DECONSTRUCTING THE DIGITAL

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Abstract

The project discussed in this paper has been conducted as part of the Autonomatic research cluster based at University College Falmouth. The cluster is focused on research projects that explore the use of digital production technologies within the context of designer maker and craft practice.

My project is concerned with developing more direct control of processes that are typically automated by CAD software and CAM tools. I believe the use of these standardised tools limit the ability of the maker to create unique visual vocabularies.

It is possible to view the aesthetic qualities emerging in the new genre of 'digital craft' - such as the use of triangulation and the quality of line produced by generic pre-set machine parameters - as a temporary phase in the digital craft timeline. As more makers adopt digital technologies, we may discover that these visual aesthetic qualities are more attributable to the technology than the maker rather than being understood as unique. The author believes it is therefore important for makers wishing to further their practice in this field to seek ways in which they can gain greater control over the processes and tools they are using.

This paper presents research that explores ways in which programmed mathematical elements in 3D CAD can be deconstructed and manipulated throughout the design and production phases. Employing an iterative designing and making process I have used this 'hand' manipulated CAD data to drive CNC machine tools in highly specified ways. This has lead to an in depth understanding of the inter-relationship between CAD and CAM as intrinsic to the development of unique aesthetic qualities. The development of a dialogue between CAD code and CNC tooling has resulted in a greater level of control enabling the realisation of complex and completely controlled patterning on 3D forms that go beyond the restrictions of standard toolsets.

This research has resulted in a range of 3D aluminium sample pieces that I have used to create a visual knowledge bank which documents the relationship between software input, machine parameters and their effects on the visual form. This knowledge has been applied to my working digital design practice enabling me to create aluminium platters and beakers that counter the affects of automation.

This paper aims to offer other makers methods which allow the potential for 'hacking' into code in order to expand the possibilities for control and creative engagement with digital tools and thereby offering more unique opportunities for developing visual vocabularies than using standard toolsets alone.

Summary

A practice based research project that aims to establish new methods for makers to deconstruct standardised toolsets in CAD and CAM software in order to achieve a unique level of visual aesthetic.

Introduction: meditative working and digital tools

Ubiquity: The commonest feature about technology, with its distributed knowledge, is that everything begins to look the same. (Dormer 1997)

A Decade ago Peter Dormer wrote this observation on craft's relationship with digital tools. Reading the same essay in 2007, it is still possible to identify with his arguments on the power of distributed knowledge embedded in Computer Aided Design and Computer Aided Manufacture systems and the direct effect they can have on the finished surface aesthetic of digitally produced objects.
Although technology is in a constant state of flux and craft makers are continually engaging with it in new and diverse ways, there has been little written on how makers might develop methods that seek to counter these dominant determiners of digital aesthetic.

I believe that Dormer was correct in his analysis of the dangers of technology for the craftsperson. The use of standard toolsets embedded within CAD and CAM software is eroding the autonomy of the individual maker and is replacing it with uniformity.
An important point to note is that the majority of software that digital makers utilise in their creative process has not been designed specifically for them; the market is so small that it holds no sway in the continual software development cycle. The impetus for developments in the majority of CAD software is to increase the speed and reduce the risk at which a single operator or team can perform a series of actions. Developers are continually seeking ways in which to make their software easier to use; many common tools and complex procedures are being integrated into wizard[1] based windows that guide the user through the task with the minimum of input, effectively decreasing the time necessary for tedious tasks, and more importantly for industry removing high proportions of risk.[2] This increase in speed and reduction in risk may fit well within the context of the engineering or Industrial design sectors where reducing time to market is a key factor in the race to stay ahead of the competition, but for craft practitioners these enhancements present several problems. The developments in wizard based tools obviate the need for personal knowledge and limit the possibility for more creative working; also, tools may be removed by the developers as more sophisticated ones are developed and their demand is no longer warranted. This possibility may prevent practitioners from developing an in-depth knowledge of a tool over an extended period of time and through practice as new software releases reach an almost annual cycle.

What is unique in the way that craftspeople use CAD and CAM systems, if anything? Are digital makers in danger of being seduced by the latest novelty software release? If wizard driven systems become prevalent will it be possible to determine the difference between two craft practitioners working with the same software?

These questions are fundamental to my research and as a maker engaged with digital technologies I feel that digital craft is heading in the same direction as architecture in the 90's, where an exploration of NURBS surfacing tools resulted in a uniform aesthetic sometimes referred to as 'blobtecture', the lure of complex forms unable to be made by hand and often by machine achieved with a couple of clicks of the mouse; as McCullough (2006) states, *'any fool could do it'.*

Through two years of practice based research I have discovered that there are a finite number of combinations that can result from the various parameters that a user can specify within CAD and CAM software, not in the forms that can be created with specific tools but rather in the treatment of surface finish. The surface is one of the first things we respond to when we come into contact with an object (Pye 1968); the way that light is transmitted from the object helps us to identify what the object will feel like and it is the sight sense that helps connect these objects to our previous

1 A wizard is an interactive computer program which acts as an interface to lead a user through a complex task, using step-by-step dialogs. http://en.wikipedia.org/wiki/Wizard_%28software%29 accesssed (25/01/07)

2 http://www.materialise.com/magics-rp/main_ENG.html
Magics software fixing wizard automates entire STL fixing process based on preset parameters

experiences. If CAD and CAM processes are limited in the types of surface that they can create, which leads to a similarity in surface, then how will it be possible for makers to create a unique visual aesthetic that allows their work to be distinguished from other makers, what will enable the viewer to define the uniqueness of a piece of digital craft?

Time is an important factor in my making process; it allows me to consider my actions and make informed decisions as to the direction in which I take a particular piece of work. The medium of 3D CAD modelling software does not naturally allow this space for thinking and although it is gratifying to create and see complex forms in real-time, the ease with which variations can be created can generate a frenzy of clicking without the necessary clarity of thought. The lack of space affects our ability to make value based judgements as to which idea is stronger. The consistent quality of the image on the screen also makes it harder to make decisions; a design taking 5 minutes has the same look as one taking much longer. Traditional methods of making such as hammering metal or even card modelling take considerably longer, and are difficult to achieve pleasing results with, however the time factor inherent in these activities allows important space to think and construct a logical train of thought.

As more makers adopt digital technologies as a means for producing physical artefacts and as CAD packages start to streamline their tools the noticeable similarity in the visual aesthetics of objects created with these methods will increase, makers will need to develop methods of working that transcend the novelty (Strzelec 2004) of these tools in order to create unique outputs. As this convergence point is approached it will be worth questioning whether the real craft is in the coding of these tools, modifiers and filters.

The method in which makers are introduced to digital technologies can be seen as an important component in the way they understand and utilise them within their practice. There are a multitude of ways to gain the necessary skills to engage with these technologies, from reading manuals to going on training courses such as TACTICS[3], or entering competitions like Repeat and Variation[4]. The use of online tutorials is also popular, particularly among students. There are thousands of user written demonstrations of particular tools, and while this network of information can be seen as a useful resource it can also negate the need for personal learning. The user becomes someone trained in 'following my lead' rather than taking a exploratory approach that may develop unique ways of using tools and ultimately allow for a more personal understanding of the software.

During my seventeen years of working with software tools I have found that almost every tool within CAD and CAM has the potential for creative manipulation. The opportunities can be mapped out into four clear production phases, input devices, CAD processes, CAM processes and output devices. Researcher Ann Marie Shillito has been conducting a project that focuses on the input phase, 'Tacitus'[5] considers how to code the actions of makers for the development of a more realistic force feedback device, Tavs Jorgensen is another researcher who is developing techniques to capture the intricacies of hand work through motion capture devices.[6]

Metalworkers have developed work that focuses on the output phase; Gordon Burnett has developed a wide range of mark making techniques through CNC milling to produce Aluminium time pieces, while Gilbert Riedelbauch has described some of the opportunities that makers can exploit from controlling the output of RP systems (Riedelbauch 2004). Riedelbauch's deconstruction of different RP software options offers makers an overview of some of the parameters that can be tweaked to achieve a variation in surface quality, however the number of parameters are relatively small, if another maker was to follow these operations would this result in

3 Tactics was a European Social funded project run by Gray's School of Art exploring the use of CADCAM in designer maker practice, http://www.tactics.org.uk/ (accessed 26/01/07)

4 Repeat and Variation was a jointly run research project between Hidden Art Cornwall and Autonomatic/UCF in 2006, for more information visit http://www.hiddenartcornwall.co.uk/brokerage/repeat-and-variation (accessed 26/01/07)

5 Tacitus is a research project run at Edinburgh College of Art, http://www.eca.ac.uk/tacitus/ (accessed 28/01/07)

6 Tavs Jorgensen is employed at UCF as a Research fellow in 3D Digital Production, personal conversations.

a similarity of surface qualities? Future opportunities for this type of creative engagement may also be reduced as the industry strives to develop RP systems and software that are essentially closed box office solutions[7], allowing designers with little knowledge of these systems to build successful models in as short an amount of time as possible. The options that Riedelbauch mentions and utilises within his work in relation to part orientation and build thickness are being removed from many software dialogues and the wizard driven formula is taking over the decision making.

By employing a 'hands on' exploratory approach to digital software and hardware I aim to develop research that is informed through personal knowledge. CNC milling will be explored from a maker's perspective to enable the translation of 3D CAD tests into physical materials creating an iterative cycle to facilitate learning in the virtual world through the context of real objects. This feedback loop is crucial to my research as it allows an investigation of 'virtual' parameter changes within CAD and CAM to be scrutinised by all my senses so their qualities can be assessed in relation with other digital manufactured artefacts. The complexity of the toolsets within CAD and CAM makes it difficult to understand the exact effects each is contributing to the end object, for this reason I will separate the components within these processes in order to establish their relationship to physical attributes.

My research focuses on the development of new techniques which aim to allow makers more opportunities for regaining control of digital processes, in particular offering potential for unique mark making that escapes the homogeneous aesthetic created by using standardised toolsets in both CAD and CAM phases of production. I have focused on the CAD and CAM phases of digital production as I believe that they are the predominant aesthetic determiners in the creation of any digital craft object, at some stage all design ideas must be processed through these tools in order to create a physical artefact. Through the CAD phase of production I aim to develop and test new methods of creating 3D surfaces in order to identify techniques for overcoming the inherent forced aesthetic of triangulation. In the CAM phase I aim to identify ways of countering the effects of 'wizard' guided interfaces in order to achieve methods of interaction and control that are more open ended and sympathetic to the desires of the maker.

CAD Phase: Tessellated Mesh

A major question for any maker engaged with 3D modelling should be, how are the surfaces of their design constructed? This is significant as it will determine the final surface quality of their object. When 3D data is transferred into CAM software the most common export file type used is the Standard Tessellation Language format (STL) which utilises a method of regular triangulation in order to capture the designed 3D form. STL files are always an abstraction of the original design so any maker not considering how this process will affect their work is allowing the programmers particular considerations on the best way to decompose a 3D form to dictate their creative output.

