for geometries involving more than two lines, how many permutations of line order and direction will there be? Since laser forming generally manipulates flat sheets, it is analogous with origami. Paper models were often used in the development and analysis of simple heating strategies, but there is no clear correlation for complex forms which are beyond simple folds, such as those involving curves, or where offset lines create curved profiles and conical sections.

The method of creating 2-D laser paths depended on the system being used. Largely this involved a Graphical User Interface (GUI) or CNC machine programming in G-code. It was never the intention to be proficient at programming; a combination of studying the manual and a hacker 'cut and paste' approach to existing programmes was taken. Using Corel Draw, drawings were converted into bitmap based plotter files and imported to the GUI, so that patterns were executed as dots rather than lines (Silve, 2006). Forming text and bitmaps resulted in incoherent forms but often resulted in interesting textures. Indeed as a result of working with lasers, there has become a place for including texture in the products designed.

The use of programming and lasers does seem to create a distance between the maker and the work. It created a physical rather than emotional distance; there is still an intense sense of creation and ownership. The experimental research did not always lead to forms that were useful for contemporary products. Likewise, forms successful in terms of process capability did not always seem aligned with the personal aesthetic choices that would have been made designing a product in a traditional crafts' framework. There is a distinction of ownership from authorship, where in some instances there has been a sense of detachment as forms and products were resulting from observations of process capabilities and control.

Dynamic or useful parts were evaluated however; they were often duplicated (showing process repeatability) and played with like pieces of card in a conventional design process and after some design development, made into objects through traditional techniques. These objects, (some examples are shown in Figures 2-5 and 7), mostly stand as a manifestation of the research outcomes, as indicators of possibilities, rather than as having been designed and made using a laser. In its simplest use, the Temperature Gradient Mechanism can create objects by folding laser cut nets as shown by the pair of silver napkin rings in Figure 2. Here the mechanism can be compared with hand-scoring, although laser forming is quicker and there is no seam to solder! It was the fascination of creating curved and undulating metal surfaces that spurred the interest in CAD/CAM and lasers. In this respect laser forming has excellent potential. The dish in Figure 3 has two curved folds. Folding by laser is permanent, the material becomes work hardened in the process and objects can be completed with the additional fabrication and soldering of components.

Figure 2: A pair of silver napkin rings, made by laser cutting and forming

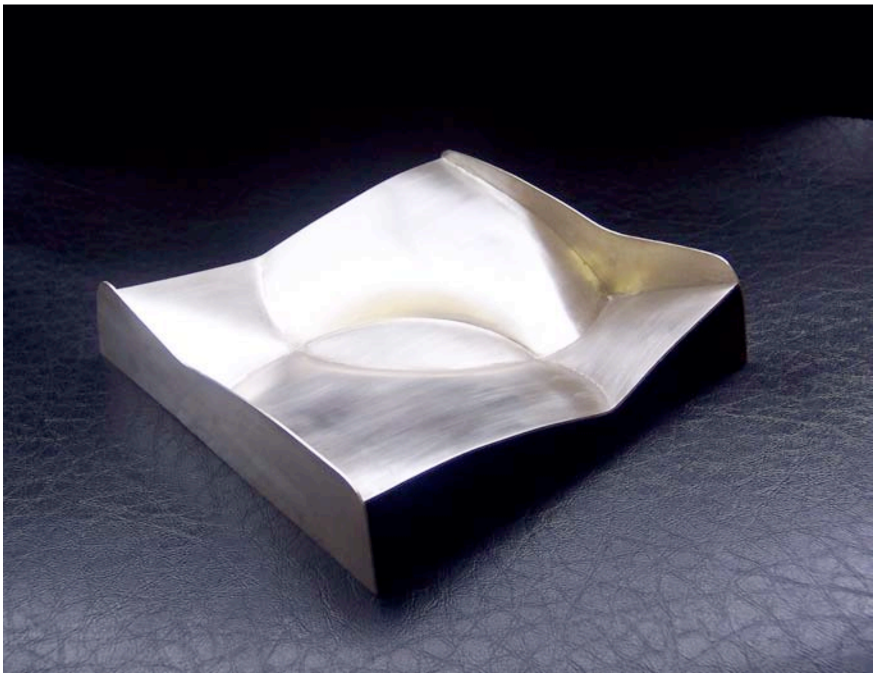

Figure 3: Silver dish using folded curves of the Temperature Gradient Mechanism, the sides have been soldered on.

