The hunt for complexity

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Introduction

> *'Adobe Photoshop 5.0 comes with more than one hundred filters that allow the user to modify an image in numerous ways'*[1]
>
> Lev Manovich 'The Language of New Media'

While listening to the presentations on digital technologies, at the recent Challenging Craft conference[2] I noted that amongst the many advantages of using Computer Aided Design and Computer Aided Manufacturing identified by several practitioners that there was repeated talk of a continuing need to achieve a level of uniqueness within their work. It seems to me that this underlying anxiety over identity is symptomatic of a current dilemma in digital making: there are an overwhelming number of standardised CAD software toolsets and a growing number of accessible CNC fabrication devices. In this automated and rapidly changing world of design and manufacture, how can an individual set about creating their unique ID?

We have reached a point where it is possible to identify similarities in visual and formal aesthetics in the work of makers utilising digital technologies. With many makers accessing similar CAD toolsets and production processes, it may be useful to ask: "are these qualities unique to the maker or the software; Is it possible for us to determine a good piece of digital craft work? The key to these questions for me lies in the heart of the design process and in the methodology that makers adopt when approaching digital technologies.

Traditional makers form an in depth understanding of the materials and tools that they work with, through various combinations of hands on experience, and technical/scientific understanding. Through this dialogue with materials and processes they are able to develop an individual aesthetic, a personal visual vocabulary. As a digital maker, I believe that it is necessary to develop a corresponding approach to the use of CAD and CAM. For this reason, my research goes beyond the Graphical User Interface (GUI) and defined 3D CAD toolsets with the specific aim of developing objects with greater personal integrity and uniqueness.

Through examples of recent research, this paper illustrates three ways in which I have approached the tools of 3D CAD in order to achieve a level of uniqueness within my work. While I understand that the methods I have developed are the product of my individual experience and knowledge, they serve to demonstrate a creative approach that might be useful to makers who wish to embark on their own journey into Computer-Aided Designing and Making.

Entering the world of mathematics

> *Is it enough for a maker to understand CAD software from the geometric perspective of Euclidean and non-Euclidean surfaces, or do we need to examine the very structure, the programming language at the core to fully understand the creative potential behind the machine?*

When using CAD software with its highly visual interface it is possible to forget that Computer Aided Design is the world of mathematics. Beneath the icons and grids lies a complex system of rules and relationships that date back to the discoveries of Euclid, Pythagoras, and Descartes. In three dimensions, there are three classes of constant curvature geometries. All are based on the first four of Euclid's postulates, but each uses its own version of the parallel postulate.

> *'If a line segment intersects two straight lines forming two interior angles on the same side that sum to less than two right angles, then the two lines, if extended indefinitely, meet on that side on which are the angles less than the two right angles.'*[3]

The "flat" geometry of everyday intuition is called Euclidean geometry (or parabolic geometry), and the non-Euclidean geometries are called hyperbolic geometry (or Lobachevsky – Bolyai -Gauss geometry) and elliptic geometry (or Riemannian geometry).[4]

All forms that are designed within a 3D CAD environment relate to the geometric principles laid down by Euclid in his treaty on mathematics, *'The Elements'*[5]. They must follow a hierarchy of structure, starting with the defining of a point within 3D space, to creating lines that bridge between points, to surfaces that are formed from networks of lines. By following this model CAD software allows the user to create file types that can be read between different software packages, thus allowing for sharing of information and also for remote viewing and building of 3D files as utilised for Rapid Prototyping technologies. Industrial CAD goes a step further by only allowing surfaces or solids to exist if they are '*well formed'*; the software is written to use a series of very rigid mathematical principles, which are embedded in the architecture of the program as an ACIS module[6](a piece of C++ programming by Dassault Systems). This allows for true inter-operability with other programs using the same mathematics engine or kernel; instead of saving each and every spatial point and its relationship within the virtual 3D world, it uses a series of relationships to define objects that can be accessed at any time by the designer, fully parametric modelling with changes being applied globally rather than just at a local geometric level.

For all this hidden advanced mathematical processing , as users we experience 'smart' wizards or just a 'click of a button'. These added levels of speeded up automation brought to us by software developers effect the ways in which we can use the tools we are only just beginning to understand. As a designer maker I find these interventions are opposed to my understanding of a creative process that is a slow and meditative act based on emergent understanding of visual and tactile phenomenon.