In order to construct 3D surfaces 3D modelling software uses pieces of geometry called 'mesh'. There are many tools and techniques that can be applied in the formation of surfaces but the end result, no matter what form, has to be constructed from a network of interconnected polygons. These polygons form the mesh. The CAD program I use to model with, 3D Max uses regular polygons[8] of 3 and 4 sides in order to construct surfaces (Insert Figure1 approximately here). At a topologically lower level, polygons are constructed from a network of vertices and edges. Polygons with more than three outer edges also require a number of hidden internal edges (Insert Figure2 approximately here). All polygons are essentially formed from a correlative number of triangles, for example a square is made from two triangles while a hexagon requires four.

Although the size of the individual polygons is relatively unimportant for the majority of users such as animators who are more concerned with the quality of images that can be rendered, it is

7 http://www.dimensionprinting.com/dimensionprinting/printers/printing-bst.shtml (accessed 26/01/07) Stratsys's latest office solution, the dimension is advertised in it's similarity to a water vendor, small and easy to use.

8 A regular polygon is a polygon which does not intersect itself anywhere, which is equiangular (all angles are equal) and equilateral (all sides have the same length). http://en.wikipedia.org/wiki/Regular_polygon (accessed 28/01/07)

however a significant consideration for makers wishing to transfer their designs to CAM software in order to create 3D artefacts. If the size of the polygons is not determined by the user in the act of exporting the model the result may be a coarse representation of the original model (Insert Figure3 approximately here). The resulting aesthetics from this triangulation within some digital craft objects may in fact be through a lack of knowledge of the software rather than any intentional action.

As part of my current research I aim to establish if it is possible to extend the types of surface aesthetic achievable through the use of CNC milling by creating tessellated meshes from other combinations of regular polygons and star[9] polygons (Insert Figure4 approximately here). In previous research I focused on the recurring use of triangular polygons within digital craft objects. This research established that it is possible to effectively remove the triangles by reducing their size to a degree that is smaller than the accuracy of the output method, however I enjoy the way that geometric facets can be utilised within a design for example to change the way light is reflected from the objects surface. This current research is intended to identify a range of ways in which I can control this effect without being limited solely to the use of triangles. It was this that formed my criteria for evaluation of my results.

My initial starting point for developing a series of CNC milled surfaces began by investigating different methods for constructing 2 dimensional planes from tessellating polygons. I found research from the field of mathematics (McNeill 2002) which described with illustrations 11 regular and semi-regular[10] tessellations and 22 Star tessellations (Insert Figure5 approximately here). I used these illustrations as reference material while building the sometimes complex structures in Autodesk's 3D Studio Max. By using a semi-regular tessellation method which combines different regular polygons I was able to test out whether my theory was possible. I started by building a two dimensional surface from a series of squares, triangles and hexagons which quickly revealed some problems arising from my construction technique of copying and pasting groups of polygons. The hidden edges in each of the four and six sided polygons started to become visible when I created a 3D form from my 2D mesh; this made the 3D surface appear to be formed only from triangles (Insert Figure6 approximately here). The orientation of the hidden edges became a determining part of the end aesthetic, by altering the orientation it was possible to either make noticeable depressions or keep continuity to the surface; as my aim was to hide these features I opted for the latter. Inner edges cannot be removed as they are a coded part of how 3D Max constructs more complex geometry, so in order to counter this dominance I started to design flat areas on my objects which would allow my work with the new tessellation to be visually determined (Insert Figure7 approximately here). By investigating this technique further through a series of CNC milled aluminium platters I have discovered a new level of control that enables me to determine the end aesthetic of the object; the development of 33 new mesh types has expanded my palette considerably. (Insert Figure8 approximately here).

Although I have discovered that it is not possible to remove the existence of the triangle from 3D CAD programs, it is possible to mask it within other types of unique mesh, creating more possibilities for the maker to alter the surface quality of the finished artefact.

A downside to my new method is the amount of time necessary to create these meshes; some of the complex star-tessellation sets can take a week to accurately create. This problem led me to seek advice from others outside my field on how to overcome these problems. A discussion with Dr Neil Sewell[11] a researcher from XAT with more knowledge of mathematics and programming than me, revealed a possible way forward by tackling the problem in reverse, so rather than trying to design out the triangles consider ways of how to remove them after the 3D form has been created.

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9 A star polygon is a self-intersecting, equilateral equiangular polygon, so named for its starlike appearance, created by connecting one vertex of a simple, regular, *n*-sided polygon to another, non-adjacent vertex and continuing the process until the original vertex is reached again. http://en.wikipedia.org/wiki/Star_polygon (accessed 28/01/07)

10 A semi – regular tessellation is composed of more than one type of regular polygon such that the polygon arrangement at every vertex is the same. http://library.thinkquest.org/16661/glossary.html (accessed 28/01/07)

11 Neil completed a PhD investigating the feasibility of multi-axis rapid prototyping using virtual machining centres at Exeter University, Neil works for eXeter Advanced Technologies research group

This would be possible manually using some post editing software such as Materialise's Magics; however the process would be time consuming for large objects with a greater number of polygons. The development of a new type of exporter that can remove triangles by following certain user definable parameters would allow any of the uniform tessellations to be created. This technique would allow anyone in the creative fields wishing to 'escape the triangle' a number of options which they could apply at the end of their current process.

CAD Phase: Coding, Programming and Scripting

I have been attracted by the idea of writing code as a lot of my work involves editing the programs generated by CAM software in order for them to be correctly interpreted by CNC milling machines; it still holds some degree of mystique. I have tried unsuccessfully to develop skills in C++ programming, the joy of physically creating something doesn't come quickly with these tools and this may be part of the reason I have given up in the past. However at the back of my mind I always have this niggling urge to try to understand the world of the coders and be able to truly become computationally flexible (Smith 2006) rather than dependant.

The fact that it is possible to write code is not necessarily any reason to dedicate time to it; for a maker essentially concerned with the creation of objects, what are the benefits and pitfalls of embracing this area? To the visually orientated craft practitioner these text heavy shorthand languages are difficult to relate to as they do not correlate easily to real world actions or objects, therefore it is not possible to simply sit down and write some code, a view shared by even hardened computer programmers (Smith 2006).

A well established reason to engage in programming is noted in an analysis of the work of Graphic Designer John Maeda, *'Maeda's fundamental idea is that to successfully design with a computer, one has to design, or a least understand, the program one uses'* (*Antonelli 1999).* The majority of CAD users ‘have little or no knowledge of the algorithms powering the programs they employ’ (Rocker 2006) and therefore cannot accurately determine to what extent their creative endeavours are their own or the result of some 'anonymous individual' (Dormer 1997). A more detailed investigation of the tools digital craftspeople use is necessary to help identify ways of customising the standard installation to allow a greater degree of control, a way to form the software to the user rather than vice-versa.

The art of coding is essentially a pragmatic activity (Silver 2006); one learns through doing and through this process builds up a body of knowledge that enables more complex tasks to be achieved. This pragmatic approach can be seen in the crafts where the act of learning through doing is well documented (Pye 1968), are these skills transferable to a new hybrid practice that embraces the coding environment? The metalsmith Sarah Silve is an example of a craft practitioner who has applied her skills of learning through doing to learn G-code[12] (Silve 2006) in order to control CNC laser forming machines. Brian Smith approaches the debate from the perspective of a software engineer but highlights the importance of an iterative design process when writing code (Smith 2006). This will strike chords with craft practitioners who frequently talk of iterative cycles in order to refine a particular process or product.

It is important to differentiate between the terms coding, programming and scripting. Ron Herrema provides a pertinent example; users program their video recorders, while coders write the system that is used to programme the recorder (Herrema 2006). We can thereby separate out these activities and the skill sets required for using both. Essentially programming is a lower level activity than coding, it enables users to control a piece of software and or hardware in which they use a combination of familiar and abstract language to communicate to these devices. Coding requires a greater level of understanding about the underlying systems and the principles on which they are based. The act of programming a video recorder or other domestic device is however infinitely

12 G-code is a common name for the programming language that drives NC and CNC machine tools. It was developed in the early 1960s.

simpler than trying to programme a piece of CAD software as it has less controllable functions, whereas computers can be seen as universal machines (Rocker 2006) as they are capable of running thousands of tools, each with a multitude of unique parameters that can be controlled. A relatively recent technique for controlling CAD without using the icon driven menus is known as scripting, originally implemented by Autodesk into their product AutoCAD in a language called AutoLisp in 1986. Scripting languages have now become a standard feature in most design software and differ from coding and programming techniques in that they offer ways to 'gain creative control without having to go so deeply into the writing of code' (Berry 2006). Many creative industries have already embraced the use of scripting from graphic designers using Actionscript to enhance Flash driven websites to Architecture where the Emergence and Design Group has developed their own algorithmic design tool, 'gener8'[13] for Autodesk's Maya.

3D Max incorporates a scripting language called Maxscript. Maxscripts are written by users and distributed as freeware, they can be found at websites such as ScriptSpot[14]. Users can utilise and combine any command that can be executed through mouse or keyboard actions in order to extend the functionality of the existing program, automate complex tasks with a high proportion of repetition, or create completely new types of tools.

My introduction to Maxscript developed through an interest in finding scripts to customise 3D Max in order to support my interests for creating unique objects that would be difficult or impossible to make by hand processes. This interest has now focused in searching for scripts that can expand and control the range of mark making techniques that are available within a CAD environment. One example of such a script I have used is 'Draw Spline' by John Burnett, this script enables the user to sketch freehand lines directly onto a 3D surface offering a more intuitive way of drawing than the standard 'point and click' line creation tools. I explored this script by creating a container to hold pens (Insert Figure9, exactly here), by adjusting the sample rate to a high level I was able to record the shakes and stutters of my hand action, which gives the appearance of a hand drawn line. A second script, 'CNC toolkit'[15] by Rab Douglas enabled me to directly generate cutting data from these lines and export them as CNC code in order to drive a milling machine in cutting a billet of Aluminium. The hand drawn component has a non machine look as if it had been hand engraved, the numerous overlapping lines give the surface a different, more intriguing quality than the automatic and efficiency generated CAM cutting data (Insert Figure10, approximately here).

The regular use of these new tools encouraged me to establish the feasibility of creating my own scripts as a way of extending my creative control over the tools in 3D Max. I choose to develop a script based on providing other makers with access and control of my tessellation meshes without the time constraints required in the hand building of them.

