

The Craft of Digital Tooling

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A thesis submitted in partial fulfilment of the requirements of
the Royal College of Art for the degree of Master of Philosophy

March 2010

The Royal College of Art

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Abstract

The tools and hand processes used in traditional approaches to silversmithing have hardly changed over the centuries. Objects are constructed using processes involving physical manipulation and control with hand tools and in particular with hammers. With the introduction of machines much of the direct handling and touch in the shaping of metals was lost. However, with the rapid advancements in technology, digital haptic equipment is making this experience available again in virtual form. As digital manufacture becomes more integrated with the silversmithing and jewellery industries, the haptic tool being developed in this research project could be beneficial in sustaining connections between traditional hand methods and the latest technology.

The aim of the research project was to investigate the application of a hammer interface in terms of traditional silversmithing and jewellery practice and to determine the benefits and limitations involved in the use of this tool in a virtual environment. The research referenced the use of traditional hammering methods, and information derived from this was carried forward to the development of a hammer interface device that explored, in depth, the nature of this particular interactivity with digital material. The research will be used to generate a different making experience that will, in turn, lead to the production of an original body of pieces.

Contents

	Page Number
Copyright Statement	2
Abstract	3
Contents	4
Illustrations	5
Accompanying material	14
Acknowledgements	16
Author's declaration	17
Introduction	18
1. The craftsman's tool; the hammer	23
1.1 Human interface device	29
1.2 Differences project	38
1.3 Development of hammer interface device	51
2. The craftsman's tool: the stake	63
2.1 Hand stake	69
3 Metal	74
3.1 Digital material development	81
4 Design	86
5 Output	95
Conclusion	106
Glossary	109
Appendix 1	111
Appendix 2	113
Appendix 3	116
Bibliography	138

Illustrations

1. The craftsman's tool: the hammer

Figure 1, Mesolithic bone hammer-head, Radius from a Aurochs - wild ox, dated from 9000-4000BC, found in River Thames at Hammersmith, London.

Museum of London, collections [online] available from:

<http://www.museumoflondonprints.com/image.php?id=60946&idx=0&fromsearch=true>

[Accessed 17th March 2009]

Figure 2, Blacksmith's hammer, Iron Age/Roman, 100 BC-AD 100

From the River Lea at Waltham Abbey, Essex, England.

Room 50: Britain and Europe, the British Museum, London.

Figure 3, Raising hammer, bronze, thought to be from 12th Century BC, discovered 1897
Enkomi, Cyprus

Room 72: Ancient Cyprus, the British Museum, London.

Figure 4, Sledge hammer, bronze, thought to be from 12th Century BC, discovered 1897
Enkomi, Cyprus

Room 72: Ancient Cyprus, the British Museum, London.

Figure 5, Stone axe in wooden haft, Earlier Neolithic, about 3700-3100 BC, Ehenside Tarn,
Cumbria, England.

Room 51, Ancient Europe 4000-800 BC, the British Museum, London 2010

Figure 6, Polished flint axe-head: Neolithic, 4000 BC - 2200 BC, found in the Thames at
Long Reach, Kent.

Museum of London, collections [online] available from:

<http://www.museumoflondonprints.com/image.php?id=60996&idx=0&fromsearch=true>

Figure 7, Two metalworker's hammer-heads, 1st-2nd Century AD, Camerton, Somerset/
Dowgate, London.

Room 49: Roman Britain, the British Museum

Figure 8, A collection of silversmithing hammers

Finegold, R. and Seitz, W. Silversmithing, Wisconsin: Krause Publications, 1983, p133

Figure 9, Charles Robert Ashbee, Bowl silver, enamel and semi precious stones, h:11cm,
1899-1900, p19

Silver of a New Era International Highlights of Precious Metalware from 1880 to 1940,
Museum Boymans-Van Beuningen, Rotterdam, 1992.

1.1 Human interface device

Figure 10, Wacom® Intuos digitizing tablet and pen

Wacom® Intuos digitizing tablet and pen

[online] available from:

www.wacom.com

[Accessed 5th October 2008]

Figure 11, Force Dimension Omega.3

Force Dimension, Omega.3 haptic devices [online] available from:

www.forcedimension.com/products

[15th October 2008]

Figure 12, CyberGlove® Systems CyberTouch™

CyberGlove® Systems CyberTouch™ [online] available from:

www.cyberglovesystems.com/all-products

[15th October 2008]

Figure 13, SensAble The PHANTOM® Omni™

SensAble, The PHANTOM® Omni™ [online] available from:

www.sensable.com/haptic-phantom-omni.htm

[15th October 2008]

Figure 14, Intuitive Surgical, Da Vinci® Surgical System

Intuitive Surgical, Da Vinci® Surgical System

[online] available from:

www.intuitivesurgical.com/index.aspx

[Accessed 26 October 2009]

Figure 15, Falcon 3D haptic arm

A1 Technologies, Falcon 3D haptic Arm [online] available from:

<http://www.rap-man.com/chameleon.asp>

[Accessed 26th October 2009]

Figure 16, Nintendo Wii™ remote

Video game action, How to hold Wii remote and Wii Nunchuk [online] available from:

<http://www.videogameaction.com/niwiisy2plbu2.html>

[Accessed 16th October 2008]

Figure 17, Nintendo Wii™ remote sporting attachments

Amazon, Nintendo Wii accessories sports kit [online] available from:

http://www.amazon.co.uk/gp/product/images/B000OVV64O/ref=dp_image_0?ie=UTF8&n=300703&s=videogames

[Accessed 12th January 2010]

Figure 18, GlovePIE interface

Image by © Kathryn Hinton, 2009

Figure 19, Nintendo Wii™ remote with ZBrush®

Image by © Kathryn Hinton, 2008

Figure 20, Trust 1200V tablet board with digital pen housed in nylon hammer head
Image by © Kathryn Hinton, 2008

Figure 21, MOD MMA7260Q 3-axis accelerometer board
Olimex Ltd. MOD-MMA7260Q 3-axis accelerometer board [online] available from:
<http://www.olimex.com/dev/mod-mma7260q.html>
[Accessed 10th February 2008]

Figure 22, Views of the hammer head model in Rhino 3D ready for rapid prototyping
Image by © Kathryn Hinton, 2008

Figure 23, Rapid prototyped black hammer head with wooden handle
Image by © Kathryn Hinton, 2008

1.2 Differences project

Figure 24, Peening, blocking, raising and light and heavy planishing hammers
Image by © Kathryn Hinton 2009

Figure 25, Interface devices; Trust digital tablet and pen, Trust digital tablet and pen housed in nylon hammer head, rapid prototyped hammer head with tilt sensor.
Image by © Kathryn Hinton, 2009

Figure 26, ZBrush® screen shot with digital disc of material
Image by © Kathryn Hinton, 2009

Figure 27, Peening;
Image by © Kathryn Hinton, 2009

Figure 28, Differing mesh quality in ZBrush®
Image by © Kathryn Hinton, 2009

Figure 29, Blocking hammer and wooden tree trunk
Image by © Kathryn Hinton, 2010

Figure 30, Blocking
Image by © Kathryn Hinton, 2009

Figure 31, Raising
Image by © Kathryn Hinton, 2009

Figure 32, Heavy planishing
Image by © Kathryn Hinton, 2009

Figure 33, Traditional hammering in the silversmithing workshop at the Royal College of Art
Image by © Kathryn Hinton, silversmithing workshop in department of Goldsmithing, Silversmithing, Metalwork and Jewellery, 2009

Figure 34, Digital hammering in the living room of a domestic home
Image by © Kathryn Hinton, 2009