The ability to bend metal towards or away from the beam without exerting force makes the buckling mechanism flexible, as is shown by the dish in Figure 4. In production, this dish might be achieved by stamping, which requires a costly die. As a laser formed prototype, one-off, or batch product, the dish was produced in around an hour and in the required material. Laser formed parts do not require any secondary processing, such as moulding or casting, as is often necessary with many other rapid-prototyping methods. Once the heating strategy is correct, the geometry may be scaled and the parameters altered to produce the product in different sizes and different materials - this is useful in the context of designed products for producing a set of items.

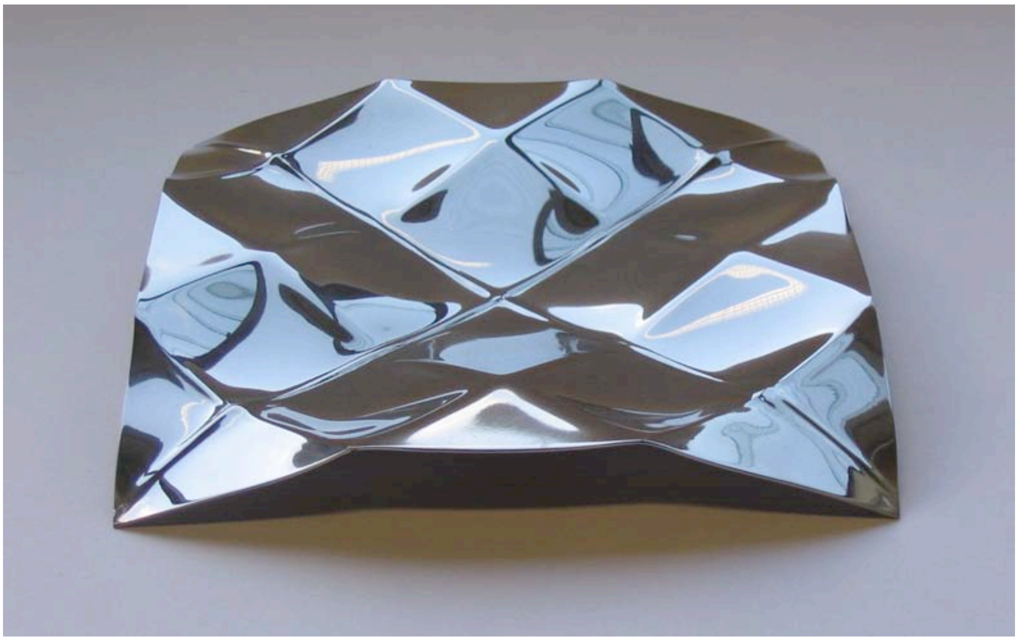

Figure 4: Dish formed by the positive and negative bending (buckling mechanism)

‘Offsetting’ a series of parallel lines produces a curved profile. This is incremental bending, and the smaller the offset between the lines, the tighter the curvature of the resulting profile (Pridham and Thomson, 1995). Extending this principle, offset lines need not be straight or parallel. Sheet forming strategies can also be adapted for tubes, as is shown in Figure 5. The body of the vase, shown on the right, was produced from a tube in half-an-hour. Scanning the bottom of the object to get the profile enables a bespoke base to be laser cut.