Starting to write a script is an intimidating task, simple actions in the 3D modelling environment become complex text burdened code in scripting. The unfamiliar terminology slowed my learning process and forced me to use a stop start method as I constantly referred to the reference manual for information. The achievement of getting a small piece of script to work was rewarding, even if it was only to draw a cube. I managed to increase the speed of my research by learning through copying, I used code from downloaded scripts, cutting and pasting it into my own creations. By changing one parameter at a time and evaluating its effect in the 3D environment I was able to establish the function of certain commands. The other aid to my learning has been a 'listener window' in 3D Max which records the actions of creation in Maxscript notation, so by creating 3D objects using my existing skills, it is possible to see beyond the visual representation on the screen to the code below (Insert Figure11 approximately here). Over many weeks I have developed my first script, 'grid builder'. I have managed to automate the process of creating a simple tessellated grid constructed from hexagons, squares and triangles and provided a number of user inputs to determine the size of the mesh (Insert Figure12 approximately here). There are some fundamental problems with the script and it does not yet offer the flexibility and functionality that I intended,

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13 http://projects.csail.mit.edu/emergentDesign/genr8/index.html (accessed 29/01/07)
14 http://www.scriptspot.com/start.htm (accessed 26/01/07)
15 http://www.rainnea.com/cnc_toolkit.htm (accessed 26/01/07)

resulting more from my current limited knowledge rather than any limitations of the language.

Unlike the other techniques discussed in this paper that have demonstrable effects on the ability of the maker to control their tools, my work with scripting has still to reveal it's potential. At the moment it is a time saving tool that may enable others to utilise my new meshes in order to build their own 3D forms, however it does not offer a technique unachievable by other means. The complexities of the language and time taken to develop new creative tools currently outweigh the advantages.

CAM Phase: Mayka

It is important for digital makers to know their tools in the same way as any other craftsperson, if one uses a CNC mill or RP machine to fabricate work then forming an in-depth understanding of these tools is necessary in order to manipulate them in ways that are controlled rather than pre-set.

Computer Aided Manufacturing software allows a user to generate Numeric Control (NC) code from a CAD model, there are various methods used to specify how to create NC code from a model depending on the type of CAM program used. Many engineering solutions such as Delcam's FeatureCAM[16] are designed for milling forms from solid blocks of material, they use a system called ‘feature recognition’ which analyses the models geometry and identifies known features such as holes, pockets, bosses etc. It then matches these features to the most appropriate machining strategy, balancing surface quality and cut-time. Other CAM solutions such as Delcam’s ARTCAM[17] and BobCAD's BobART[18] are aimed at the creative industries such as sign writing and jewellery. These programs allow toolpaths[19] to be generated from a more diverse range of sources such as photographs, they utilise 'wizards' to facilitate non expert use, and aim to allow the user more choice in relation to the type of tooling they wish to use. Both expert and non expert systems have been designed to remove risk and in doing so have created a system of objects that are homogeneous in terms of surface aesthetic.

The CAM program I use is called Mayka[20], developed primarily as a machining solution for companies who use CNC milling machines but are not engineers. Schools, sculptors, model makers and small to medium enterprises are their main market. Mayka can offer the new user of CNC milling a quick way to process NC code through its relatively simple user interface, however in order to develop any unique mark making techniques with this software it is necessary to investigate the various control parameters further.

One method I have developed utilises Mayka's simulation tool, this is traditionally used to visually represent the exact path of the cutting tool for error and safety checking purposes. The software is capable of calculating how to machine a 3D surface with any cutting tool (real or imaginary), the simulation will show the cut marks from this user defined tool on the surface (Insert Figure13, approximately here). I have discovered that this simulated surface, tool marks and all can be saved as a hybrid of the original 3D CAD but with the machines unique process added to it. This procedure can be repeated as many times as desired in order to create layers of varying marks which would be impossible to CAD model independently (Insert Figure14, approximately here). The layering is a unique way of controlling the incidental tool marks into a surface texturing technique. Another method I have developed subverts a technique for cutting large amounts of material from around a designed surface. Mayka is programmed to remove all the excess material surrounding the design as quickly as possible, by placing lines called 'islands' directly on the surface I can prevent Mayka from following the most direct route. The islands effectively act as barriers which can be used to influence the cutpath being generated, transforming it from a way of

16 http://www.featurecam.com/ (accessed 29/01/07)
17 http://www.artcam.com/ (accessed 29/01/07)
18 http://www.bobcad.com/features_bobartprox.html (accessed 29/01/07)
19 A toolpath is a vector along which the tool tip will travel in order to cut away material surrounding a 3D form.
20 http://www.picasoft.com/english/mayka.php (accessed 29/01/07)

removing material into a decorative tool (Insert Figure15, 16, approximately here).

CAD software allows makers to experiment and take risks (Strzelec 2004), as these virtual forms do not hold the same value as physical artefacts. However, making objects in metal using a CNC mill returns an element of risk, seeing a milling machine plough through solid metal at 8 metres a minute can be a scary experience. Risk is present in the long amount of time involved to reach a finished product and also through the many cost implications such as cutting tools. What effect this has on a makers ability to develop a series of test pieces from which to form knowledge is still not clear but it is obvious that the lack of reference material available in regards to surface finish and tool choice is a problem when making decisions that affect the end result of the object. Although CAM software has attempted to eliminate the need for test pieces through the use of simulation, these have not yet reached the quality necessary to be useful to the digital craft maker. The feedback that you get from looking and touching a CNC machined piece of metal provides more information than the CAM simulations and makes it easier to visualise how the effect would look on a completed object.

The need to develop a database of physical samples became clear to me, so I focused my research on documenting the various parameters that can be altered in Mayka that directly affect the quality of the surface when milled in Aluminium. I opted for a systematic and rigorous approach to the testing of these parameters in order to develop a thorough understanding rather than following my visual instincts. The two main parameters that control the differences in the finished milled surface are the tool diameter and the distance between each pass of the tool over a given surface; this is known as the increment value. By altering these variables it is possible to achieve different qualities in surface detail, this can be measured and is referred to as a ridge value. The ridge value can be calculated prior to machining using a formula that links tool diameter and increment value. I have developed a simple Excel spreadsheet that makes calculating this value easier. Using my Excel spreadsheet I established a range of test variables that would illustrate the largest range of surface finishes whilst remaining perceptible. This enabled me to narrow down the number of samples needed for each cutting tool. The chosen samples were then CNC milled in Aluminium, the ability to view the cutting marks from different angles is a great advantage in understanding their quality in the real world.

I recognise that the limitation of the physical database is the inability to code the information into a more distributable media such as a web page. The sheer number of numeric inputs that can be entered within the different parameters means that the database can only serve as a guide, but it has already provided useful, particularly when introducing other makers who are unfamiliar to the process of CNC milling. For example, I worked with a Textile Designer Ismini Samanidou as part of Hidden Art's Repeat and Variation project. Ismini's project focused on adding a third dimension to her digital designed CNC jacquard woven textiles through forming paper thread using CNC milled moulds. The database acted as a reference of real world results that enabled me to articulate to Ismini what various numeric values in the CAM software meant. The samples also allowed Ismini to focus her range of tests by selecting the types of marks she felt would translate well into the fabric.

Despite the noted limitations, the database is a useful aid for the craftsperson; it visually communicates how small numeric parameter changes affect the surface quality of a finished milled object.

CAM Phase: HPGL Output

I have identified the importance of output file types from CAD software and their direct effect on the surface aesthetic of 3D objects; by also considering this at the end of the CAM phase I have revealed new ways to manipulate CNC cut file code.

For generated cutpaths to be understood by any CNC machine they have to be exported through a Post processor, this adds some additional lines of code to the start and end of the file which enables the machine to understand the program. A Post processed file can be edited using a text

editor such as WordPad, each of the necessary X, Y and Z machine movements are coded line by line. The text that represents the 3D component can be edited but when working with complex surfaces it is common to have over 100 000 lines of code which is unmanageable to work with in an informed manner.
(Insert Figure17, approximately here)

Mayka comes with hundreds of different Posts, one of these is the Hewlett Packard Graphics Language[21] (HPGL) file format left over from the era of 2D pen plotters. Knowing that plotters are essentially 2D CNC machines I wondered what effect saving a 3D cutpath through this 2D post processor would have. After much searching through various programs and company websites I found that the 2D graphics program CorelDraw had kept an HPGL import plugin even in the latest releases. This allowed me to open the HPGL file as an editable 2D vector drawing, the 3D Data had been compressed into one 2D layer, effectively opening the code to a new set of editing tools. Each point in the file can be moved, deleted or even redrawn. The advantage of being able to edit the code as a visual component is two fold: firstly any mistakes that the software may generate can be corrected; secondly it offers greater opportunities for treating the cut file as a creative element that is not just the result of an automated process but something that can be controlled and edited as the user sees fit. (Insert Figure18, approximately here)

I have used this technique to create intricate patterns that enhance the surface of my 3D objects, examples such as the milled surface of 'T7' and 'ST8' exhibit the complexity achievable. The ability to edit or draw the cutpath with familiar tools in CAD allows me to attain a level of refinement that is unachievable by using the standard tools alone. (Insert Figures 19, 20, approximately here)

Although the parameters within CAM software already allow a degree of user specification, they are fairly prescriptive and numerically driven; my method allows users to treat cutpaths and NC code as the start of a creative process rather than a means to an end.

Conclusions:

'The quality of the outcome will depend less on the technology than on those of us who master it.' (McCullough1998)

The research aims were to establish whether it is possible to extend the vocabulary of digital designed and manufactured craft objects through a rigorous analyse of the toolsets used in the CAD and CAM phases of production. I proposed that by deconstructing these complex toolsets into their individual components it would be possible to establish new ways of working that allowed digital craftspeople opportunities to regain personal control in order to create unique visual aesthetics.

Through the CAD phase I have established that by considering the geometric content of 3D CAD forms it is possible to create objects that escape the uniformity of standard tessellation techniques. The methods I describe are driven from my desire as a maker to overcome the limitations of existing software by customising my making tools in order to create more visually stimulating and unique objects. These objects do not escape a CAD aesthetic any more than a hammered bowl escapes a hammered aesthetic but the processes used in their production open up new levels of control that enable me to define an objects qualities. My research into achieving another level of control through Maxscript has yet to become tangible and the results of this will need to be disseminated to other makers who use 3D Max, this will enable me to test whether my new mesh types truly offer opportunities for makers to develop unique aesthetics or will it still be possible to identify my visual language through these objects?