Figure 35, First round
Image by © Kathryn Hinton, 2009

Figure 36, Second round
Image by © Kathryn Hinton, 2009

Figure 37, Third round
Image by © Kathryn Hinton, 2009

Figure 38, Fourth round
Image by © Kathryn Hinton, 2009

Figure 39, Fifth round
Image by © Kathryn Hinton, 2009

Figure 40, Sixth round
Image by © Kathryn Hinton, 2009

Figure 41, Seventh round
Image by © Kathryn Hinton, 2009

Figure 42, Eighth round
Image by © Kathryn Hinton, 2009

Figure 43, Ninth round
Image by © Kathryn Hinton, 2009

Figure 44, The tenth and final round
Image by © Kathryn Hinton, 2009

1.3 Development of hammer interface device

Figure 45, A hammerstone used 2-1.5 million years ago by the habilines, thought to be the first human tool makers.
Natural History Museum London, Our Place in Evolution, section 3 humans as toolmakers

Figure 46, Rhino 3D rendering of a proposed hammerstone interface device.
Image by © Kathryn Hinton, 2009

Figure 47, Exploded view of nylon hammer with electronic components
Image by © Kathryn Hinton, 2009

Figure 48, Testing the use of two computer mice in ZBrush®
Image by © Kathryn Hinton, 2009

Figure 49, Front and side view of ZBrush® material manipulated by two computer mice
Image by © Kathryn Hinton, 2009

Figure 50, Front and side view of ZBrush® material manipulated by two computer mice with adjusted Z Intensity
Image by © Kathryn Hinton, 2009

Figure 51. Arduino Diecimila microcontroller board
Arduino Diecimila board [online] available from:
<http://www.arduino.cc/en/Main/ArduinoBoardDiecimila>
[Accessed 12th November 2008]

Figure 52, DE-ACCM3D 3 axis accelerometer
Total Robots Limited, Robotics, Control and Electronics Technology,[online] available
http://www.totalrobots.com/buffered-3d-accelerometer-p-251.html?main_page=product_info&products_id=251
[Accessed 5th October 2008]

Figure 53, Force Sensing Resistor
Active-Robots, Robotics and Electronic Technology, Sensors - Membrane Potentiometers
[online] available from:
<http://www.active-robots.com/products/sensors/sparkfun/force-sensitive-resistor.shtml>
[Accessed 30th November 2009]

Figure 54, Spring switch
Image by © Kathryn Hinton, 2010

Figure 55, Switch with separators
Image by © Kathryn Hinton, 2010

Figure 56, Slide switch
Image by © Kathryn Hinton, 2010

Figure 57, Layout for PCB board in hammer handle
Image by © Kathryn Hinton, 2010

Figure 58, Rhino 3D model for CNC milling
Image by © Kathryn Hinton, 2010

Figure 59, Milled maple handle with PCB development board
Image by © Kathryn Hinton, 2010

Figure 60, Rhino 3D model for rapid prototyping
Image by © Kathryn Hinton, 2010

Figure 61, Hardware components in hammer head
Image by © Kathryn Hinton, 2010

Figure 62, Final hammer interface device
Image by © Kathryn Hinton, 2010

2. The craftsman's tool: the stake

Figure 63, Raising stake

Image by © Kathryn Hinton, 2009

Figure 64, Different stakes for planishing contours of piece

Finegold, R. and Seitz, W. *Silversmithing*, Wisconsin: Krause Publications, 1983, p183

Figure 65, Mushroom stake in holder, mushroom stake directly in vice, raising stake, Z-Corp rapid prototyped stake

Image by © Kathryn Hinton, 2009

Figure 66, An example of an awkward stance for hammering

Image by © Kathryn Hinton, 2009

Figure 67, ZBrush® mesh hammered on different stakes

Image by © Kathryn Hinton, 2009

Figure 68, Left and right hand working together

Image by © Kathryn Hinton, 2009

Figure 69, Rhino 3D render of wooden stake

Image by © Kathryn Hinton, 2009

2.1 Hand stake

Figure 70, Ball held in left hand and struck by hammer in right hand

Image by © Kathryn Hinton, 2009

Figure 71, Uneven hammered disc

Image by © Kathryn Hinton, 2009

Figure 72, Proposed design for a hand stake

Image by © Kathryn Hinton, 2009

Figure 73, Hand stakes

Image by © Kathryn Hinton, 2009

Figure 74, Stake with horizontal and vertical copper wires

Image by © Kathryn Hinton, 2010

Figure 75, Example of shaped stake

Image by © Kathryn Hinton, 2010

3. Metal

Figure 76, The Rillaton and Ringlemere gold cups, Early Bronze Age 1800- 1600 BC, Rillaton, Cornwall and Ringlemere Farm, Kent. The British Museum.

Room 51: Ancient Europe 4000 BC-800 BC, the British Museum, London

Figure 77, Face-centred cubic structure

Read. H. H. *Rutley's Elements of Mineralogy*, 26th edn, 1970, London: Thomas Murby & Co.

Figure 78, Hiroshi Suzuki, Miyabi- Fire I, hammer-raised Fine silver, H 31cm x Ø 25.5cm 2006

Schroder, T. *Hiroshi Suzuki*, London: Scala Publishers Ltd, 2010, p59

Figure 79, ZBrush® default mesh disc

Image by © Kathryn Hinton, 2009

Figure 80, Stretched points of ZBrush® mesh

Image by © Kathryn Hinton, 2009

Figure 81, ZBrush® polygon mesh sub- divided

Image by © Kathryn Hinton, 2009

Figure 82, Blender mesh imported into ZBrush®

Image by © Kathryn Hinton, 2009

Figure 83, Creating a digital spoon blank

Image by © Kathryn Hinton, 2009

3.2 Digital material development

Figure 84, Exposed Trust tablet 1200- V2 digitising board

Image by © Kathryn Hinton, 2008

Figure 85, Copper wire was sewn through fabric

Image by © Kathryn Hinton, 2008

Figure 86, Sewn flexible material and the hammer with digitising pen

Image by © Kathryn Hinton, 2008

Figure 87, Testing the flexibility of the exposed polypropylene digitising tablet

Image by © Kathryn Hinton, 2009

Figure 88, Squares cut from the tablet board to test flexibility

Image by © Kathryn Hinton, 2009

Figure 89, Proposed silicon material board

Image by © Kathryn Hinton, 2010

Figure 90, Development of an interface tool using Arduino and conductive material as a pressure sensor

Image by © Kathryn Hinton, 2009

4. Design

Figure 91, Jeroen Verhoeven, Cinderella table, Birch plywood 2005
Victoria & Albert Museum, London, collections [online] available from:
<http://collections.vam.ac.uk/item/O121769/table-cinderella-table/>
[Accessed 12th February 2010]

Figure 92, Geoffrey Mann, Flight landing, Long Exposure series, 700 x 350 x 350 (mm)
Mfr. Glass
Studio*mrman, Geoffrey Mann home page, [online] available from:
<http://www.mrmann.co.uk/flight/>
[Accessed 28th February 2010]

Figure 93, Rhinoceros 3D 4 default viewports
Image by © Kathryn Hinton, 2010

Figure 94, ZBrush® interface
Image by © Kathryn Hinton, 2010

Figure 95, Radial symmetry 4, 8, 100 points
Image by © Kathryn Hinton, 2009

Figure 96, Hammering mesh with single cursor point and a radial count of 42
Image by © Kathryn Hinton, 2009

Figure 97, Symmetrical vessel design sketches
Image by © Kathryn Hinton, 2009

Figure 98, Raised fine silver vessel
Image by © Kathryn Hinton, 2009

Figure 99, Different views of digital vessel
Image by © Kathryn Hinton, 2009

Figure 100, A selection of mesh attempts for circular bowl with square inside
Image by © Kathryn Hinton, 2009

Figure 101, Gerald Benney sterling silver jug
Benney, G. Gerald Benney: goldsmiths, silversmiths and fine enamellers, date unknown,
London: Hillingdon Press, p15.