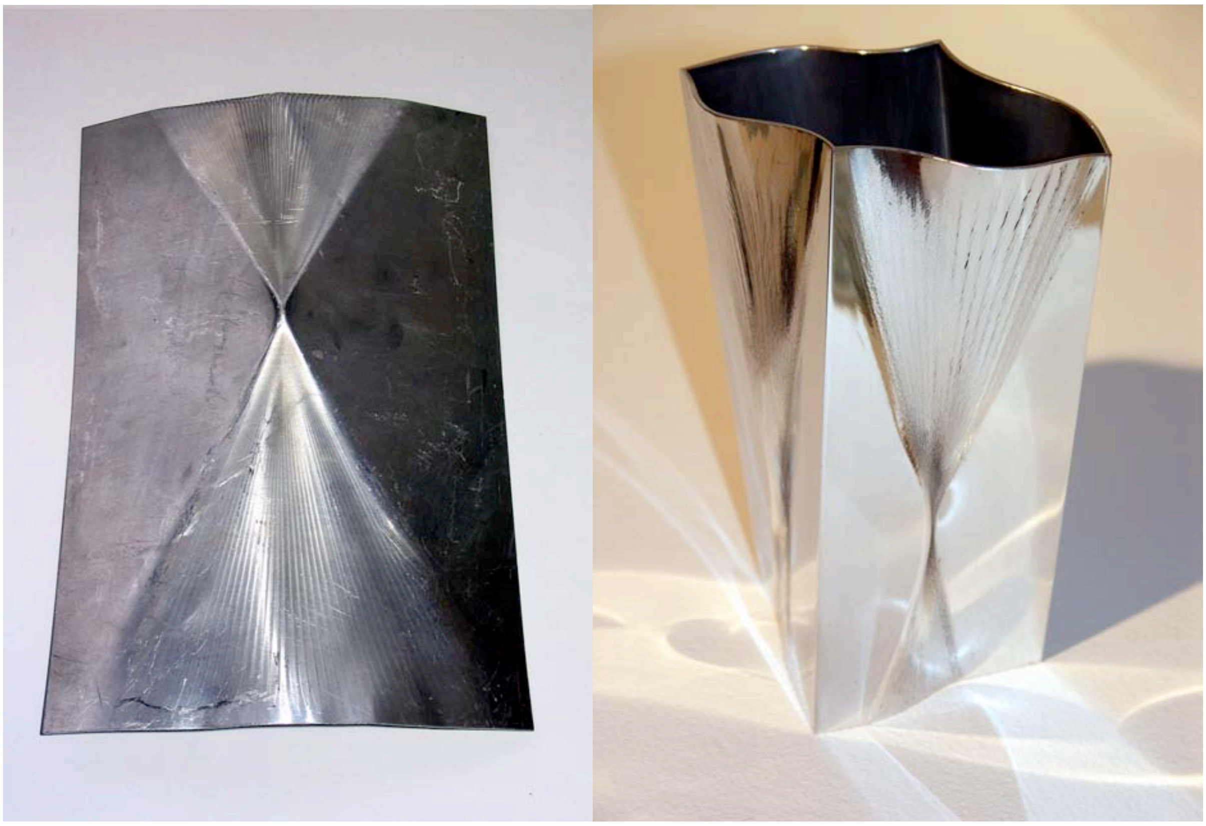

Figure 5: Vase formed from square tube, using the principle of a sheet experiment

The development of a personal design identity through laser forming did not really begin to evolve during the initial study. After the capabilities of the process had been investigated, it was possible to consider how to use them directly in metalwork products: in other words it wasn't until the design and product interaction, rather than the control of the process, was at the fore that stand alone products could be developed. Furthermore from a consumer's point of view, the products should fit into the context of the craft rather than be examples exercising the capabilities of a new process. More recently the work with laser forming has a more playful approach and considers creating a range of products around a principle geometry. The prototypes shown in Figure 6 are examples of work in this vein. The top two dishes have started from a bench folded box that has been laser welded. The rocking prototype (bottom right), comprises of two sheets that were resistance welded prior to forming. The laser has formed the top sheet and the bottom sheet has been curved in response to the forming.