In the CAM phase I have developed a fundamental change to the way makers can interact with

[21] HPGL was developed in the eighties by Hewlett Packard as a way of sending information to pen plotters, which were then in widespread use as a way of creating large technical drawings in colour from CAD http://en.wikipedia.org/wiki/HPGL (accessed 26/01/07)

machine code, by transforming the text into an editable vector format I have enabled makers to edit and create cutpath data with familiar CAD tools. This technique can be easily explored by other users of Mayka and it will be important to discover if the ability to edit code in a more visually orientated way allows these practitioners more control over the machines they use to create their work. The creation of a physical database has also enabled me and others to make informed decisions when developing new work; however its dissemination is limited at present. A future possibility for extending this work could be through the development of a web database containing force feedback data from the machined surfaces, using a haptic interface users could perhaps experience more feedback than from a purely image based source. The research I have conducted expands Mayka's boundaries and as such I consider one of the most appropriate ways to disseminate my research is through the software developers. I have developed a good relationship with Picasoft and currently report any improvements I would like to see in future releases; because of the small market of Mayka my comments can have a direct influence on the way the software may develop. I aim to develop a more formal agreement that will allow me to work directly with their programmers in order to integrate some of my ideas and develop new unimagined tools that expand the level of user interaction.

New software tools are being developed every year which aim to give the intended market more speed and efficiency, it is important that craft practitioners who utilise CAD software in their work to identify where the creative potential lies within these tools. Perhaps it will be more appropriate to learn how to abuse, rather than use these systems in order to develop a creative niche. I have resisted keeping up with latest versions of 3D CAD as for me craft is a meditative process and the importance of taking ones time to discover and master these tools is of primary concern. The digital tools craftspeople utilise are designed to make things quicker which ironically prevents many from achieving a deeper understanding and developing unique methods. The challenges that CAD, CAM and CNC systems present to the digital craftsperson can be traversed in numerous ways; the successful practitioner will employ their creativity in combination with personal knowledge and much practice in order to master these tools. This level of engagement will enable practices that transcend the boundaries of standardised tools in order to create visually unique craft objects.

Figures:

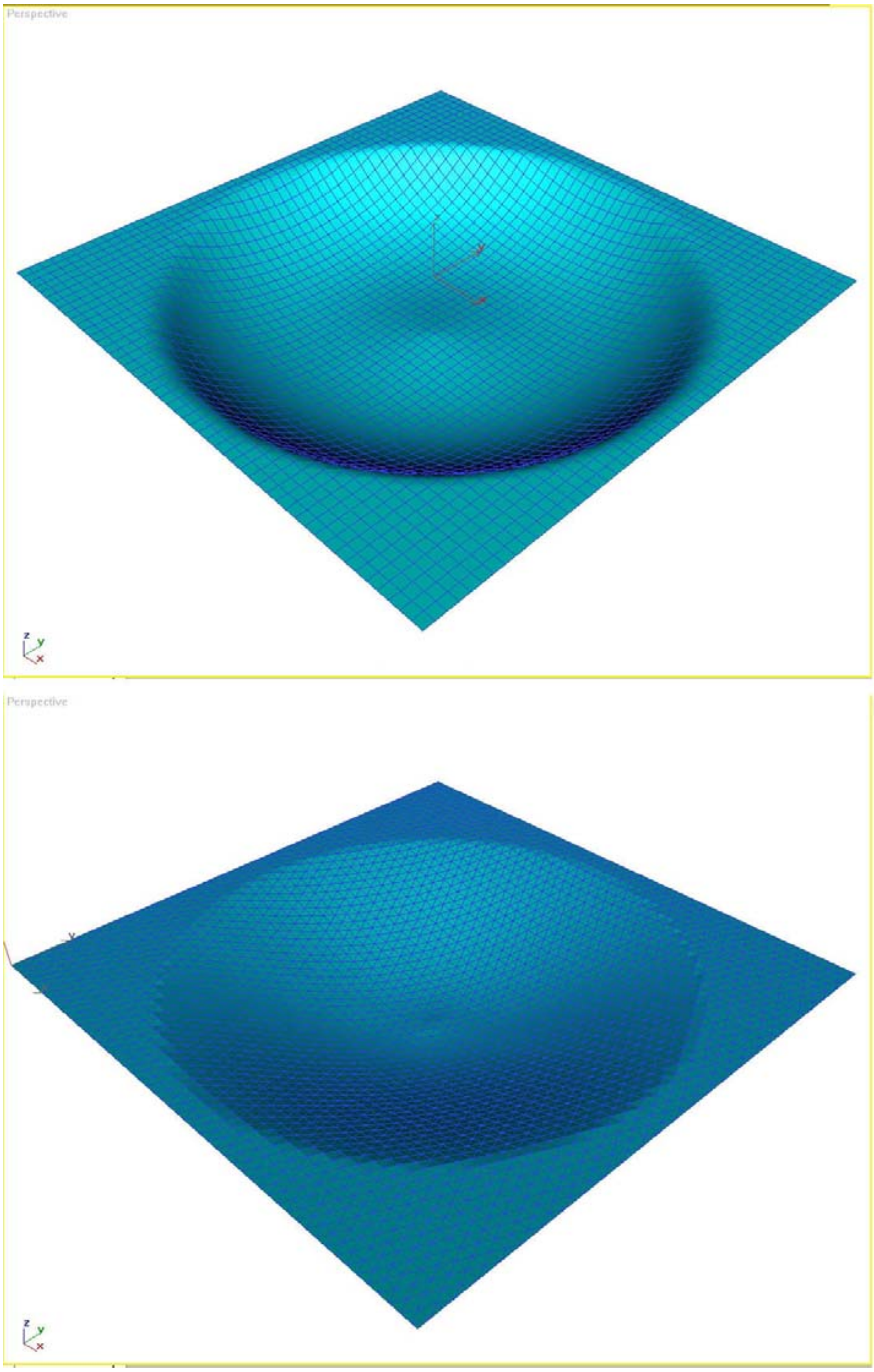


Figure 1: Typical mesh from 3D CAD software utilises square or triangular polygons.

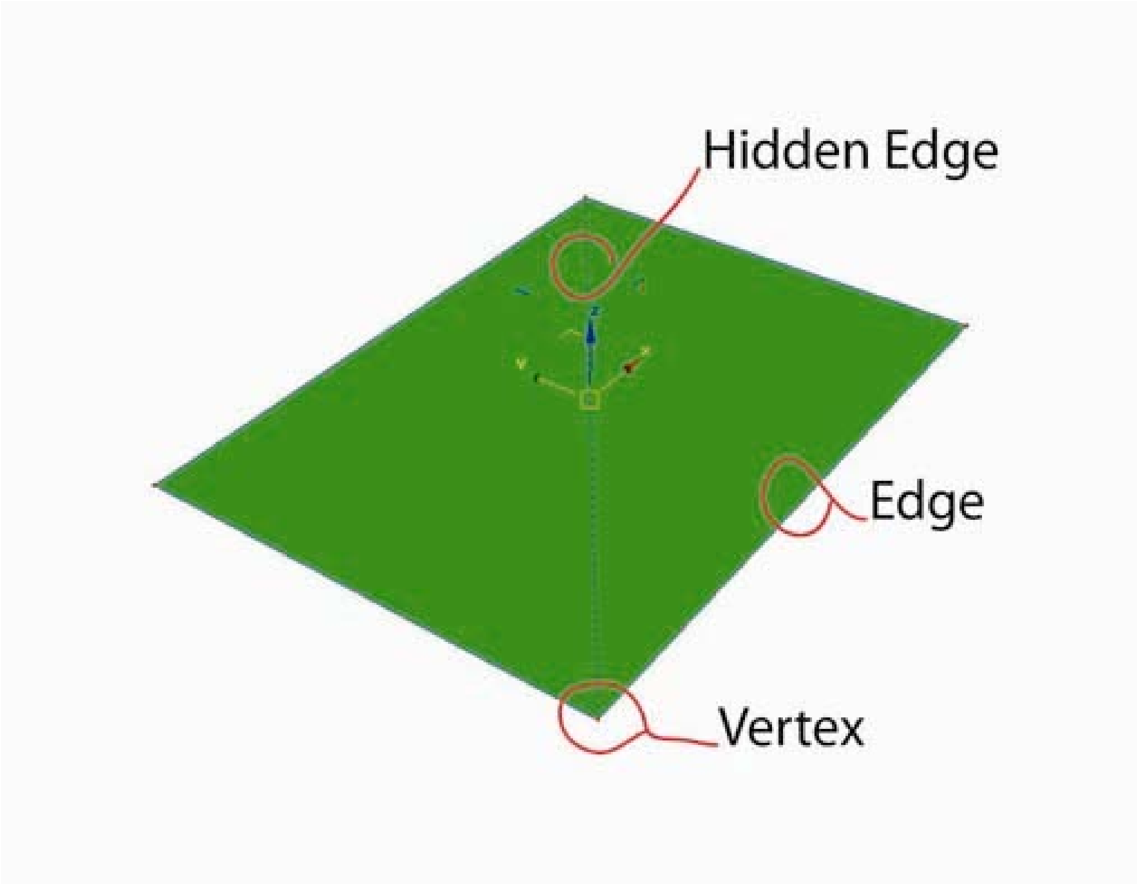


Figure 2: Illustration showing the geometric elements of a 4 sided polygon.

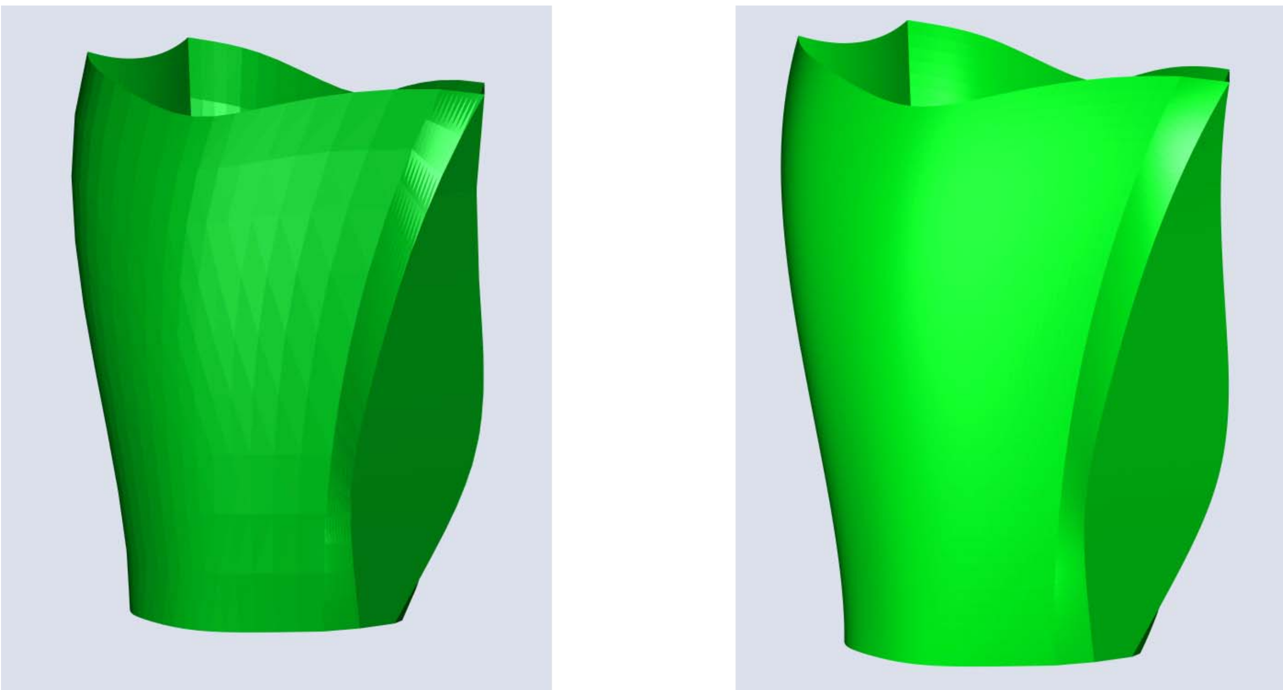


Figure 3: 3D form saved through STL exporter, the image on the left is the default settings, on the right I have increased the setting to hide the triangles.