> *Will we need to become hackers to achieve creative results?*

Automation as driver

CAD software is evolving at an astonishing rate, with new version releases now almost less than 1 year apart. However the digital maker is not having an impact on how software is developed, primarily because they constitute an extremely small percentage of the market share. It is the engineers, industrial designers and the games industry that has embraced these technologies and helps guide the development of the tools they use. That future is one that is primarily based on increasing efficiency through developments in GUI, the use of wizards to automate the design process and designing software architecture that allows for the translation of data without loss

between various packages and onto manufacturing methods. This quote from Lev Manovich for me raises a crucial point as to the end goal of software development.

> *'If the few artists working with computers in the 1960s and 1970s had to write their own programs in high-level computer languages, beginning with the Macintosh , most artists, designers and occasional users came to use menu based software applications- image editors, paint and layout programs, Web editors, and so on. This evolution of software trajectory governing the computer's development and use: automation.'*[7]

Consider the name of the popular architects' software AutoCAD and it starts to raise questions over the use of 'auto' as a prefix: will the software do your design work for you?

Virtual versus Manual Tools?

In the virtual environment, the digital maker is faced with the uneasy proposition of using CAD tools designed for the purposes of other disciplines and a excess of functions that speed up the process at which an operator can reach an outcome. Some of these tools, such as lathe and extrude operations, visually mimic processes we already know, but in operating them in virtual space we move away from knowledge that is acquired through their use in the real world.

In his book, *Abstracting craft*, Malcolm McCullough suggests that a move to more tools that are linked to real experience would allow makers to get more out of the process of using CAD:

> *'Representing particular abstract operations as tools is the best way yet developed for engaging the kinds of actions and intents that have traditionally motivated the craftsman. All this suggests that software tool makers would do well to place more value on tacit knowledge: the best tools will account for levels of mastery and psychology of participation, and conversely tool users should get more leverage from software's formal constructions.'*[8]

However, I feel that developing CAD tools with this approach would remove the need for exploration and discovery of what more abstractly defined tools are capable of achieving. Why should we be limited to what we already know? McCullough gets closer to this idea later in the same chapter:

> *'Our use of computers ought not to be so much for automating tasks as for abstracting craft.'*[9]

Practice-based research carried out by makers to date has revealed many positive aspects of using CAD as an integral part of designing and making. There is a diverse range of examples using a variety of methods and materials, Gordon Burnett has exploited his knowledge as a Metalsmith in order to create highly detailed and complex surface milling and colouring through the use of CNC devices. Rapid Prototyping has enabled Martin Woolner to develop a range of storage solutions for interior spaces. Katie Bunnell and Justin Marshall have utilised their understanding of ceramics processes to help translate CNC milling prototypes into industrially produced low relief tiles.

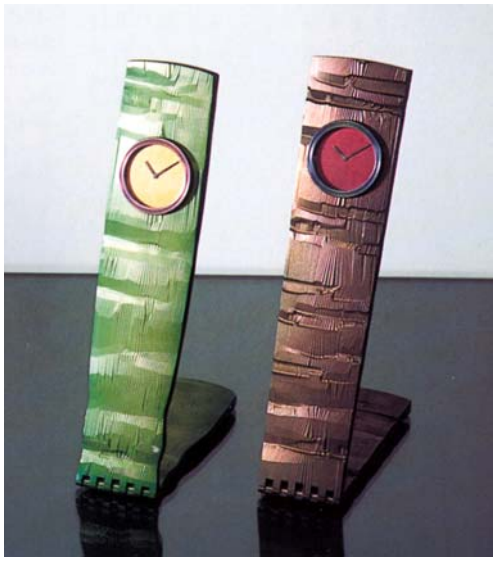

Image 1

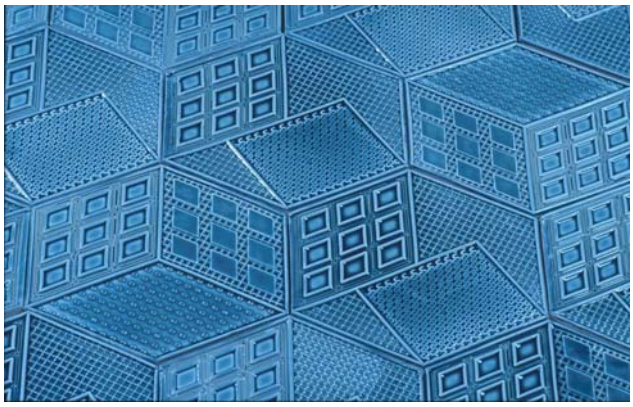

Image 2

One aspect that recurs in research outcomes is the ease with which a range of variations of a particular design, including rendering objects in different textures and patterns can be explored and recorded. This view is not exclusive to designer-makers, but is shared by a variety of users of the technology. Designs visualised in 3D virtual space can be usefully viewed by other designers, clients and engineers.