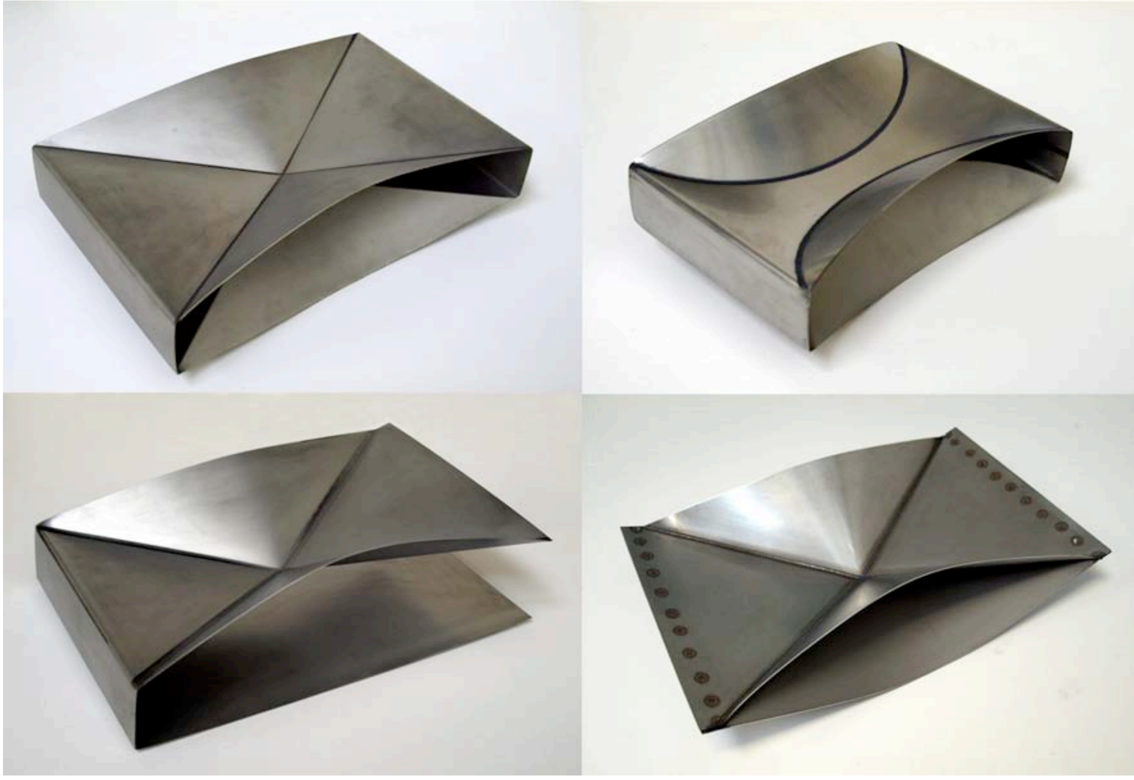

Figure 6: Double skinned stainless steel dishes around simple geometries.

4. A designer's methodology and approach conclusions

The experimentation was mostly empirical although to substantiate theoretical concepts and parameters, a scientific approach was sometimes used. In particular a study of laser parameters and strategies for bending square tubes in a single axis was undertaken. The hypothesis was that since laser forming is an asymmetrical heating process that the resulting compression would vary along the heating line. The merit of the laborious research was that after proving the principle, it could be applied to bending tubes in multiple axes for objects. The principle was validated through sectional analysis and involved measurement of the increased wall thickness through microscopes. Likewise, an intensive parameter research was carried out on silver alloys. The premise of the research was that since laser forming is an expensive process it warrants use with an expensive material; silver is an important material in the context of silversmithing but it is expensive and cannot be used like paper as was the case when exploring process capabilities. The difficulty of forming silver had been that the heat affected zone is wider than that supposed for other materials at the same parameters because of the material's conductivity - this effect had been demonstrated in copper by Arnet and Vollertsen (1995). Consequently the work with silver was underpinned by analysis of thermocouple data to monitor the materials' diffusivity and the parameter affects on the heat affected zone. The study resulted in the benchmarking of the forming mechanisms for 1mm sheet silver.