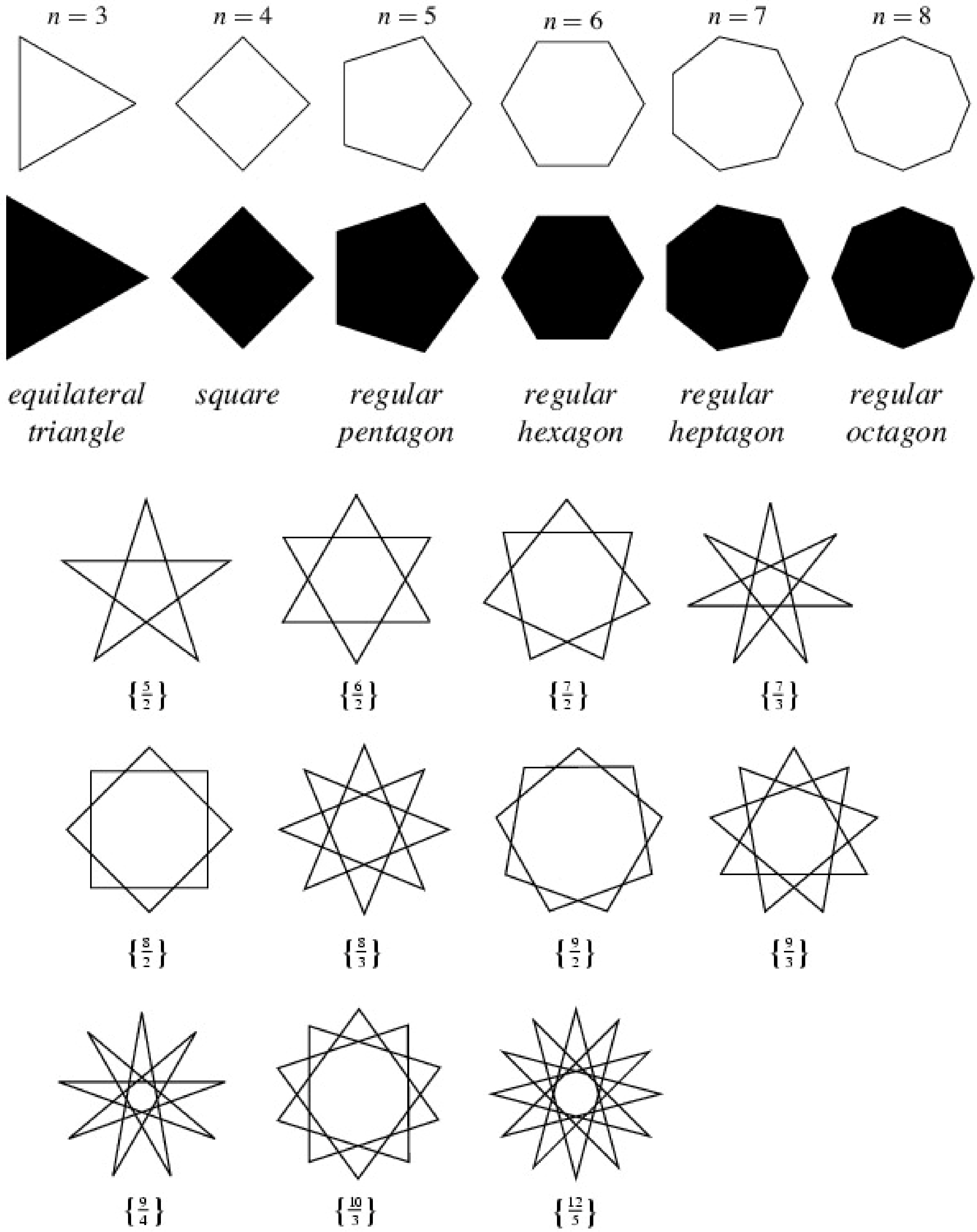
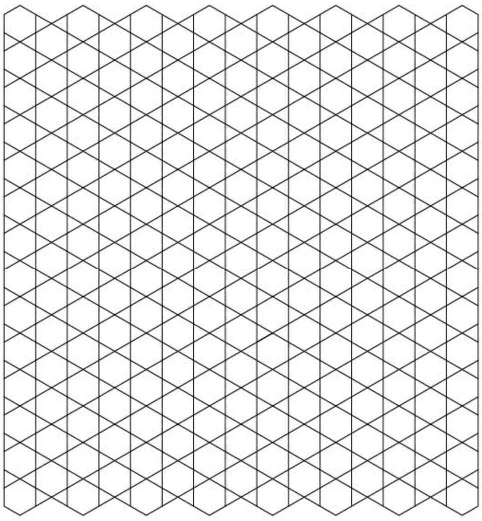


Figure 4: Illustration of regular polygons (top) and star polygons (bottom), images from http://mathworld.wolfram.com/RegularPolygon.html (accessed 28/01/07).



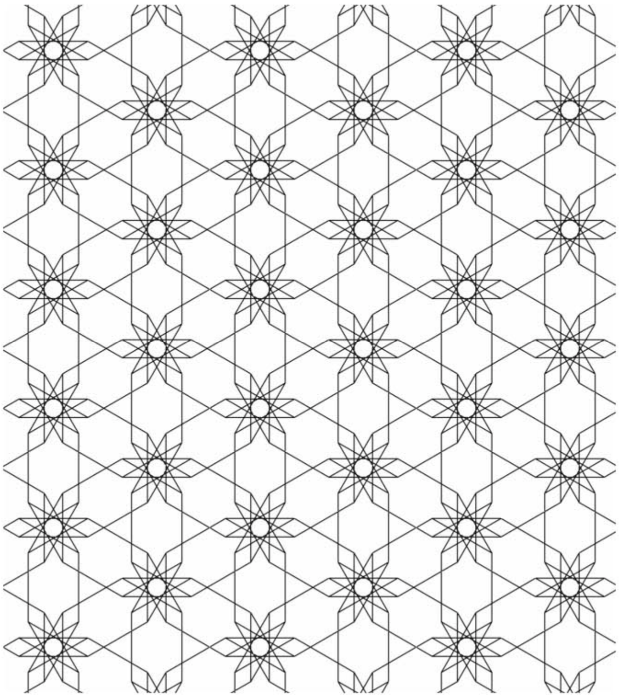


Figure 5: Tessellated mesh examples, on the left a semi-regular tessellation (6,3) and on the right a star-tessellation (12, $^{6}/_{5}$, $^{12}/_{7}$).

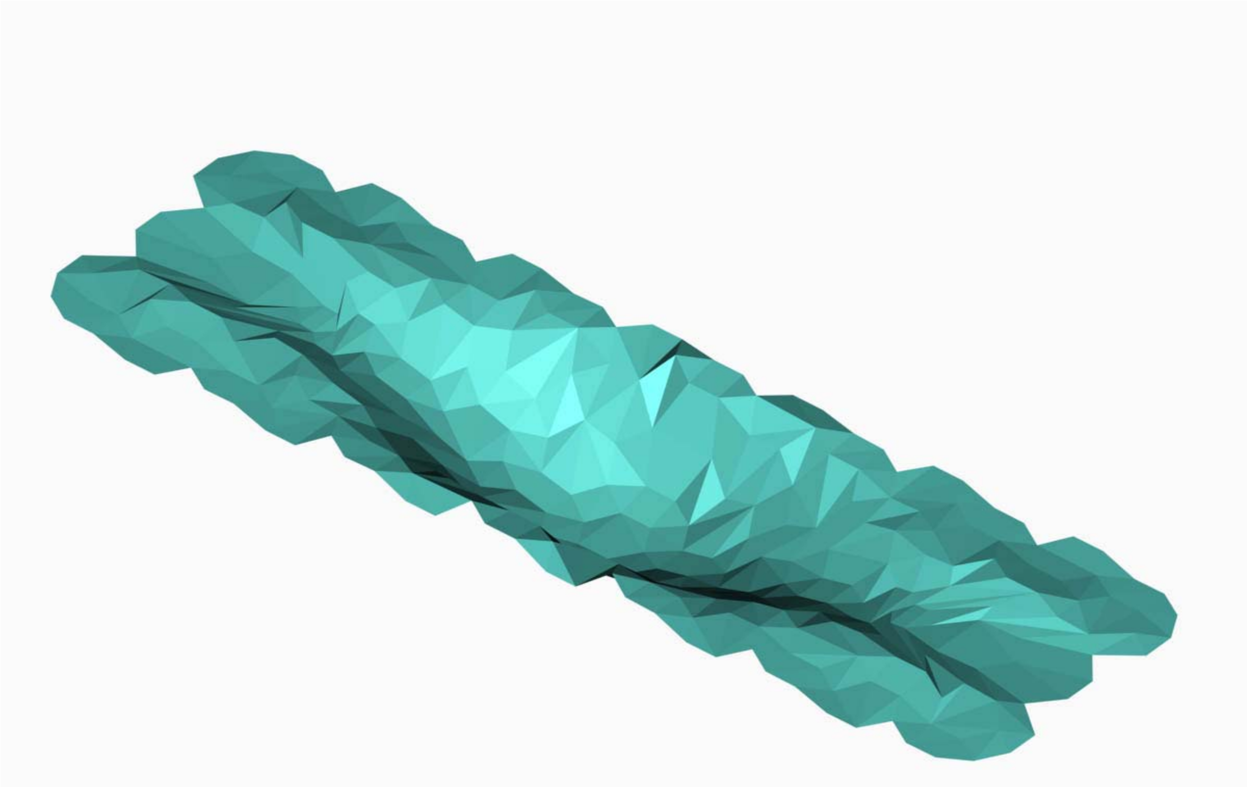


Figure 6: 3D surface created from hexagons, squares and triangles revealing hidden internal edges after being deformed.