Figure 102, Alpha
Image by © Kathryn Hinton, 2010

Figure 103, Texture on ZBrush® sphere
Image by © Kathryn Hinton, 2010

5. Output

Figure 104, Grant MacDonald, EnvisionTEC Perfactory® Model.

Corti, C. Investing in Technology Grant MacDonald –Silversmith, 2005, *The Goldsmiths' Company Technical Bulletin*, The Technology and Training Department, Issue 2, p3.

Figure 105, Electro Optical Systems, Direct Metal Laser Sintering in precious metal.

Corti, Christopher W, Laser sintering of precious metal powders, *The Goldsmiths' Company Technical Bulletin*, The Technology and Training Department, April 2006, p4.

Figure 106, Digital ZBrush® mesh, Solidscape wax, cast sterling silver

Image by © Kathryn Hinton, 2010

Figure 107, Stages to realise physical object in silver

Image by © Kathryn Hinton, 2008

Figure 108, Drummond Masterton, Hexabubble Bowl, Aluminium, h: 25mm w: 175mm d: 175mm, 2005.

Wynne, S. & Woolner, M. (2006) *Interface Exhibition Catalogue*, A Devon Guild of Craftsmen and Innovate- Centre for Creative Industries, a University of Plymouth Centre of Expertise, Exeter: Ashley House, p33.

Figure 109, Exploded CAD rendering of press forming tool

Image by © Kathryn Hinton, 2010

Figure 110, Copper pressing

Image by © Kathryn Hinton, 2010

Figure 111, Rhino 3D modelling for CNC milling

Image by © Kathryn Hinton, 2010

Figure 112, Wax milled on Datron M9 CNC milling machine

Image by © Kathryn Hinton, 2010

Figure 113, Front and back view of milled wax

Image by © Kathryn Hinton, 2010

Figure 114, RapMan Pro from A1 Technologies

A1 Technologies, Rap-man replicating rapid-prototyper [online] available from:

www.rap-man.com/index.htm

[Accessed 26 October 2009]

Figure 115, RoutOut CNC, 3 axis Z90 CNC Router

Routout CNC, CNC Router [online] available from:

www.routoutcnc.com

[Accessed 4th January 2010]

Conclusion

Figure 116, Computer render of faceted surface superimposed onto interior as example of applications for hammer interface device in interior architecture.

Accompanying Material

DVD

1_tablet and pen

Film by © Kathryn Hinton, 2008

2_tablet and nylon hammerhead

Film by © Kathryn Hinton, 2008

3_hammerhead with tilt sensor

Film by © Kathryn Hinton, 2008

4_Peening_traditional

Film by © Kathryn Hinton, 2008

5_Peening_3Rounds tablet and pen

Film by © Kathryn Hinton, 2008

6_Peening_3Rounds tablet and nylon hammerhead

Film by © Kathryn Hinton, 2008

7_peening_3rounds hammerhead with tilt sensor

Film by © Kathryn Hinton, 2008

8_Blocking_traditional

Film by © Kathryn Hinton, 2008

9_Blocking_tablet and pen

Film by © Kathryn Hinton, 2008

10_Blocking_tablet and nylon hammerhead

Film by © Kathryn Hinton, 2008

11_Blocking_hammerhead with tilt sensor

Film by © Kathryn Hinton, 2008

12_Raising_traditional

Film by © Kathryn Hinton, 2008

13_Raising_tablet and pen

Film by © Kathryn Hinton, 2008

14_Raising_tablet and nylon hammerhead

Film by © Kathryn Hinton, 2008

- 15_Raising_hammerhead with tilt sensor
Film by © Kathryn Hinton, 2008
- 16_LightPlanish_tablet and pen
Film by © Kathryn Hinton, 2008
- 17_LightPlanish_tablet and nylon hammerhead
Film by © Kathryn Hinton, 2008
- 18_LightPlanish_hammerhead with tilt sensor
Film by © Kathryn Hinton, 2008
- 19_Heavy planish_traditional
Film by © Kathryn Hinton, 2008
- 20_HeavyPlanish_tablet and pen
Film by © Kathryn Hinton, 2008
- 21_HeavyPlanish_tablet and nylon hammerhead
Film by © Kathryn Hinton, 2008
- 22_HeavyPlanish_hammerhead with tilt sensor
Film by © Kathryn Hinton, 2008
- 23_Audio_traditional raising
Audio recording by © Kathryn Hinton, 2008
- 24_Audio_Digital_tablet and nylon hammerhead
Audio recording by © Kathryn Hinton, 2008
- 25_Hand stake
Film by © Kathryn Hinton, 2009
- 26_Mushroom stake
Film by © Kathryn Hinton, 2009
- 27_Mushroom stake in holder
Film by © Kathryn Hinton, 2009
- 28_Raising stake
Film by © Kathryn Hinton, 2009
- 29_ZCorp_stake
Film by © Kathryn Hinton, 2009
- 30_Wooden stake
Film by © Kathryn Hinton, 2009

Acknowledgements

I would like to thank my parents, Hilary and Roger Hinton, for their invaluable support throughout the research.

I would also like to thank the following people for their help and assistance;

Michael Rowe and Dr David Humphrey, MPhil supervisors.

Professor Hans Stofer, Head of Department Goldsmithing, Silversmithing, Metalwork and Jewellery, Royal College of Art.

Dr Leon Williams and David Turtle for their technical assistance with electronics and software programming.

Stewart Lawrie for advice with software development.

Peter Musson, assistance with CNC milling.

Mark Trela, assistance with rapid prototyping.

Author's Declaration

1. During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification.
2. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Kathryn Hinton

March 2010

Introduction

The traditions of silversmithing and jewellery have been challenged by the use of technology since the introduction of the machine. My research aims to examine the introduction of a computer interface device that resembles a traditional tool to merge silversmithing techniques with computer aided design (CAD). This new hybrid device would offer the maker a new experience in digital making.

Tools and the manipulation of metals are the leading element of craft practice. Traditional hand making sets crafts apart from industrial machine produced objects. The animosity towards machines and new technology has divided the craft community as they battle to weigh the positives with their concerns. These traditionalists believe machine manufacture taints the ideals of craft and the beauty of hand making.

Makers of silverware and jewellery pride themselves on the hand making skills they have acquired either through college or apprenticeships. They believe that these skills are what define them as craftsmen but also separate them from mass production. David Pye, Professor of Furniture Design at The Royal College of Art from 1948-1974, summarized their response when he wrote,

If I must ascribe a meaning to the word craftsmanship, I shall say as a first approximation that it means simply workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgement, dexterity and care which the maker exercises as he works.¹

As the silversmithing trade has decreased, due to a rise in alternative materials and cheaper mass-produced goods, fewer students have taken on apprenticeship schemes preferring to go through college training where more emphasis is placed on concept ideas and design skills. With the loss of the large silversmithing workshops the knowledge transfer from master craftsmen also disappears. Silversmiths need to be willing to share their skills with the next generation of makers. The diverse methods of making by hand and the intuitive response of

¹ Pye, D. *The Nature and Art of Workmanship*, Cambridge, Cambridge University Press, 1978, p4.

experienced silversmiths cannot be learnt from books and manuals. As the trade is diminishing and as new technology becomes more prominent these invaluable trade skills need to be nurtured.