Speeding up, Saving time

CAD software seems to engender in the user a sense of frantic urgency, to explore all possible outcomes while with the same brush failing to establish a strong and rigorous method. It has been noted by Paola Antonelli[11], that an increase in speed and automation in computer processing can result in a sidelining of actual design process: 'trigger happy cut and paste' has been highlighted as one of the specific reasons for a loss of resolved and articulate CAD design work.

> *'The majority of books about computers are simply technical instruction manuals. The more time people spend leaning about and tinkering with computers, the less time they spend setting goals or applying existing skills. And at a most general level, the more we learn how to do, the less we know what to do.'*[10]

There is a contradiction here for makers: they feel the urgency to learn new tools, to try out a wide range of filters and actions immediately available at the click of a mouse because 'they can'. The visual results are often instantly gratifying, presenting novel qualities that have not previously been experienced. In the short term they may impress, but in the longer term they may turn out to be something that everybody can do. This intrigue with new tools is not unfamiliar to a maker seeking a new departure for their work, but it is their mastery over a sustained period of time, in making subtle nuances attributable to an individual hand and eye that makes their use significant.

With learning books trying to keep pace with software developments, titles such as, Teach Yourself 3D Studio MAX7 in 24 Hours only serve to highlighting the anxiety CAD users have towards keeping up, makers seem to have been caught up in the fast lane and have accelerated their learning by the same thinking processes that generated the software, I feel that there is a link between this method of learning and use of software which leads to the formulaic results that we are staring to experience.

Time for me is one of the most important factors when working with CAD; however it is not the acceleration of time through labour saving tools, it is the necessity to make time for exploration and reflection on ideas developed with these tools.

My practice: Triangles, Patterns and Variables

I was introduced to the process of CNC milling by Gordon Burnett while studying at Grays School of Art in 1997. The emphasis on experimentation with this tool has formed a core part of my current methodology. Through the use of these digital technologies I have never been interested in the potential to increase my productivity , the emphases as always been about extending the possibilities for designing and making unique forms and objects.

Image 3

Throughout my initial experiments with CADCAM I concentrated on developing a new body of knowledge that would enable me to create objects from drawings made outside of the computer environment. I spent time exploring surfaces that challenge what is know in computational mathematics as first order continuity law. It states that angular lines cannot co-exist with smooth lines within the same surface.
I took what Tanya Harrod refers to as a Guerrilla tactic and started deliberately designing surfaces that forced the software towards resolving areas with both smooth and sharp lines in them. The results were at times disastrous with large gouges being removed from the steel bed of the CNC milling machine, but through hours of checking lines of CNC code I eventually managed to achieve machinable surfaces that were teetering on the edge of this peculiar mathematical law.

This approach to digital technologies seems to be specific to makers; there inquisitive nature has led many to subvert the intended use of Computer Numeric Controlled devices. Gordon Burnett has developed his own unique visual aesthetic through altering large segments of Numeric Code.

As a questioning digital designer, I like to challenge not only the tools within the software but also the principles that it is built on. I don’t believe you should learn software, certainly not in the way that is suggested through manuals and help files; the

process for me has always been about discovery; what happens when I combine this tool with that one? Is this particular feature unique to this piece of software? Essentially my methodology stems from this exploratory approach, I dissect software looking for something that will allow me to develop a shape, form or pattern that is unique. I transfer files between numerous programs in order to develop specific qualities.

I am interested by the idea of complexity and how things that exhibit complex tendencies seem to be able to be created from the layering of simple actions or components. These layers can be seen as variables that have many different possible inputs and therefore can generate an almost infinite number of outputs. Using this definition I have formed a method which allows me to develop and create unique and complex objects which disguise their histories and require close scrutiny to appreciate the various levels that they are composed from.

I too enjoy the speed of digital tools and the potential for rapid development of ideas, but I recognise the flaws in this way of working and although the results can produce some complex forms, for me they lack any real significance or meaning. I strongly believe that after an initial clickfest it is important to reflect and establish methods for using these new tools.

A hands on approach to the production of the ideas is very important for me, I see the creative potential within the means of production as much as it is in the software tools. In this respect I have been particularly fortunate to be able to be both the designer and the machine operator. By gaining an in depth understanding of the machine and how it works I have been able to develop my ideas further than if I only had the CAD to work with.