Figure 7: 'ST1', CNC milled dish, Aluminium 280mm diameter, 22mm depth.

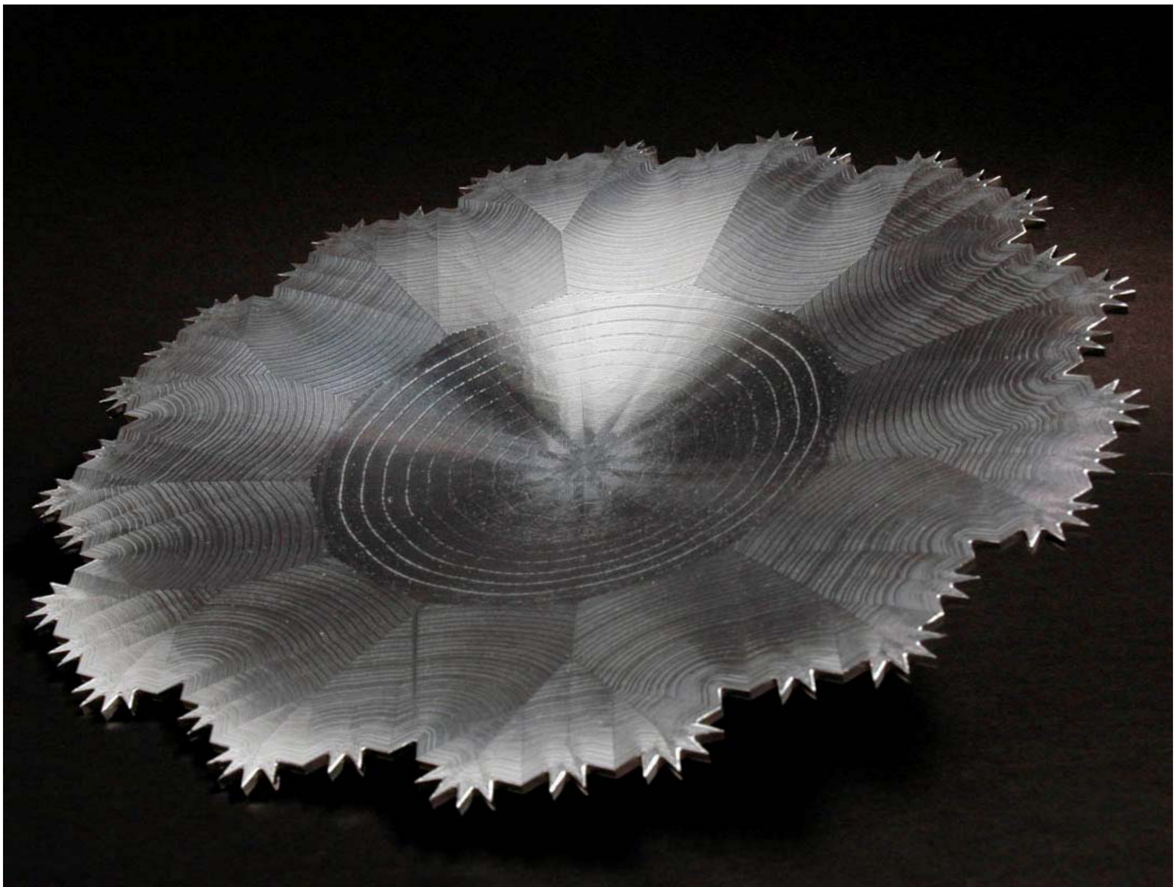


Figure 8: 'ST4', CNC milled dish, Aluminium 300mm diameter, 25 mm depth.

Figure 9:Decorated Pencase, CNC milled, Aluminium, 130mm by 55mm by 12mm.

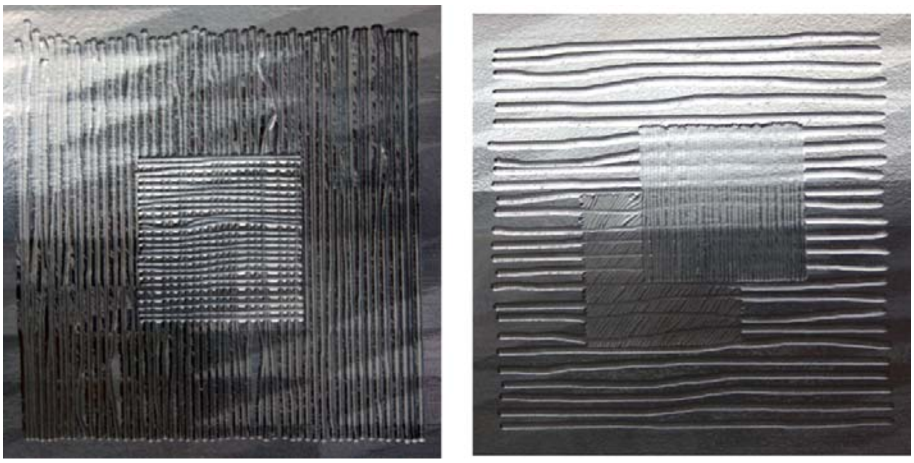


Figure 10: Test pieces exploring the possibilities of 'CNCToolkit' and 'Drawspline'

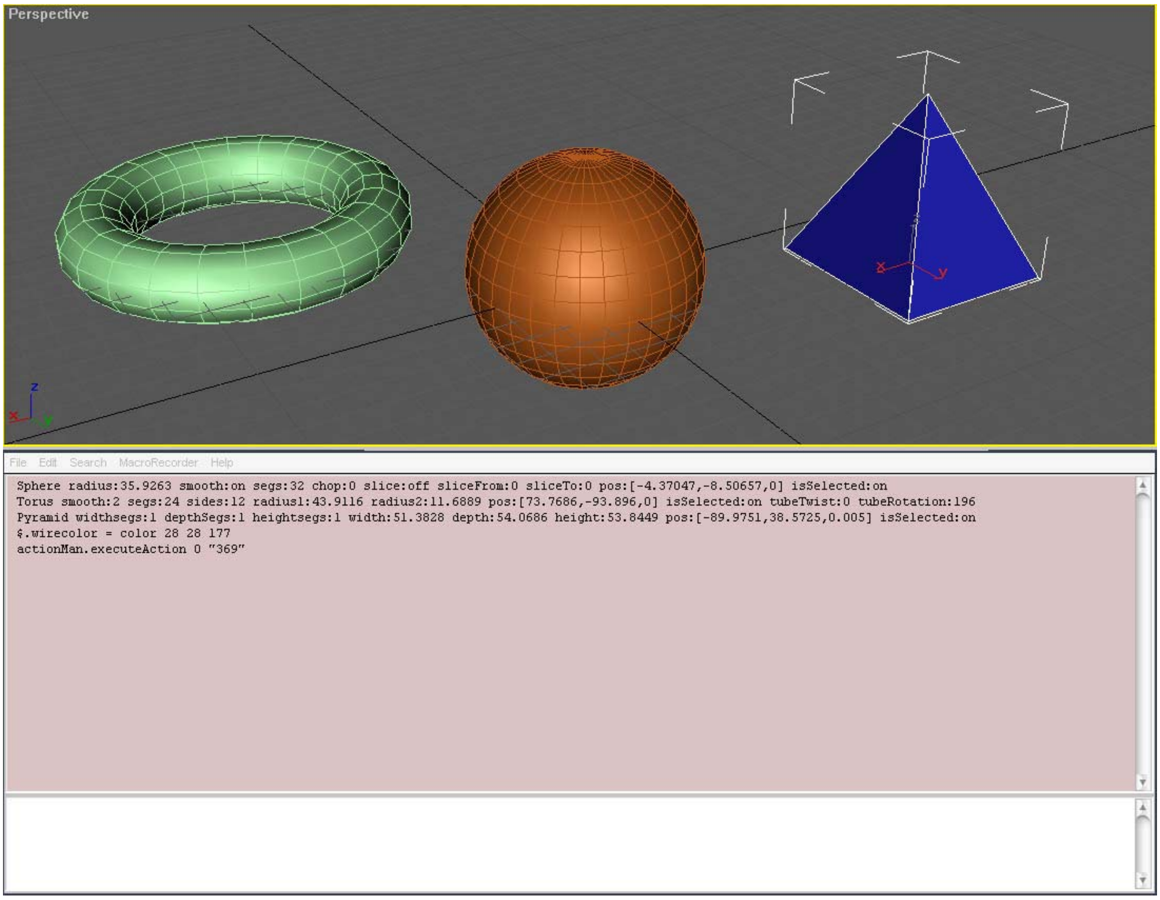


Figure 11: The Maxscript listener window, showing some primitive objects with their underlying code.

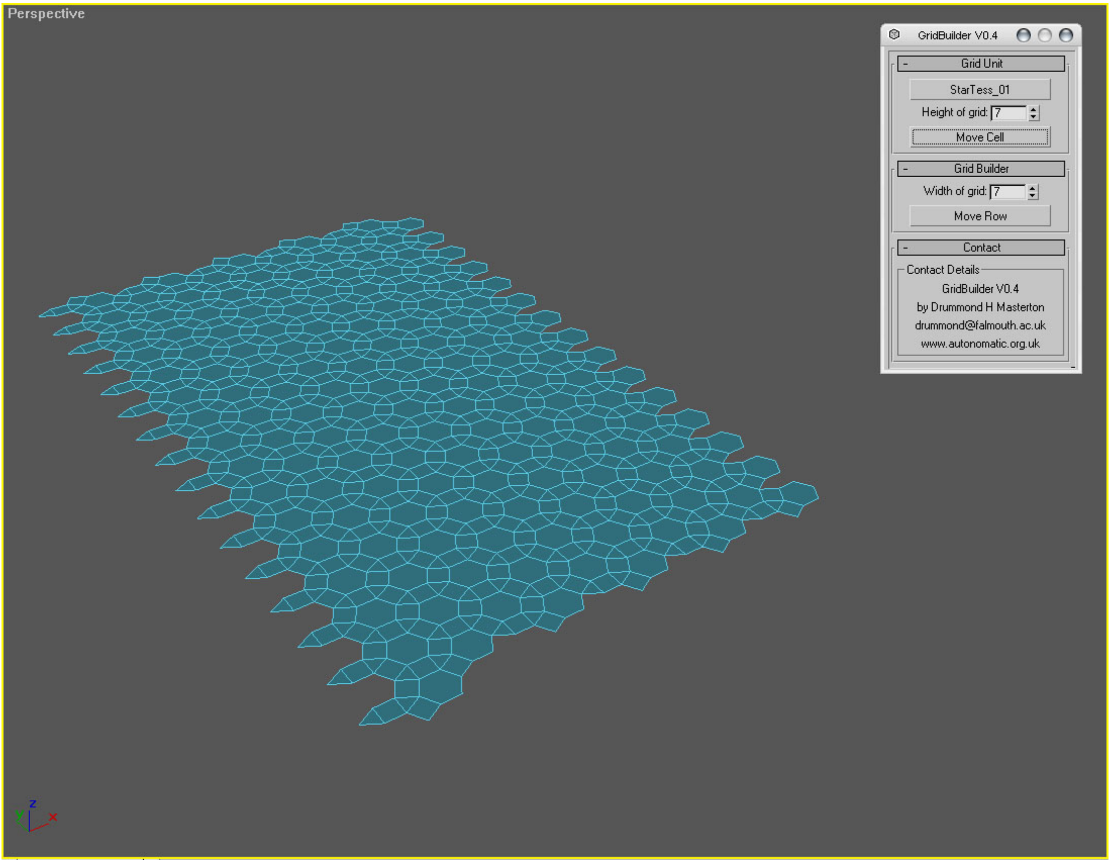


Figure 12: Screen grab from 3D Studio Max showing my script, 'Gridbuilder' and an example of the mesh that it can create.