Richard Sennett in his book, *The Craftsman*, notes,

In a workshop where the master's individuality and distinctiveness dominates, tacit knowledge is also likely to dominate. Once the master dies, all the clues, moves, and insights he or she has gathered into the totality of the work cannot be reconstructed; there's no way to ask him or her to make the tacit explicit.²

Makers have an intuitive nature and learn their craft by teaching themselves through methods of trial and error. The most common method of training is taught in undergraduate colleges that provide silversmithing and jewellery courses. The courses are lead by established makers who pass on their skills and teach a basic knowledge of the wide range of techniques for the student to be able to realise their designs and if a student becomes enthusiastic about a certain technique more in depth training is given. Although technical training can be given it is primarily down to the maker to use these skills in conjunction with judgement and understanding of the tools and materials.

Machines were introduced to reduce labour intensive production and increase the quantity of goods being produced. They also opened up the possibilities of undertaking processes previously unachievable by hand wrought methods. Machines were used to replace the mundane simple tasks but skilled labour was still necessary for complex fabrication. Metal workers have seen the evolution of technology transform from mechanised press forming and spinning into rapid manufacture.

The seduction of CAD lies in its speed, the fact it never tires, and indeed in the reality that its capabilities to compute are superior to those of anyone working out a drawing by hand.³

² Sennett, R. *The Craftsman*, England, Allen Lane, 2008, p78.

³ Sennett, R. *The Craftsman*, p80.

Mass production has developed to a stage where it can produce good quality and technically demanding models from computer drawings. The use of CAD software is beneficial in the design process as it enables the designer to view their model in a 360 degree rotation. It is also programmed to calculate and render the piece at a click of a button to give a realistic representation of a physical object. The machine has a clinical approach while the hand can apply more delicate methods of working.

With the development of new technology in the craft sector, makers have debated over the notion of the computer as a new craft movement. The computer in the process of creating an object means the maker has to adapt their traditional skills to design using the computer mouse and CAD interface. The only skills required after rapid manufacture and casting reside at the bench cleaning up the casting. If this process can be defined as a craft movement then the emphasis is placed on the machine as the craftsman and the human as the designer. However if the computer is described as a tool the craftsman is still in control of every stage of production and chooses to use the computer when necessary. The use of technology in modern society seems to be irreversible, but by using CAD and manufacture as a tool alongside traditional processes, a maker has more choice and possibilities to design and produce work.

With the acceptance of new and old techniques integrating, more time and effort can be placed on integrating craft making techniques with human interface devices. Creating new innovative objects using new technology challenges traditional processes as the machines can produce intricately designed objects difficult to make using hand processes

Although there are many haptic⁴ devices that enable the designer to create more freely in three-dimensional software applications, the lack of familiar interfaces that resemble hand tools the hand making element is isolated from CAD. The novelty of CAD has subsided as makers are now including new technology within their work to push the boundaries of these machines capabilities. However many craftsmen see CAD as a means to a faster end in the production process. To exploit the full potential of new technology, makers have started incorporating it as a method of design to broaden the possibilities for original work. By researching the parameters and functions available within the software's interface new work

⁴ Haptic refers to the sense of touch. Haptic technology refers to interface devices that immerse the user through the sense of touch.

can be produced. One of the aims of the project was to discover whether the use of a haptic interface would benefit or restrict the creative flow of the craftsman.

As a silversmith I approached this research with experience of making, using hand tools and sheet metals and it is that knowledge that I have drawn on in developing a hand-held interface, in the form of a hammer, to explore new possibilities in the relationship between computer-aided design and traditional craft practice. Using the traditional technique of raising as a foundation for the development of a hammer interface device I analysed the physical and technical stages of the process from the hammer to metal and stakes. The involvement of metal is an integral part of the raising experience, but as my research dealt primarily with the action of hammering I concentrated on researching sheet metal related directly to the raising process within the context of the project.

The following chapters explore the development of different hardware components to determine the best method of data input and physical interaction between the maker and computer. To create a hammer interface device I developed and researched the possibilities proposed by different ideas. These were analysed through small projects set throughout the duration of my research to test the limitations and collect data to undertake further development. To test and design throughout my research I used ZBrush® 3.1[®], a three-dimensional modelling program, by Pixologic™.⁵ The software's interface and properties of its digital material lend themselves to the action of hammering as the material is malleable.

In the first stages of the research I explored different electronic hardware towards the creation of a hammer-based interface device using sensors to detect movement and pressure. This approach, using existing technologies and commercially available haptic devices was designed to gain an understanding of the research possibilities and to establish if a hammer was the best method for input. As the raising process also includes stakes and metal I explored their potential as possible input devices.

Once the tool was completed I explored the potential of its use in ZBrush® to design a range of objects that highlight the process of digital hammering. The final stage of my research involved realising the objects in physical material. Using technologies available within the

⁵ www.pixologic.com

Department of Goldsmithing, Silversmithing, Metalwork and Jewellery at the Royal College of Art I investigated the best method to output the digital objects.

The research was not designed and developed to replace traditional tools and methods of working, but to expand and augment them and to explore the potential offered for new technologies.

1. The craftsman's tool: the hammer

In prehistoric times tools evolved as an extension of the hand to perform tasks such as hammering and cutting.

*The hand becomes a mallet when it makes a fist at the end of the lever that is the arm but it can only strike relatively soft materials, and not for long.*⁶

Animals instinctively use natural resources around them as tools though they are unlikely to recognise the value of a particular implement or develop an attachment to it. For example, otters use stones to crack open mussel shells - a use of a specialised tooling technique, the stone used for the process is not retained but discarded. The stone is a simple implement and there are more to be found when required. In contrast, craftsmen develop attachments to their tools as they become accustomed to the properties of particular tools and ways of working with them. Also the materials needed to create them are often not readily accessible and the processes they use to make them are time consuming.

*There are no fire-using animals nor are there animals that routinely fashion new tools, improve upon old tool designs, use tools to make other tools, or pass on accumulated technical knowledge to offspring.*⁷


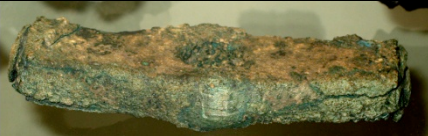
The actions of using tools might be similar between some animals and humans but humans have the ability to make tools and adapt them to suit different functions. The action of hammering is not restricted by complex movements, however the various silversmithing techniques using different hammers has to be learnt and perfected. This is integral to my research, using traditional skills with a familiar tool I explored the development of a hammer interface device that would not require extensive knowledge to use.

⁶ Comte, H. *Tools; Making Things Around the World*, Paris, Harry N. Abrams, Inc., 1997, p28.

⁷ Basalla, G. *The Evolution of Technology*, Cambridge, Cambridge University Press, 1999, p13.

*Frankly, it's too simple to think that any individual could pick up a hammer, strike it down blindly... and succeed. The movement is indeed elementary. But something that is repetitive, that requires attention, awareness, and a sense for movement, for its spare quality and weight, is what is known as dexterity.*⁸

Hammerstones were thought to be the earliest tools used to strike as their strength and weight coupled with human action made them effective. A stone was a natural choice as a tool for hammering, but the right shape and weight had to be found. Throughout the ages, as new materials were discovered craftsmen utilised the different properties to create varying weights and sizes of hammer (Figures 1-4). However the fundamental components comprising of a head and handle have hardly changed.