Escaping Triangles

During my study at the Royal College of Art in the GSM+J department I had the opportunity to experiment with the technology of Rapid Prototyping. The Saunders wax deposition machine was not rapid in any respect of the word with some of the models that I printed taking in excess of 250 hours to build. The defining aesthetic aspect to these models was the triangulated effect which was deliberately applied to accentuate ideas I had about the process of map making.

Image 4

This triangulation is also achieved by saving objects as Stereolithography or STL files, although this triangulation can be effectively removed by decreasing the size of the triangles to an almost microscopic level. The most important aspects that I learned while working with these technologies came in the transformation of these exact representations through more traditional processes, in this case investment casting in silver. The combination of a precise model and the unpredictable nature of the casting process goes some way to creating a more human quality to the work.

Recently more designer makers have been using the production method of RP and exploiting the triangles that are a result of the STL file format used. There are a large number of cases where these triangles are talked up by the maker as a positive thing, a happy accident; Gilbert Riedelbauch creates beautiful mathematical forms whose elegance is imbedded in the smooth flowing lines of minimal surfaces through the use of RP, yet he refers to the use of the triangles as a deliberate action[11]. I believe that this is mainly afterthought and a counter to critics concerns over issues of control of the process. In the future such work that fails to have a true rationale for using these triangular patterns will seem tired, as the aesthetic is a direct result of the process and can be easily simulated by other makers, resulting in a plethora of objects with few distinguishing features.

This enforced triangulation prompted an investigation of how to remove the triangle, which was perhaps a futile exercise. I started by researching the principles behind the STL format and discovered that although all surfaces are ultimately triangulated only those with curvature reveal this idiosyncrasy.
This led to the exploration of different types of tiling with the knowledge that there had already been a significant amount of work conducted in this area by mathematicians and by craftsmen as visible in the geometric patterns in Islamic design[12].

Instead of designing an object in CAD from a series of particular tools and then saving the result as a STL file. I decided to initially build a series of flat surfaces which were constructed using a range of Semi-Regular Plane Tessellations and Infinite Tessellations[13]. My initial test was constructed in 3D studio MAX using a combination of hexagons and triangles. I then altered this surfaces point by point until I had described a 3Dform, in this case a simple bowl. The process was extremely time consuming however the result achieved a level of complexity that would have been difficult to model using just a series of existing operations. The object had incredibly sharp geometric features, that although had escaped the use of software defined meshes, still had an identifiable mathematical aesthetic, or what Tanya Harrod refers to as a ‘CAD aura’[14].

Through the process of CNC milling I was able to output these forms in aluminium and Perspex and this enabled me to evaluate the surfaces under a variety of lighting conditions and more importantly with my hands.

This technique has enabled me to develop a range of work that builds from the ground up and allows me to choose a method that rather than being arbitrarily applied can be designed and controlled. As mentioned before this process is extraordinarily time consuming but it has value embedded as it can achieve a level of uniqueness that comes from the maker rather than the software.