The use of scientific methods and knowledge of materials science have their place in the use of lasers in art and design, as they can really help us understand why the results are achieved. It can seem, however, that the scientific route is an endless trawl to the light 'at the end of the tunnel' and only worthwhile if the ends justify the means with a creative outcome. Over the past 15 years or so, before lasers became integrated into art and design, several designers and crafts practitioners seized, or made their own opportunities to work with lasers. Often the framework for doing this was within an academic environment, and it was particularly common for practitioners to find themselves in engineering research groups, hence the influence of scientific methods in the research. This was also timely with the emergence of the 'Practice-led' PhDs. As lasers have become more user friendly with closed systems on the market, and CAD/CAM, lasers and RP have become a part of the designer's toolkit, it appears that the mystery of how the 'black box' works and the implications of materials science is no longer a relevant thing to understand – at least in some instances where processing can proceed by trial and error following the guidelines of the manufacturer's recipe book.

The laser power, beam diameter and velocity affect the distribution of heat through materials. As a craft's practitioner, this draws parallels to other tools, for instance the sensitivity that can be employed for manipulating metals rather than 'hitting it with a hammer'. It is this understanding of the laser variables that the laser is a source of light and heat to be harnessed with different levels of intensity to give specific materials interaction such as cutting, marking and welding that is key to working with lasers. This understanding exceeds what can be found in recipe books. This approach enables practice to be extended by empirical working and is not bound to assumptions and existing benchmarks.

5. The unobtainable quest Vs the desire for speed and repeatability?

The utilisation of the experimental outcomes in artefacts which speak to the consumer or audience is crucial as it enables practice to evolve and the research to be communicated. The audience is the eventual purchaser but also other designers that may wish to use the process. From the perspective of the consumer, how important is it to them that the product has used new technology? It is the quality and intent of the design that is the attraction, the use of technology needs to extend beyond novelty and perhaps be muted. New technologies are the vehicle by which new aesthetics can emerge - they can enable things to be made which were previously unachievable by conventional methods. This has been a driver for many practitioners who come to use lasers because they see a connection with the way they work, or the forms or marks they seek to achieve. Harrod (2002) points out that in using new technologies, there is a pre-occupation to validate the use of the process by making objects 'unobtainable by other means' and this seems to have been a continual question when disseminating the laser forming research. An answer to the 'unobtainable' can be seen in Figure 7, where the upsetting mechanism has created ridges on the tube wall and simultaneously formed the tube by the loss of surface area. Another aspect of the unobtainable is certainty of the forming result at least given the current stage of process development worldwide.

Figure 7: Ridges of upsetting in a vase.

Is the unobtainable material specific? It is also worthwhile considering aesthetics obtained from working with other materials and traditional manufacturing processes for potential translation into the laser materials processing domain being investigated, for instance, can some of the voluptuous forms achieved in plastics be achieved by lasers in metal? Then again this may bring us back to equations with the capabilities of hand raising and the laser is humbled to the status of providing speed.

From the time that lasers and Rapid Prototyping became used by ‘designers’ certain aesthetics began to emerge that were the clear exploitations of the processes for the unobtainable. With laser cutting a particular fascination with geometry and tessellation, with rapid prototyping the exploitation of supporting structures in interwoven parts. Fortunately it would seem that now the technology is more embedded in practice that the inclusion in products is more sophisticated. For instance as well as use in products, the opportunities of RP combined with animation and the internet have opened up new paradigms for designing bespoke or limited edition products (Atkinson, 2004). Similarly, there is a move towards including consumers in the design process of products resulting form digital fabrication, which blurs the boundary between amateur and professionals (Atkinson, 2009). To this end, perhaps the quest for the unobtainable is not as prevalent as it was, that the technologies can now be employed in more human-centred systems of design, and that the opportunities for ‘speed’ in terms of resolving design issues and having a sustainable practice have more currency. From a personal perspective however, experimentation is extremely beneficial for achieving the design identity, but it is the further manipulation that re-establishes the link between the ‘untouched by hand’ outcomes and the designer’s intention; the speed at which the laser can process materials or the physical achievement of the parts themselves has limited value.

Participatory research

With a growing community for digital fabrication, the question is whether outside of an academic environment practitioners can have the opportunity, time and facilities to develop an experimental and critical approach to digital fabrication. Several bureaus offer taster days on technology and software, and some even offer New Product Development (NPD) style schemes that can but favour smart approaches to designing for manufacture with a linear relationship with established technology. For designers, particularly those with little CAD experience, there seems quite a number of hurdles and the need to commit a lot of time and money to begin working with lasers and rapid prototyping. Taster days and software courses can get the ball rolling, but is there a case to be made for designers being able to access technology in a risk-free, cost-effective framework that enables empirical research and creative outcomes to flourish?