	
<p>Figure 1, Mesolithic bone hammer-head, Radius from a Aurochs - wild ox, dated from 9000- 4000BC, found in River Thames at Hammersmith, London.</p>	<p>Figure 2, Blacksmith's hammer, Iron Age/Roman, 100 BC-AD 100 From the River Lea at Waltham Abbey, Essex, England.</p>
	
<p>Figure 3, Raising hammer, bronze, thought to be from 12th Century BC, discovered 1897 Enkomi, Cyprus</p>	<p>Figure 4, Sledge hammer, bronze, thought to be from 12th Century BC, discovered 1897 Enkomi, Cyprus</p>

The major development for the hammer came with the inclusion of a handle. This allowed a major improvement with precision striking and in achieving maximum efficiency with each blow. It also kept the hand away from the head and the vibrations that occur at the point of impact. However establishing the best way to attach the head to handle posed a challenge.

⁸ Comte, H. *Tools; Making Things Around the World*, Paris: Harry N. Abrams, Inc., 1997, p31.

Methods evolved from binding with thong to boring a hole in the hammer head. Weight, balance and means of reducing vibration through handle to hand also had to be considered (figure 5-7).

Before the discovery of metal, depending on need and what nature supplied, clever people attached a stone to a handle by tying two wooden shafts around it or by placing the stone at the end of a handle forming a buffer. The head was attached by wicker weaving or by intertwining a length of cord, which may have been held in place by resin or gum.⁹

		
<p>Figure 5, Stone axe in wooden haft, Earlier Neolithic, about 3700-3100 BC, Ehenside Tarn, Cumbria, England.</p>	<p>Figure 6, Polished flint axe-head: Neolithic, 4000 BC - 2200 BC, found in the Thames at Long Reach, Kent.</p>	<p>Figure 7, Two metalworker's hammer-heads, 1st-2nd Century AD, Camerton, Somerset/Dowgate, London.</p>

As the hammer is a simple tool consisting of a head and a handle it was relatively easy for craftsmen to adapt its basic form to suit their specific needs. By filing and shaping the hammer face or handle a craftsman can customise the tool to attain the best possible comfort and control. This is particularly relevant to silversmithing as the hammers are made in generic forms and can be modified or shaped to a desired curvature depending on the piece. Gripping the hammer at the end of the shaft at the opposite end to the head ensures the best weight distribution and maximum energy efficiency. The handle is usually made out of seasoned hickory to absorb the impact of the hammer blow.

The introduction of metal tools overshadowed stone and wood as they could be easily shaped and if fractured could be recast. Silversmithing became more diverse as makers utilised the

⁹ Comte, H. *Tools; Making Things Around the World*, Paris, Harry N. Abrams, Inc., 1997, p283.

range of specialist tools available. Within the silversmithing trade there are a dozen different types of hammer ranging from wooden mallets to those for metal raising, blocking and planishing¹⁰ (figure 8).



Figure 8, A collection of silversmithing hammers (Finegold and Seitz 1983)

The physical action of hammering, as a striking movement, has remained unchanged since prehistoric times, but the tools with which to carry out the task have developed in diverse ways from hammer stones. The fly press was introduced to apply more force than a human arm could muster. The fly press and the hydraulic press¹¹ are advantageous for mass production as they can lift or compress under large amounts of applied force without the human operator getting tired.

The vision of technology conjures up images of new machines and grand inventions, but the term applies to processes too. The English Industrial Revolution of the eighteenth- and nineteenth-century, brought about by the introduction of steam power fuelled by coal, pushed machine production and mass manufacture forward at a time when small handcraft businesses were dominant.

Modern technology is constantly being developed to be more accurate, reliable and faster and with its ability for mass production it raises the issue of the struggle between man and machine and the idea that eventually machines will dominate the work force. Although this is true to some extent as machines and robotic arms have been introduced to undertake the

¹⁰ These hammers have different shaped faces to compress, stretch or refine the form of the metal object. Planishing is the final hammering process to create a smooth, even finish on the surface of a metal piece

¹¹ A hydraulic press applies varying amounts of force by using a lever to apply pressure to liquid in a cylinder that produces a compressive force upon the work.

monotonous tasks associated with production it is still man's ability to think that separates man and machine.

*Genuine thinking is, rather, man's most essential manner of being man.*¹²

The human hand is the link between material and the finished object as it shapes and forms the piece using the hammer through different hand processes to impose a craftsman's personal touch. However, as machines took on the task of making, craftsmen had to adapt to new roles required to maintain equipment and overseeing the process.

New technologies were rarely plucked from obscurity, but evolved out of existing ideas. Some ideas were seen as fads, but useful technology can be found in the silversmith's workshop where mechanical tooling sits alongside traditional hand tools. The hydraulic press was introduced to press thick metal in ways impossible or very difficult to achieve with a hand-held hammer, however a hydraulic press cannot give a delicate planished finish achievable through the hand process. Technology has enabled change and a freedom of choice, which can be seen through different methods of production within silversmithing. However it is still met with suspicion by traditionalists.

This has long been the case since the introduction of steam powered machines in the Industrial Revolution as they were seen as a threat towards workers jobs and thought to reduce the quality of goods produced. However over time modern machines have evolved that can create three-dimensional objects from computer drawings with intricate detail that can be difficult to produce through traditional hand processes. Rapid prototyping technology, which takes a CAD model and prints the material in layers fused together using lasers, has become available within the creative industries.

With the increasing reliance on machine manufacture it was inevitable craftsmen would fight to preserve the traditional methods of working. The Arts and Crafts movement of the late nineteenth- to early twentieth-century fought to preserve the true properties of material and handmade processes as a rejection of sterile mass-produced objects. The members saw the machine as an attempt to belittle the craftsman. Charles Robert Ashbee (1863- 1942) was a

¹² Heidegger, M. *The question concerning technology, and other essays*, London, Harper & Row, 1977, introduction xiv

silversmith who shared such views and worked to promote the ideas of Arts and Crafts as he felt machine production lost the delight of hand making. Ashbee set up a workshop for craftsmen as he believed small communities of silversmiths would design and work better.

So anxious was Ashbee to preserve the integrity of his craftsmen that he discouraged recruits who had any trade experience for fear that they may corrupt the others.¹³

In 1888 Ashbee created the Guild of Handicraft that was based on nature and an affinity with materials and the workshop practices of the Middle Ages.¹⁴ He also liked to show traces of traditional hand-worked process by leaving the planished marks of the makers' hammer on the surface of the finished piece (figure 9).



Figure 9, Charles Robert Ashbee,
Bowl silver, enamel and semi precious stones, h:11cm, 1899-1900, p19

An aim of my research has been to integrate traditional hand processes with modern technology. The use of a traditional process as a basis for the research highlights the importance and association with these techniques. While using the hammer interface device I introduced the handmade element back into the digital making with emphasis on the visual makers mark in the final physical objects. The following chapter consider commercial haptic devices that enable the user to interact with the interface through the sense of touch.





¹³ Clifford, H. (1993) *20th Century Silver*. London: Crafts Council. p29.

¹⁴ For further reading See Clifford, H. (1993) *20th Century Silver*. London: Crafts Council.

1.1 Human interface device

The idea of a digital tool came into being with the introduction of USB-HID¹⁵ data input. This has enabled modern haptic devices to communicate with operating systems allowing better human computer interaction. Mice, keyboard and game controllers work using this method of connection and this has paved the way for developers to create more complex devices that better simulate human movement.

As virtual reality (VR)¹⁶ and the complexities of computer graphics have developed so have the technological advancements in input devices. The developments in computer software have brought about the desire for better human-computer interaction and as a result human interface devices with pressure sensitivity and force feedback are the latest developments for three-dimensional software designers. These have been developed in the form of gloves and pens to maximise their ergonomic handling (figure 10-13).