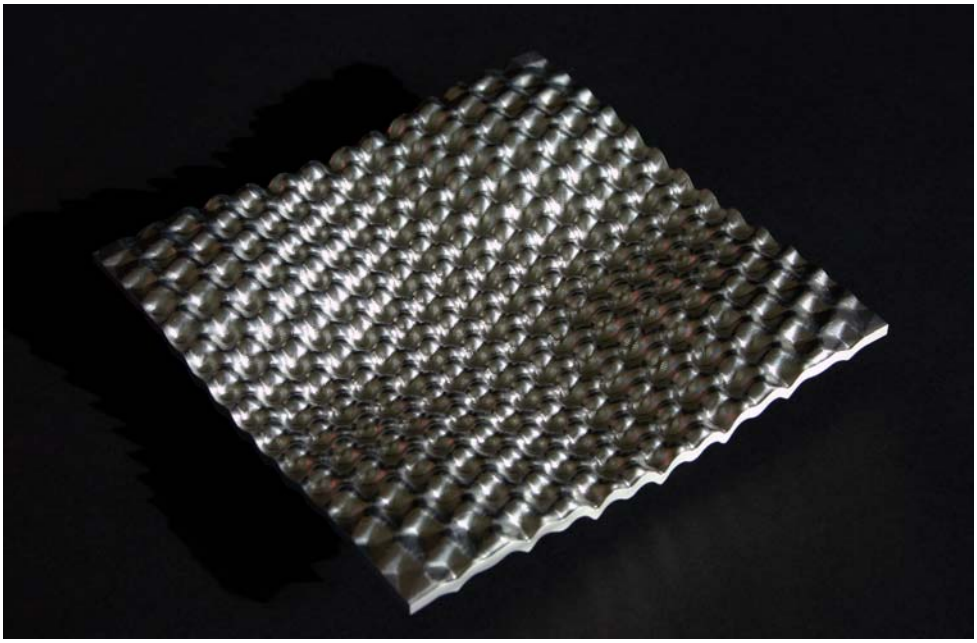

Image 5

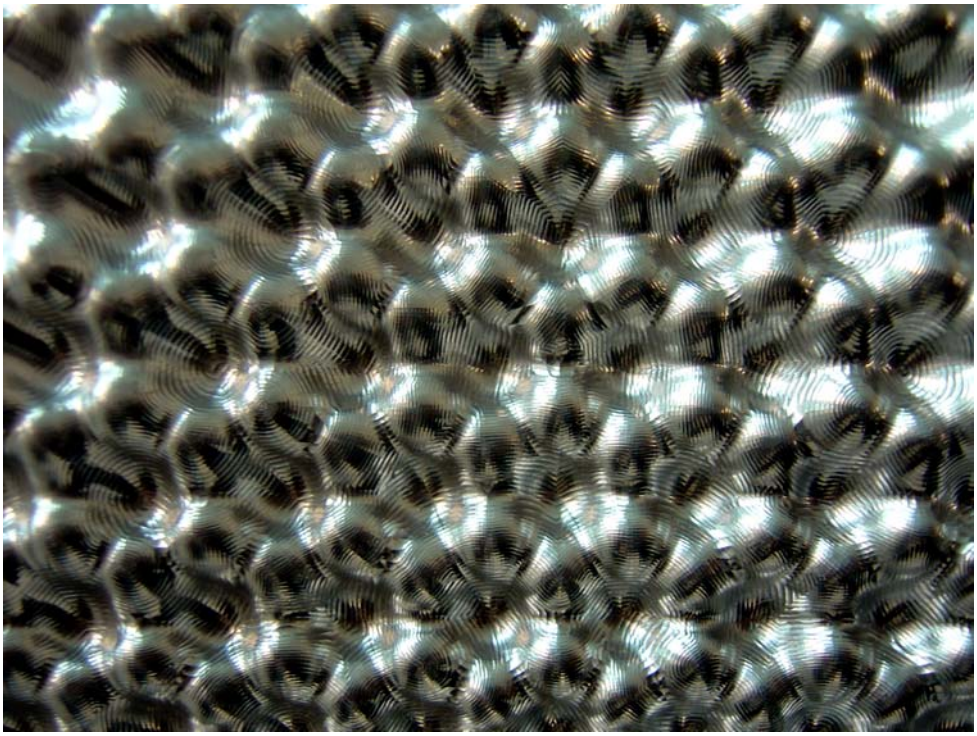

Image 6

Setting up Parameters and Variables

My research has focused on the process of CNC milling and what creative potential might be able to be exploited within the CAM software that processes the files for cutting by machine. Variables have always interested me particularly within a design process, the complexity of the process allows for almost infinite outcomes with only a few changeable components. Within the CAM software I use there are over 14 variables, which if you do the maths gives over 11,112,006,825,558,016 possible combinations and this is before you even consider what choices are made within the variables. With this ammo I have been exploring some of the various combinations, using my previous experience of the field to pinpoint areas that could yield interesting results.

The software that I use to machine my 3D forms is called Mayka[15], a tool made for makers? It has a variety of generic cutting techniques that allow users to achieve a high level of finish with little thought. Although this software is mainly geared towards automation of processes, there is still a great deal of flexibility to be discovered by the probing mind.

To the first time user default choices may seem to be the most appropriate, this highlights the position of many digital artists, in that they see the idea as complete when it leaves the CAD software and the fabrication is a means to an end. What I propose is that this stage can present the start of a process that reveals new creative vistas that are closer to a traditional making/designing process than is afforded when not considered.

I have found in my own work that the world of CAD is brought to life through the translation of my virtual objects into real materials. Objects can be more accurately critiqued than concepts within the mind; they react to their environment and afford scrutiny by others. My methodology allows there to be a dialogue between my ideas and the qualities achieved through the making process.

By reducing the process of milling into its individual components I have been able to come to a better understanding of what each variable is capable of achieving. The main factor that has helped in revealing these properties is the development of what I call *base* forms; these are essentially simple surfaces that are composed of a slight curvature. These have formed constants within my testing and allowed me to focus on the specifics of CAM software rather than CAD modelling.

My first realisation came after exploring a field called *clearance* value, this allows the user to specify a small amount of material to be left uncut so that a more accurate cut can be applied later in the process. I found that by altering this value to one that is greater than the total Z value of the object, the software would compute a new surface offset to the given value. This also created a softening effect to steep sided angular geometry.