In a further project, practitioners working in metal, but not necessarily silversmithing and jewellery, were able to undertake short laser forming projects. Most participants had similar geometric fascinations with the process, this may in part be due to their exposure to the outcomes of initial laser forming projects. It would be interesting to see if a designer undertook an extensive study of laser forming, where they would end up.

Neil Parsons is a young product designer who was interested in using laser forming for furniture. A small scale model of his CAD stool (shown in Figure 8) was made using the laser at Brunel. The facilities did not enable the part accessibility to create a full-scale model, but allowed us to evaluate and modify the curves. The laser forming of a full-scale metal stool was undertaken at Carr's Welding using an Nd-YAG laser mounted on a robotic arm. The stool was achieved in a few hours but the time could be reduced with some parameter optimisation; however it goes some way to demonstrating the potential commercial viability of laser forming.

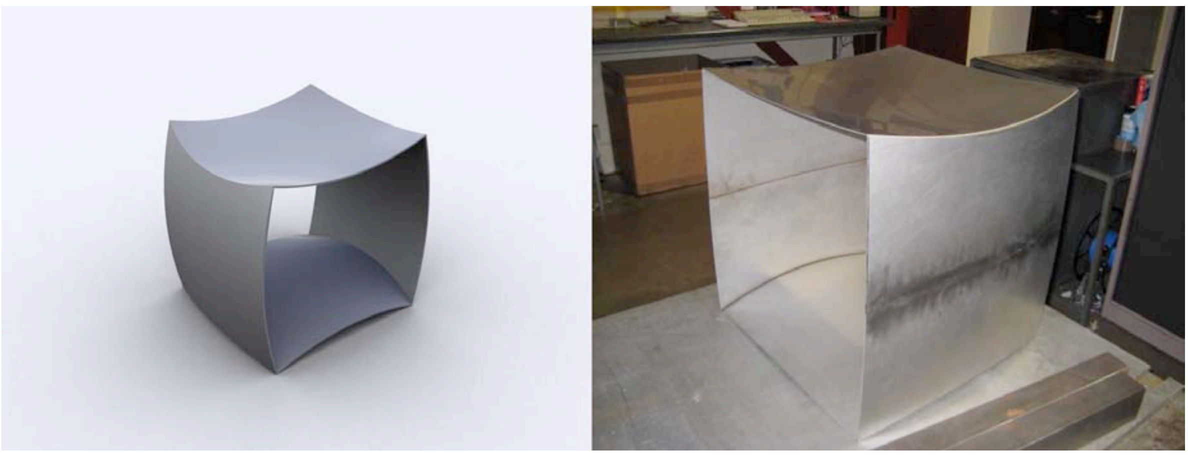

Figure 8: Stool project with designer Neil Parsons and Carr's Welding.

Elizabeth Hodgson is a sculptor who produces organic pieces mainly in copper and steel (Hodgson, 2009). Elizabeth initially wanted to explore how she could use laser material processing in her work; although she also undertakes community arts projects, and had just started work on a playground sculpture for a school in Hampshire. The project seemed a suitable vehicle for initial experimentation enabling Elizabeth to see what the process could do, and brought its own range of values. The concept for the sculpture was a tree, with leaves derived from the children's drawings. Involving participants is core in community arts projects, which aside from widening participation, can aim to improve people's sense of well-being and inclusion within the community; projects may also serve to address aspects of environmental regeneration. The collaboration lay in translating the drawings into three-dimensional metal forms using laser cutting and forming. The value of the work, as well as lying in the end product and its use in the sculpture, was in the translation process, the notable decision making, and the different meaning that the engagement had for both participants.