	
<p>Figure 10, Wacom® Intuos digitizing tablet and pen</p>	<p>Figure 11, Force Dimension Omega.3</p>
	
<p>Figure 12, CyberGlove® Systems CyberTouch™</p>	<p>Figure 13, SensAble The PHANTOM® Omni™</p>

Many of the interface devices, an example is the SensAble PHANTOM® Omni™ have a force feedback element to enhance the sense of touch. However this is not fully resolved as

¹⁵ USB-HID refers to the USB device class that represent human interface devices such as computer mice, keyboard and game controllers.

¹⁶ Virtual reality is a computer hosted environment. The viewer can immerse themselves in real or imaginary worlds created on the computer screens or through stereoscopic equipment.

the feedback is just a succession of vibrations and does not feel realistic. The idea of trying to create a force feedback element is not something I have focused on in the research as the hammer will strike a surface that provides real world physical feedback. Many devices that have force feedback capabilities are also attached to a moveable arm and base which can restrict their movement and flow of working. The hammer interface device is designed to be a tool free from a parent base.

An example of a successful area where technology has been applied is in Medicine. Medical human interface devices, such as robotic-assisted laparoscope (RAL), are designed for use in non invasive surgery (figure 14). The Da Vinci[®] Surgical System recreates the surgeon's index finger and thumb on a miniature robotic arm. This enables the surgeon to work inside the body without the need to open the patient up resulting in less scarring and a quicker recovery. The surgeon uses the hand controls to manoeuvre a set of robotic hands or implements. This is the most beneficial way of working in precision surgery, but the equipment is expensive and not always accessible to practice on. The hand does not have direct interaction with the material as they control miniature robotic arms, this is similar to the hammer interface device as it manipulates the object on screen.

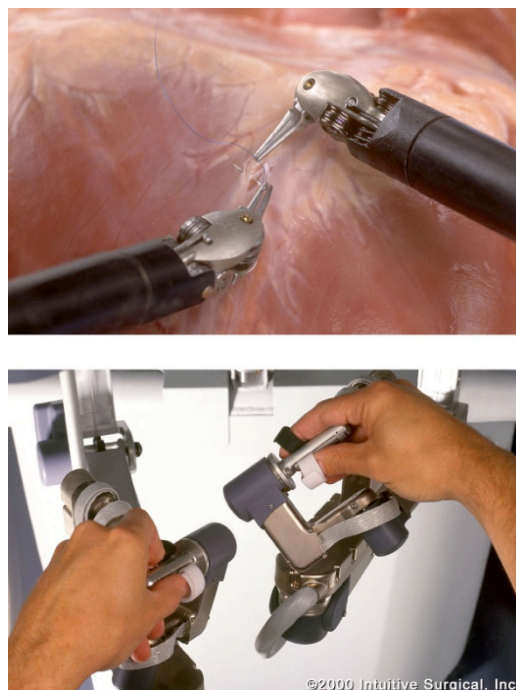


Figure 14, Intuitive Surgical, Da Vinci[®] Surgical System

Digitising tablets and haptic devices have been successful in the creative industries where productivity is enhanced by simulating tools used by designers and artists. However the actions of all the different craft tools cannot be represented by the selection of human interface devices available as specialist areas such as silversmithing have specific tools which do not require the same action as using these devices. My research has explored the possibilities of a human interface device based on the hammer which is an essential tool for silversmiths. However as the hammer is a common tool it is possible for it to be adopted into other areas of craft and design.

*It is a creative and imaginative process, but that imagination lies above all in seeing ways in which existing devices can be improved, and in extending the scope of techniques successful in one area into new areas.*¹⁷

The use of a hammer interface device could be applied to other areas in the creative industry that already apply hammer techniques such as panel beating or repair and restoration. However I believe the best application for the hammer interface device is for use by metalworkers as it could provide benefits for a maker who suffers from repetitive strain injury induced by hammering or limited by other physical disabilities as the hammer interface device does not require the same amount of force as traditional tooling.

Tacitus¹⁸ a research project developed at Edinburgh College of Art by Ann-Marie Shillito and completed in 2004 took the ideas of craft techniques as a basis for developing a haptic interface device that would be relevant to craft practitioner's methods of working. Shillito's research comprised of working with makers on a number of studies into their working practice. It incorporated existing haptic devices such as gloves and digitising pens towards understanding the limitations with input devices and used the data to develop a haptic interface device that could be used by creative artists and designers. Anarkik3D¹⁹ is a company founded in 2006 as a spin off from this research and with the experience and knowledge acquired through the project they were able to create the Falcon 3D haptic arm along with the Cloud9 software program to encourage creative artists to sketch and design initiatively (figure 15).

¹⁷ Mackenzie, D. and Wajcman, J. (eds) *The Social Shaping of Technology*, 2nd edn. Buckingham, Open University Press, 1999, p8.

¹⁸ <http://www.eca.ac.uk/tacitus/>

¹⁹ <http://www.anarkik3d.co.uk/>



Figure 15, Falcon 3D haptic arm

The benefits of using human interface devices to embrace the user in a world of interaction have been exploited by the computer games industry as they compete to create the ultimate realistic gaming experience. Computer gaming has played a large part in refining new technology and when Nintendo® brought out its Wii™²⁰ console it was ground breaking (figure 16). The Nintendo Wii™ remote uses infrared sensors to communicate information and motion sensors to register the player's physical movement. There are a lot of attachments for the Wii™ remote that resemble sporting and musical equipment that make gaming seem more realistic (figure 17). The continuing commercial need for developers to invent the next level of gaming will push the boundaries of design and research to new more elaborate devices enhancing the gamers' experience.



Figure 16, Nintendo Wii™ remote



Figure17, Nintendo Wii™ remote sporting attachments

²⁰ <http://www.nintendo.com/wii>

This idea of commercial gaming has been taken to another level by Microsoft® who alongside their Xbox® live console²¹ have created Project Natal a gaming experience in which they claim ‘You are the controller’²² as there are no physical controllers required as the console captures the movement of the player directly. Although the technologies in these applications continue to push the boundaries of human computer interaction they refer less to the controllers and more towards the movement involved.

There are many projects by engineers and developers who utilize the hardware found in the Nintendo Wii™ remote. Jonny Lee, a researcher at Microsoft®, has published projects on the internet that use the Wii remote as a motion capture device for applications such as low cost white boards, or finger motion tracking²³. Another software developer, Carl Kenner, has created GlovePIE²⁴ a free Programmable Input Emulator that can control a wide range of input devices including the Nintendo Wii™ remote with a P.C computer allowing control of the cursor (figure 18).

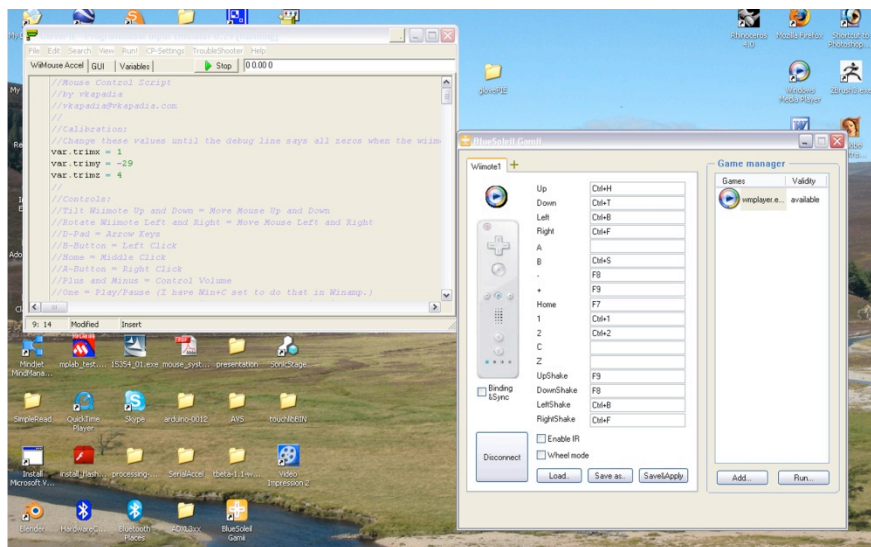


Figure 18, GlovePIE interface
Image by © Kathryn Hinton, 2009

By using GlovePIE I was able to test the hardware in the Nintendo Wii remote on my P.C which gave me an understanding of the control I would have with the hammer and also if there would be any advantages to using the Wii remote in my project (figure 19). Although

²¹ <http://www.xbox.com>

²² <http://www.xbox.com/en-US/live/projectnatal/>

²³ <http://johnnylee.net/projects/wii/>

²⁴ <http://glovepie.org/>

there was a tilt sensor to register the location and movement of the cursor there was still no Z pressure. The only advantage is its wireless capabilities: something that could be included via a Bluetooth^{®25} sensor in my own research.