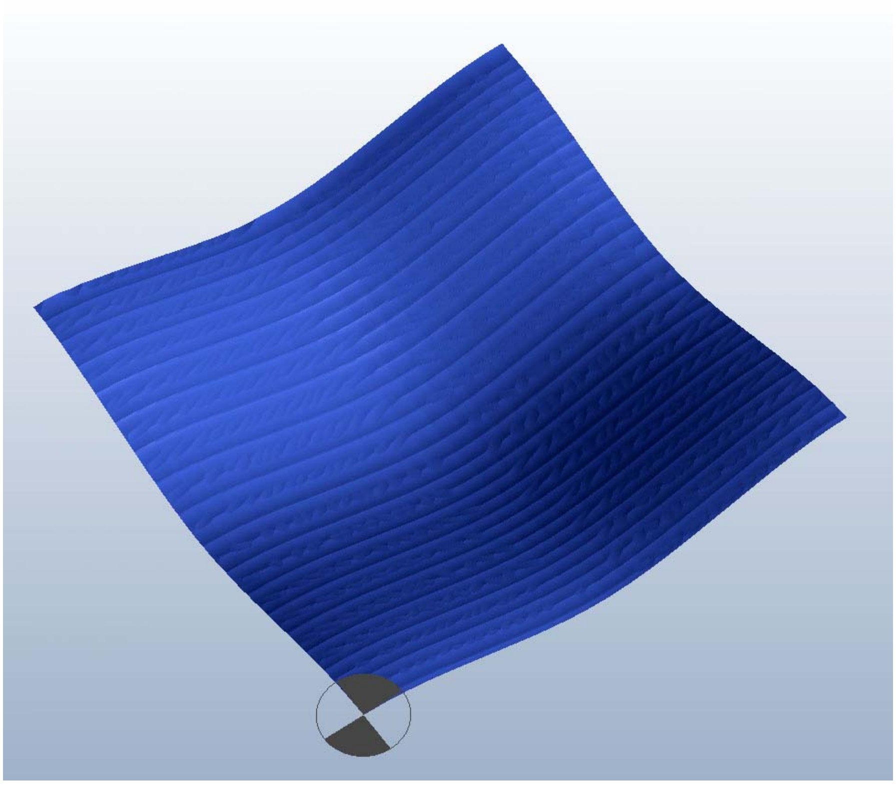


Figure 13: Screen grab from Mayka showing how cutpath simulation can be used to embed cutting marks into the original CAD model.

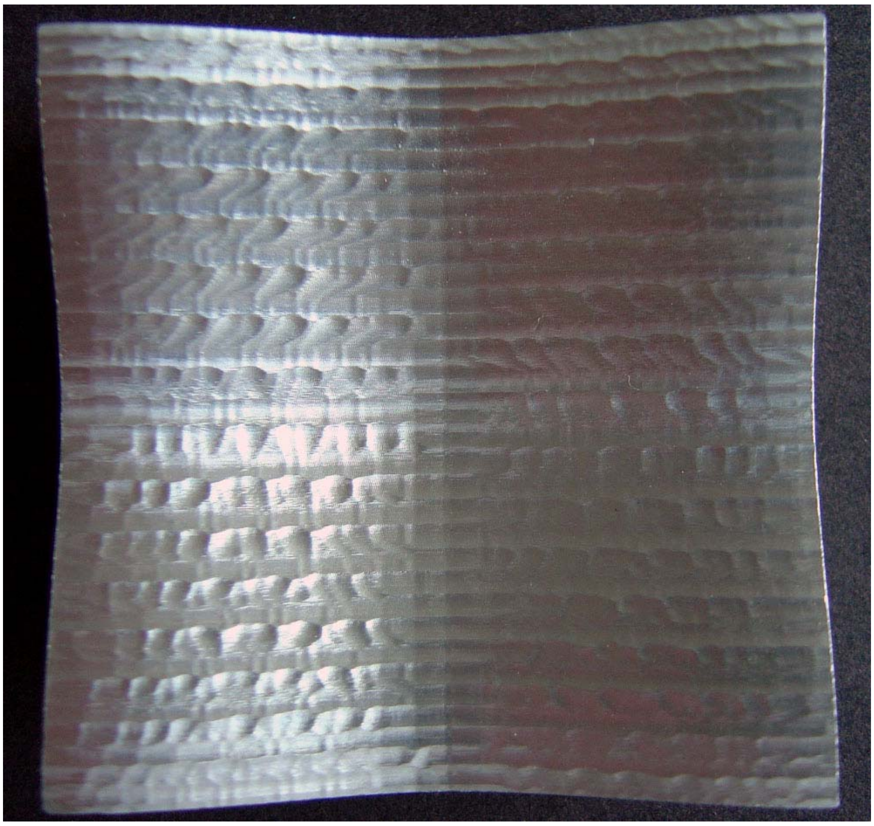


Figure 14: Test piece showing how cut marks embedded in Mayka can be cut with a smaller tool in order to add more detail. In this case a 12mm ball ended tool was used for the simulated cut and then cut with a 1mm ball ended tool on the CNC mill.

Figure 15: 'Whisky Tumbler', 4 axis CNC milled Aluminium, 80mm diameter, 80 mm depth. The Pattern is a consistent depth despite the undulating surface.

Figure 16: 'Cloud Bowl AS3' CNC milled Aluminium, 340mm by 120 mm by 18mm. The top two images show how the use of guide profiles can control the direction of the cutpath.

```
0 BEGIN PGM 1000 MM
1 TOOL CALL 4 S7600
2 M06
3 L X-100.873 Y-100.621 R0 FMAX M13
4 M18
5 L X-100.873 Y-100.621 Z6. F9999
6 L X-100.873 Y-100.621 Z6.
7 L X-100.873 Y-100.621 Z1.
8 L X-100.873 Y-100.621 Z1. F360
9 L X-100.873 Y-100.621 Z1. F720
10 L X-94.873 Y-100.621 Z1.
11 L X-94.977 Y-99.508 Z0.7
12 L X-95.286 Y-98.433 Z0.4
13 L X-95.789 Y-97.435 Z0.1
14 L X-96.468 Y-96.547 Z-0.2
15 L X-100.873 Y-100.621 Z-0.5
16 L X100.873 Y-100.621 Z-0.5
17 L X100.873 Y-99.141 Z-0.5
18 L X-100.873 Y-99.141 Z-0.5
19 L X-100.873 Y-97.662 Z-0.5
20 L X100.873 Y-97.662 Z-0.5
21 L X100.873 Y-96.182 Z-0.5
22 L X-100.873 Y-96.182 Z-0.5
23 L X-100.873 Y-94.702 Z-0.5
24 L X100.873 Y-94.702 Z-0.5
25 L X100.873 Y-93.222 Z-0.5
26 L X-100.873 Y-93.222 Z-0.5
27 L X-100.873 Y-91.743 Z-0.5
28 L X100.873 Y-91.743 Z-0.5
29 L X100.873 Y-90.263 Z-0.5
30 L X-100.873 Y-90.263 Z-0.5
31 L X-100.873 Y-88.783 Z-0.5
32 L X100.873 Y-88.783 Z-0.5
33 L X100.873 Y-87.304 Z-0.5
34 L X-100.873 Y-87.304 Z-0.5
35 L X-100.873 Y-85.824 Z-0.5
36 L X100.873 Y-85.824 Z-0.5
37 L X100.873 Y-84.344 Z-0.5
38 L X-100.873 Y-84.344 Z-0.5
39 L X-100.873 Y-82.864 Z-0.5
40 L X100.873 Y-82.864 Z-0.5
41 L X100.873 Y-81.385 Z-0.5
42 L X-100.873 Y-81.385 Z-0.5
43 L X-100.873 Y-79.905 Z-0.5
44 L X100.873 Y-79.905 Z-0.5
45 L X100.873 Y-78.425 Z-0.5
46 L X-100.873 Y-78.425 Z-0.5
47 L X-100.873 Y-76.945 Z-0.5
48 L X100.873 Y-76.945 Z-0.5
49 L X100.873 Y-75.466 Z-0.5
50 L X-100.873 Y-75.466 Z-0.5
51 L X-100.873 Y-73.986 Z-0.5
52 L X100.873 Y-73.986 Z-0.5
53 L X100.873 Y-72.506 Z-0.5
54 L X-100.873 Y-72.506 Z-0.5
55 L X-100.873 Y-71.027 Z-0.5
```