Figure 9: The leaves project with sculptor Elizabeth Hodgson for Barncroft School

The drawings were digitised by flat-bed scanning. The outlines and features were traced by Elizabeth in Adobe Illustrator, which was something she hadn't done before. There was some interpretation of the children's intentions - did we see what they had visualised? If they could make their leaf 3D what would it look like? After tracing, the drawings were evaluated as to their perceived relationship to existing laser forming experiments. Processing knowledge was applied when creating CNC programs to consider the form that could be achieved; for example veins lend themselves well to folding, and cutting holes within the leaf enabled it to become more three-dimensional when heated by the laser. In terms of processing, the leaves were all cut and then the forming program was run. The project emulated a production process, albeit a very organic one, which felt very different from the controlled laser forming experimentation. The leaves were formed with Elizabeth present and the leaves removed when they looked 'about right'. The resulting leaves had aesthetic qualities associated with hand making (Figure 9). They were further considered by Elizabeth in terms of creating a finish relative to the form and the effect that the environment would have on the weathering of the leaves over time.

As a result of the project, Elizabeth is more familiar with pathways to access CAD/CAM; she has since used abrasive water jet cutting, and the possibilities for using laser forming in her own work are likely to be explored in the future. The project's approach also embodied current ideas of involving the consumer within the process. The collaboration opened up new avenues of creating CNC programs for laser forming. The scanning translation method works well when the resulting form is expected to be asymmetrical, and there is scope for accepting an unpredicted or 'impressionistic' form such as a leaf. The use of hand drawings, photographs or found objects (methods which have been used in further collaborative projects) to create programs, gives a sense of ownership to the commissioner or user, as well as a less linear experimental process. This degree of free programming is not valued or prevalent in engineering laser forming research where the research methods are primarily systematic experimentation and Finite Element Analysis. As such, the technology has shifted in its application from engineering to design, crafts and the arts.

Lasers and technology embedded in education

Whilst excitement surrounds the use of lasers being used creatively in design and where materials can transcend disciplines and processes, there are potential issues in education concerning CAD/CAM, lasers and RP. When lasers and RP first emerged there was some concern about the devaluing of hand skills. As an advocator of the opportunities technology can bring, this seemed somewhat short sighted at the time, since surely technology would complement existing practice, and these technologies were just new tools to do new things. As Bunnell (2007, p38) describes it, 'its not about replacing craft skills with computing, it's about bringing all the skills and tradition that we have in making, combining them with new technologies, and seeing how they might interweave and enhance each other'. Nevertheless, in developing the skills of new designers, to what extent do we expose them to technology and hand making? Their education in emerging technology cannot be ignored. It has its place in the design process and in manufacture, yet the concept of what it is 'to make' is being reinterpreted at school level. Do students still value hand skills? It is the tacit knowledge and principles of materials science that enables us to be informed in making and manufacturing the products we can. If students do not gain hand skills do they still achieve a materials understanding? In their use of CAD/CAM and RP, which approach are we to encourage them to take? The creative or the manufacturing? Neither is any more valid. It would appear that a different avenue may be taken at the perceived boundary between product design and craft. Product design whilst having enquiry, is rooted in products that can be manufactured, whereas craft is more firmly centred on hand skills and the consumer's appreciation of them and as such crafts may be likely to focus on the creative merits of lasers. This is a critical area which will affect the approach of new designers, and the evolution of the disciplines as well as the creative applications of new technology. It is an ironic situation since it has been the designer's fascination with materials and making that led them to CAD/CAM and RP technologies in the first place.

Conclusion

The boundaries of design disciplines have been blurred, and cross disciplinary working does not hold the same weight or intrigue as it once did. This has enabled a greater exchange of ideas and collaborative working that builds on the skills of the stakeholders. Designers have become adept at using software, technologies and managing partnerships to explore and validate concepts as products and systems. There are many factors in the mix such as co-design and the involvement of users. The arena is diverse and networked, in a professional context it has moved away from an argument of hand versus machine, but how this transcends into education will be interesting. Some things need to remain constant, that the design process and the tangibility of outcomes are at the heart of design. Hopefully value will continue to reside in the properties of materials underpinned by the relationship with making as the ways of working with technology continue to expand.

Acknowledgements

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