Figure 19, Nintendo Wii™ remote with ZBrush®
Image by © Kathryn Hinton, 2008

The idea of a digital hammering device evolved out of work on my Master of Arts course in the Department of Goldsmithing, Silversmithing, Metalwork and Jewellery at the Royal College of Art. The premise for my project was to create a device that resembled a hammer and could be used with CAD software to design using silversmithing skills. The hammer interface device was developed using the hardware available in a graphics tablet comprising of a digitalising tablet and pen. With the technology available I was able to experiment by housing the digital pen in a nylon hammer-head that I could use like a real world hammer to create objects in ZBrush® (figure 20).



Figure 20, Trust 1200V tablet board with digital pen housed in nylon hammer head
Image by © Kathryn Hinton, 2008

²⁵ Bluetooth provides short range wireless communication between the computer and portable or fixed devices.
<http://www.bluetooth.com/English/Pages/default.aspx>

After examining the possibilities of developing software and programming device drivers I realised it was unrealistic to research and develop a digital tool and learn coding, to the extent necessary, in the time scale of an MPhil. I planned to use the advice and expertise available in the department to develop the hardware and software aspects of the project. During my MA course I purchased a MOD MMA7260Q 3-axis accelerometer board created by Olimex Ltd.²⁶ (Figure 21). This preassembled component had been programmed to emulate the movements of a mouse in three-dimensional space. I decided to use this to undertake my research as it would be a good starting point to incorporate into a hammer as it controlled the mouse cursor on screen and had a switch on the side which can be rewired to a button on the face of a hammer.



Figure 21, MOD MMA7260Q 3-axis accelerometer board

The three-dimensional mouse works through a tilting action as it has an accelerometer attached that determines the tilt angle of the mouse cursor in the X and Y axes. I designed a hammer-head in Rhinoceros®²⁷ CAD software, also known as Rhino 3D, which housed the hardware and also had a sprung hammer face to act as a pressure switch wired to the existing button on the side of the three-dimensional mouse (figure 22). At this point, as the push button had no pressure scale in the Z axis the research was focused on devising a method of capturing the pressure to create a realistic strike.

²⁶ www.olimex.com

²⁷ <http://www.rhino3d.com/>



Figure 22, Views of the hammer head model in Rhino 3D ready for rapid prototyping
Image by © Kathryn Hinton, 2008

The hammer head was rapid prototyped in black Objet²⁸ Polymer resin and attached to a wooden hammer handle with a button for rotating the object and manoeuvring on screen. However as the position of the hardware was not correctly situated in the hammer head this button became the main one for striking (figure 23).



Figure 23, Rapid prototyped black hammer head with wooden handle
Image by © Kathryn Hinton, 2008

The following chapter examine the differences between traditional hand raising and the same process undertaken with the hammer interface device. Using a graphics tablet and the existing

²⁸Objet Geometries Ltd: <http://www.objet.com/>

hammer interface device I devised a series of projects to compare and contrast them to the traditional technique of raising and analysed the results to develop a more realistic tool.

1.2 Differences project

This project was designed to highlight the differences between raising a piece of metal with traditional hammers and stakes, with a hammer interface device designed to perform the same action of hammering but in a virtual environment.

The process of raising begins by peening a blank disc of metal with an even thickness. This involves hammering on a flat metal surface using a hammer with a slightly domed face (Figure 24). This stretches the disc of metal to thicken the outer edge. Striking a course round the disc from the middle to outer edge gives the illusion that the piece is made from thicker metal than it actually is. The next stage is to block the initial form into a bowl shape using a rounded steel or wooden blocking hammer and either a sandbag or a recess in a wooden former usually a section of tree trunk. The bowl shape makes it easier to start the raising which is done by striking the metal with a steel raising hammer on a steel stake. The stakes have different shapes to enable the manipulation of metal into the desired form. Once the metal has been formed into the required shape it is given an all over planish with a steel planishing hammer on a stake that supports the contours of the piece. This finishing stage hammers out any dents or irregularities picked up in the previous raising step.



Figure 24, Peening, blocking, raising and light and heavy planishing hammers
Image by © Kathryn Hinton 2009, Royal College of Art

The hammers shown in Fig. 24 were used in this project as each has their different function to form the metal into the final piece.

The right hand holds the hammer at the base of the handle at the opposite end from the head letting the muscles in the forearm and the weight of the hammer head do the work. The left hand holds the work in place on the stake and supports it while being struck. The body is positioned in front of the stake and in line with the elbow. An integral part of my research is to recreate this positioning and movement and encapsulate it in a tool with a pressure sensitive Z axis that will represent the force of the strike.

For the differences project I used three interface devices at different stages of development. These included a Trust graphic tablet and pen²⁹, a Trust pen housed in a nylon hammer used with the tablet board³⁰ and a hammer with a three-dimensional mouse with a 3 axis accelerometer housed in the head³¹ (figure 25).

The Trust tablet and pen has pressure sensitive technology in the Z axis which is important as ZBrush® reads the manipulation of material in the Z axis. It was difficult to compare the tablet and pen with the techniques of hammering as it closer resembled the actions of writing. However the pen was still used by striking the tablet to create a hammering effect. As a result the Trust digital pen was housed in a nylon hammer to create a more realistic hammering device. The third device, the digital hammer with three-dimensional mouse, was not developed enough to be able to strike the hammer face on a surface and the strike was controlled by a button on the handle.

To gain a systematic evaluation of the hammering process each stage was treated as an individual element and documented in a logical manner through photography, film and audio recordings³². I repeated a course of traditional hammering with each of the haptic devices to determine the differences between them that would help develop a realistic digital hammer.

²⁹ See DVD, 1_tablet and pen, for film.

³⁰ See DVD, 2_tablet and nylon hammerhead, for film.

³¹ See DVD, 3_hammerhead with tilt sensor, for film.

³² See Appendix 4 for notes on each stage of the traditional and digital processes of hammering



Figure 25, Interface devices; Trust digital tablet and pen, Trust digital tablet and pen housed in nylon hammer-head, rapid prototyped hammer-head with tilt sensor.
Image by © Kathryn Hinton, 2009

The interface devices were used with ZBrush® 3.1 a three-dimensional modelling software package by Pixologic³³. To simulate the disc of copper being struck in the traditional section of the project a digital disc of material was created in ZBrush® (figure 26).