Building on the research mentioned in the last section, I now applied this new knowledge to some of my tessellated surfaces with sharp geometries. Through experimenting with various tool settings and clearance values I was able to use the CAM software as a modelling tool to create objects with a level of complexity that would be impossible to repeat with just one piece of software.

My second realisation was a response to the following statement:

> *One of the criticisms of objects produced using digital technologies is that through the uniform method of production they can often seem very sterile.*

My research has attempted to find ways in which I can counteract this affect. The method involves the integration of designed patterns applied to three dimensional forms through the process of CNC milling

Patterns have been an intrinsic part of my work since I adopted the use of digital technologies, I have always attempted to control the technology so as to remove the uniform aesthetic and achieve results that are closer to hand work such as engraving, although paradoxically still unachievable by any hand.

A CNC milling machine can recreate extremely complex patterns, however most users are limited by the software with its, quickest is best approach when determining cutting paths. These simple methods create arbitrary X and Y cut files that are not sympathetic to the 3D form.

Up until this point I had been using these methods to cut 3D forms, the results displayed some interesting qualities where the cutting tool had left its mark upon the surface; however these marks are easily repeatable by most people using the software. From this understanding I set about trying to establish a way that I could control this parameter within the software, so I would be able to create unique patterns on the surface that were of my design, not the software's.

Several tests using a variety of settings and tools proved unsuccessful and it was not until after a period of reflection that I arrived at the solution. The same piece of software is capable of what is called 2.5D cutting where the operator only needs to specify a zone or shape that they want to process. For several months I had been using this tool to cut out the completed 3D forms from their surrounding material, oblivious to its real creative potential. With this new knowledge I recognised that I could effectively control the movement of the tool by using a designed pattern from a program such as Adobe Illustrator. This has opened up a whole new area of exploration and has allowed me to cut both the form and pattern simultaneously, therefore adding another level of complexity that I can utilise in the creation of unique objects.

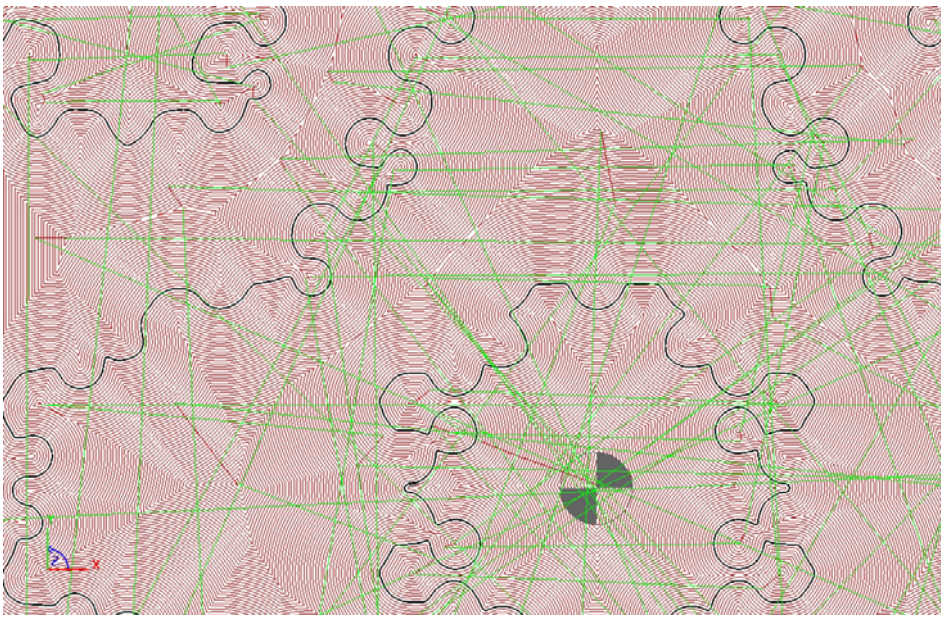

Image 7

I have found through this research with digital technologies the importance of creating physical objects; this has enabled me to be far more analytical than is possible while viewing virtual objects on a screen. The objects that I consider as finished outcomes have been the result of numerous tests and have been conceived through the accumulation of knowledge that occurs through a daily practice of using the specified CNC devices.