Figure 17: Sample of typical CNC code

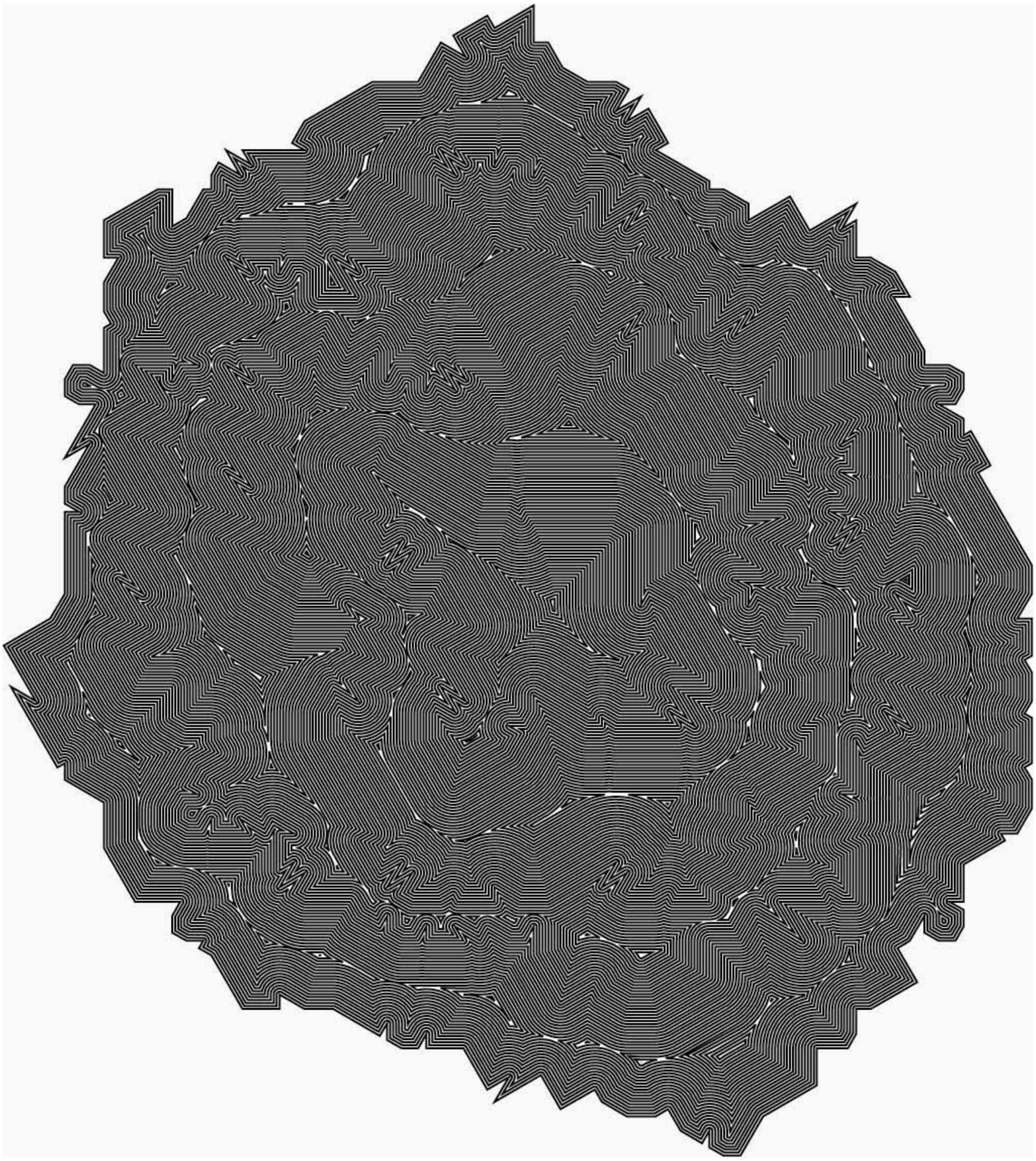


Figure 18: Example of complexity and control achievable through editing cutpaths using an HPGL exporter and a standard CAD software package.

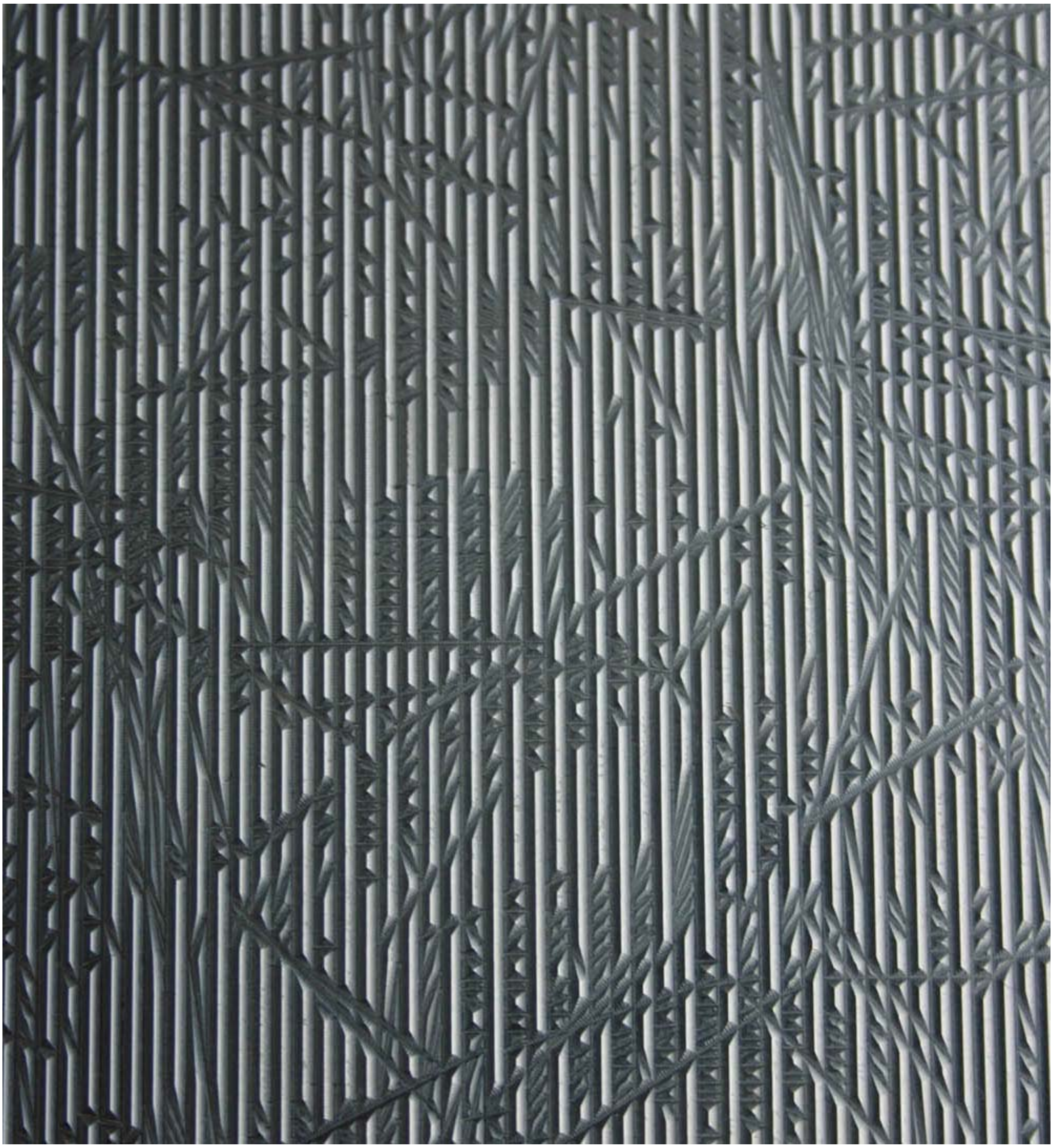


Figure 19: Test piece exploring the new mark making possibilities achievable using conventional CAD tools such as lines to draw cutpaths.

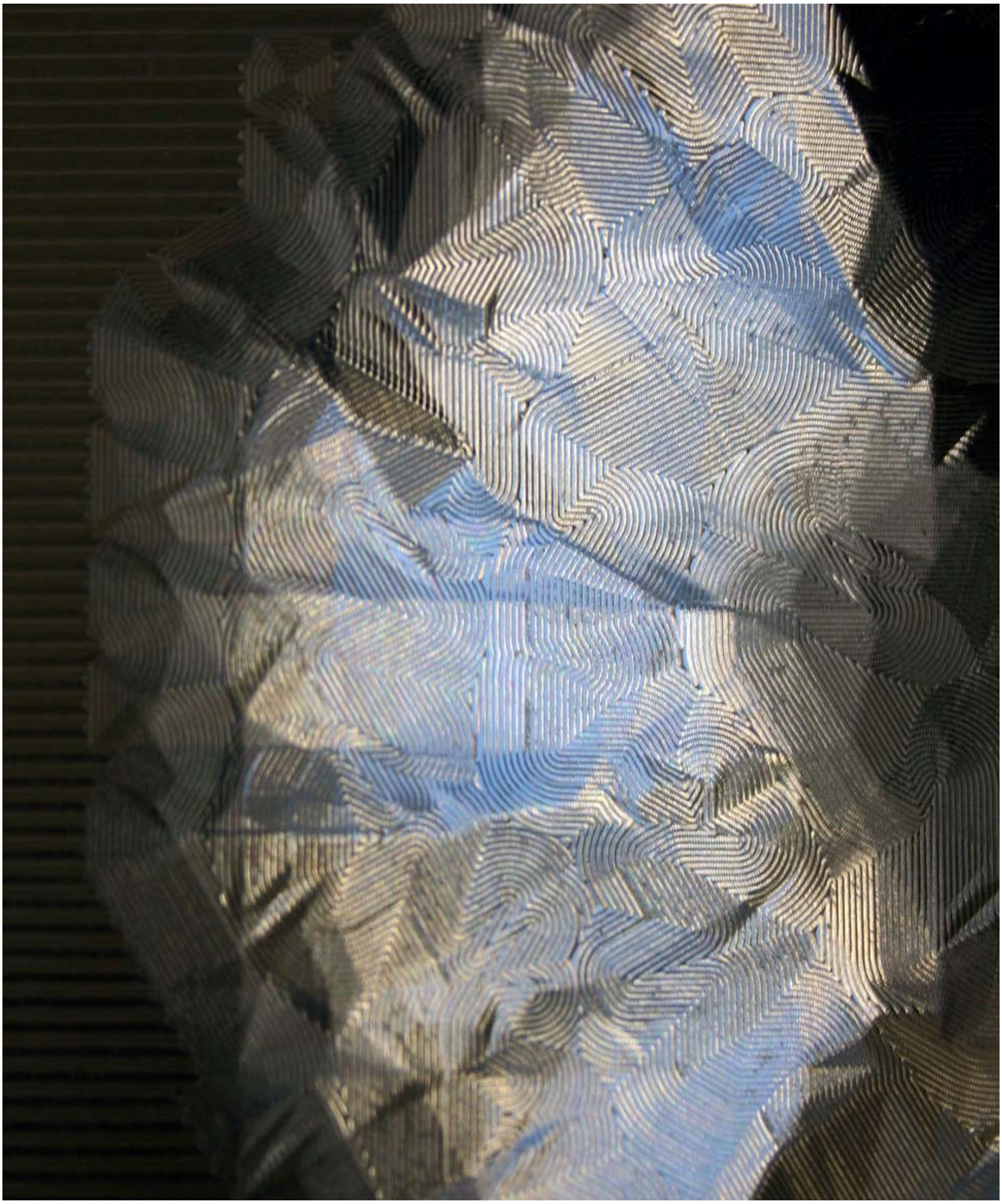


Figure 20: Detail of CNC milled surface on ‘ST14’, cut marks created using a combination of automated techniques and hand drawn lines.

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