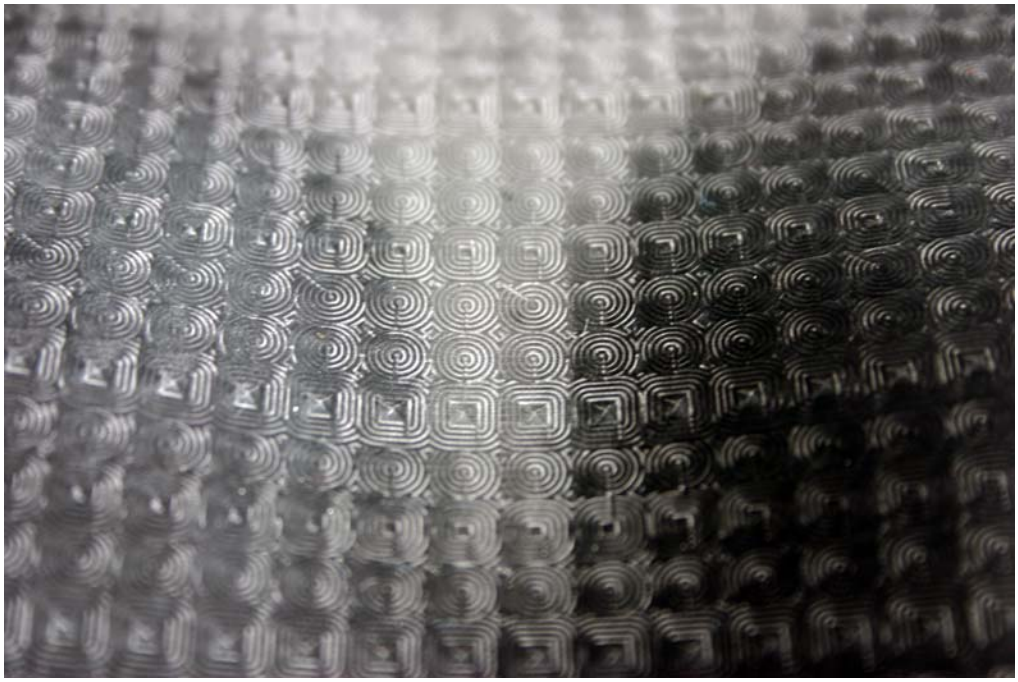

Image 8

The techniques that I have developed for advanced form creation and mark making have been distilled over a long period of time and are a result of making a space between my thought process and the software being used. By taking this approach I have been able to think about these tools in a more abstract manner that has brought a more relevant understanding of how they can be applied creatively within my practice.

Evaluation

With digital technologies becoming cheaper and more accessible, the number of practioners engaging with CAD and CNC devices is set to rise. Perhaps now would be a good opportunity to pause and take stock of what has been achieved by those already using these tools. It will be essential in this period of rapid growth for makers to adopt strategies that enable creative and unique outputs. At this point it would be worth asking:

> *How can we develop in depth CAD/CAM Skill?*
> *How will we be able to tell a good piece of digital craft?*

I feel that the answers to these questions are interwoven and the first can not be separated from the second.

Developing CADCAM skill is like the practice of any other skill, in that it requires time and dedication to explore the full range of possibilities. The greatest lesson I learnt from my Tutor Gordon Burnett, came from the lack of information he gave me about how he used CAD, I can now see the value in this approach. By not following established models new challenges are presented, you apply your level of understanding and knowledge gained from experience outwith of the computer environment, and in doing so you allow for a more exploratory approach to learning these new tools. Rather than an understanding I feel it is more important to have a misunderstanding of these tools, as this presents ways to utilise them which were not thought by the developers but are unique to the individual.

Tanya Harrod referred to my object *'Memoryscapes'* in her talk at Pixel Raiders 2001.

> *"Otherwise unobtainable" – that seems to be an important ingredient of the ideal new media applied art work.*[16]

I feel that by extending this statement we can reach a new understanding of how makers might be able to tell a good piece of digital craft. Although it is possible to create unique forms using digital technologies as mentioned this can no longer constitute the idea of the unobtainable. A more useful meaning may be formed from the idea of layering; it is an idea that is not specific to digital practice and can be seen to borrow from a traditional model of craft and design.

> *By assembling simple layers the maker can achieve a level of complexity that is difficult to trace or repeat.*

By layers I mean anything that is used in the creative process to achieve a visual output.
We get a sense of wonderment from objects that cannot be understood on a first viewing, successive viewings seem to reveal more and more as if previously hidden to the viewer. As noted in my research the objects created using this complex series of layers will need to be disassembled by the maker so they can understand how one layer complements or detracts from the previous. By adopting this method I believe that the digital maker can create objects that will be meaningful and valued for their process as much as their outcome.

I am approaching these questions from the perspective of a maker rather than the audience.

Image 9

Customization of Tools

As I have discussed, the speed at which software has developed has sidelined the requirements of most of the design community that is not concerned with high volumes of production. It is possible to see the automation used for low level repetitive commands creeping into the creation end of the software spectrum, Architect Chris Wise hints at this possibility:

> *'Maybe soon the technology will grow to define both the system and the treatment of the resulting art – learning from itself, and even from outside the algorithm completely. Imagine if such a technology could dip into humanity when it needed inspiration, not vice versa'*[17]
>
> *If this happens who is the designer?*

By returning to the fundamentals of software, programming language, whole areas of new research for designer makers could be engaged by allowing them to alter the framework in which their actions take affect. Makers have always sought to design the tools they use to make with, from metalsmiths creating their own customised stakes to innovators such as David Pye fabricating his own routing machines to create unique bowl forms[18]; it seems only natural that the digitally engaged maker would want to do the same within CAD software.

If we take a glance at other disciplines that use digital media, such as graphic design or film effects we can find a model where the software is essential only a simple framework, but one which allows there to be a development of creativity through their own specific scripting language. Programs such as Macromedia's Flash, uses a formal language called action script to allow designers to describe particular actions for any part of the software. This allows designers to customise the software to create unique web experiences that go beyond what is humanly possible within the original framework.

Within the pages of *Computer Arts* you constantly read articles from the film and games industry about having to developing new algorithms to describe particular phenomena, these developments require large teams of software writers and many months to develop. What this shows is that most software houses view their CAD packages as a framework which provides the bare bones, this then has to be stretched through customizing the product with various plugins.

So it seems strange that makers should be satisfied with the tools that they have in front of them, tools written not by 3D object makers but by programmers. There is obviously some boundaries to cross from visually located tools to mainly text based tools. There is research being conducted in this field; projects such as Tacitus by Anne Marie Shillito are taking a bottom up approach to describing force feedback technologies that are of use to makers; the inclusion of a programmer in this team allows custom code to be written.[19]

The majority of 3D CAD software has the potential for expansion by the user, programs such as 3D Max and Alias Wavefront's Maya are built with an open architecture to allow third parties to develop specific plugins. However the process of making such plugins is not easy and requires an understanding of the programming language C++, however there exists several well established online communities of users willing to lend a hand and share their knowledge of the field.[20]

A good primer to this area is through the *design by numbers* program[21] written by John Maeda for designers and artists. He manages to show the shift in skill within the creative field from that of a motor coordination which takes many years to develop to one of sequence storing, the knowledge that this set of button clicks combined with this one will produce an interesting result. His program is a framework which allows users to explore simple code to produce creative 2D images. The book builds the users knowledge sequentially from the very basics of defining the page colour to the more complicated procedure of mouse tracking. The book offers a model that could be useful for makers wanting to establish a methodology when integrating CAD into their process.

I am not saying that digital designer makers should all go out and learn C++, but I think there will be value in collaborative projects between programmers and makers to develop new and hack existing code.

I feel that this will be the area which could hold exciting creative development for the future. By embracing these technologies and taking ownership of them makers will be able to develop a greater diversity of methods that allow them to achieve a unique complexity within their objects.

Endnotes

[1] Manovich, L., *The Language of New Media*, MIT press, London 2001, p. 123.
[2] Challenging Craft, International Conference, Grays School of Art, Robert Gordon University, Aberdeen, Sept 2004.
[3] Euclid, 300 BC
[4] http://mathworld.wolfram.com/Non-EuclideanGeometry.html
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[12] AD magazine, Islam +Architecture, VOL 74 n6., Wiley Academic 2004.
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Images

1. Gordon Burnett, Clocks, CAD/CAM, milled and anodised aluminium, 1996.

2. Katie Bunnell and Justin Marshall, Low relief ceramic tiles, CAD/CAM milled, Ram pressed stoneware ceramic, 2001.

3. Drummond Masterton, Study for *24*, CAD/CAM, milled aluminium, 1998.

4. Drummond Masterton, detail of *Memoryscapes*, RP model cast in Silver and patinated, 2000.

5. Drummond Masterton, *Hexabubble Bowl*, CADCAM, milled aluminium, 2004.

6. Drummond Masterton, detail of *Hexabubble Bowl*, CADCAM, milled aluminium, 2004.

7. Drummond Masterton, screen image of milling cut file from Picasoft's Mayka CAM software, 2004.

8. Drummond Masterton, detail of *GridTerr4*, CADCAM, milled Perspex, 2004.

9. Drummond Masterton, Whiskey Cup (1 in a series), CADCAM, milled aluminium, 2004.

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