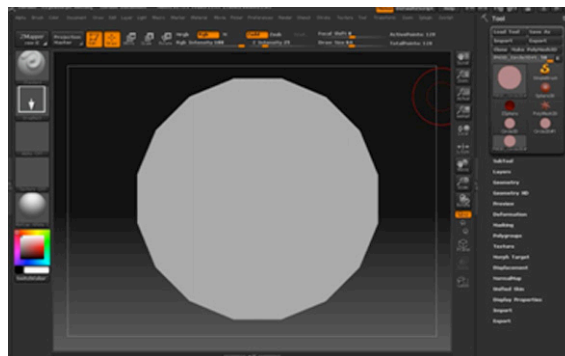


Figure 26, ZBrush® screen shot with digital disc of material
Image by © Kathryn Hinton, 2009

The benefits of using ZBrush® over other CAD software, such as Rhino 3D³⁴ meant I could manipulate the points of the digital material directly from the hammer strikes. The lines, solids and surfaces in Rhino 3D are made up of NURBS³⁵ which are manipulated by using the standard tools on the program menu and navigated by clicking and dragging the mouse, it does not react to pressure in the Z axis.

³³ ZBrush software, www.pixallogic.com

³⁴ <http://www.rhino3d.com/>

³⁵ NURBS are Non-Uniform Rational B-Splines representing curves and surfaces making up mathematical models created in CAD software.

The programmed functions on the toolbar in CAD software do not resemble traditional hand tools. These functions are good for precision and engineered forms, but the handmade element of being able to control the material is lost. On the other hand ZBrush® allows the user the ability to sculpt the material by pushing and smoothing the individual points of a three-dimensional mesh. With traditional hammering I have to think about the position of metal on the stake, the force of each hammer strike and the rotation of metal to keep the raising symmetrical.

The role of a digital hammer interface is to bridge the gap between the craftsman and the computer as increasingly more makers are using CAD to realise their designs. This is why it is significant that the digital interface replicates the touch and feel of a traditional tool. However my reservations lie in the fact that the connection between the maker and material is lost through the lack of physical contact and whether the enjoyment that comes with this can be replicated through the computer. The physical involvement with manipulating the material is something that is integral to the craftsman and is translated into their work. Through my research I have explored whether it is possible to keep the same emotional attachment to making or whether the computer creates a sterile environment.

The results of the raising process were documented after each stage through a series of images identifying the similarities and differences of traditional and digital hammering tools. To present a visual overview of the physical differences individual discs of copper and digital material were used for each stage.

Peening

The first stage is the peening course that cannot be replicated in the digital realm as the disc of material in ZBrush® has no thickness (figure 27). A thickness can be assigned to an object in ZBrush® and manipulated but it does not react as it would in the traditional peening process. The techniques of peening work by compressing the metal between the steel hammer and stake forcing the metal to stretch towards the outer edge giving a thicker appearance. This is not possible in ZBrush® as the material is positioned in three-dimensional space. In the traditional hammered peening stage the left hand works in unison with the hammer strikes. The left hand turns the disc of copper rhythmically after each hammer strike and adjusts the metal on the stake accordingly to support it. The sound the hammer makes as it strikes the metal is an indication that the method of hammering is correct against the stake.

As the only sounds produced by the digital interfaces are on the plastic board or surface they hit it eliminates sound as a method of determining whether the hammering is even. As a result sight becomes the dominating sense.

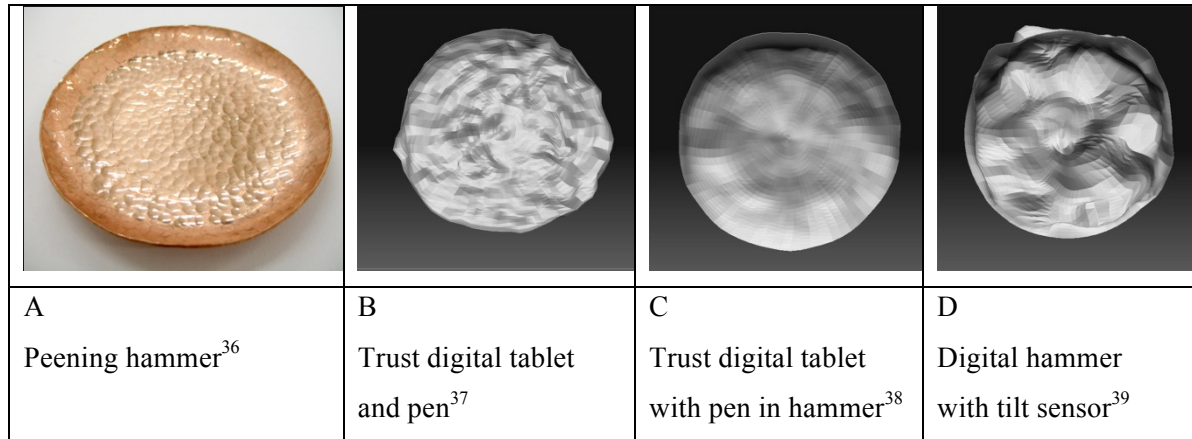


Figure 27, Peening;
Image by © Kathryn Hinton, 2009

The copper was softened through the process of annealing. This is when the metal is heated gentle with a gas torch to soften the work hardened metal. The copper disc will need to be annealed after each course of hammering. This is not applicable to the digital material as it is not limited by the properties of metal. However the geometry of the digital mesh can be altered from a basic geometric surface to a finer mesh structure creating more points to hammer (figure 28).

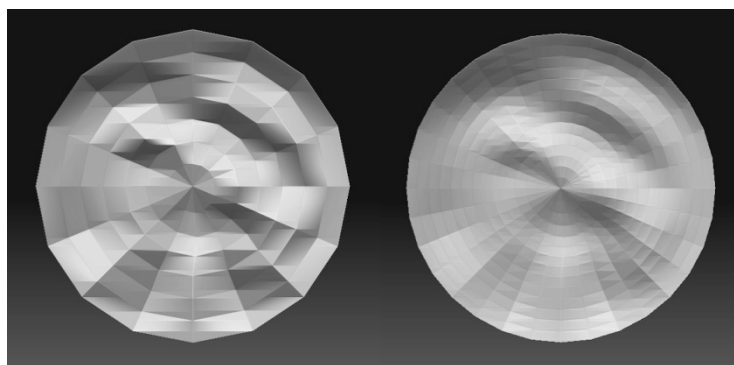


Figure 28, Differing mesh quality in ZBrush®
Image by © Kathryn Hinton, 2009

³⁶ See DVD, 4_Peening_traditional, for film.

³⁷ See DVD, 5_Peening_3Rounds tablet and pen, for film.

³⁸ See DVD, 6_Peening_3Rounds tablet and nylon hammerhead, for film.

³⁹ See DVD, 7_peening_3rounds hammerhead with tilt sensor, for film.

The course of hammering with pen device B differs from C and D as the hold and position of the pen enables a more delicate method of tapping. The pen was not lifted very far off the board after each strike and this put strain on the wrist as a rapid course of tapping was required to recreate the hammering technique. Unlike the traditional technique of hammering where the hammer strikes the same point on the stake and the left hand rotates the metal, the digitalising tablet board renders the left hand useless. The right hand has to make a circular motion around the board to reproduce a course of hammering.

Blocking

After peening the copper disc was blocked using a steel blocking hammer into a depression in a wooden tree trunk (figure 29). The biggest difference in this stage of the project was the lack of a tree trunk for the digital interface devices.



Figure 29, Blocking hammer and wooden tree trunk
Image by © Kathryn Hinton, 2010, London

Device B had to be used with the digitising board as it locates and senses the pressure of the pen. However the board had a large flat A4 surface and could not be manipulated into a hollow depression. In the following chapter I explore the idea of creating a flexible material that could be used in conjunction with a hammer interface device.

Device C is the nearest to a traditional hammer although it is used by striking the digitising tablet board. This explains why there is a noticeable difference in pressure from devices B

and D (figure 30). Also there is an apparent difference in the uniformity of device C's surface when the geometry of the digital mesh is increased.

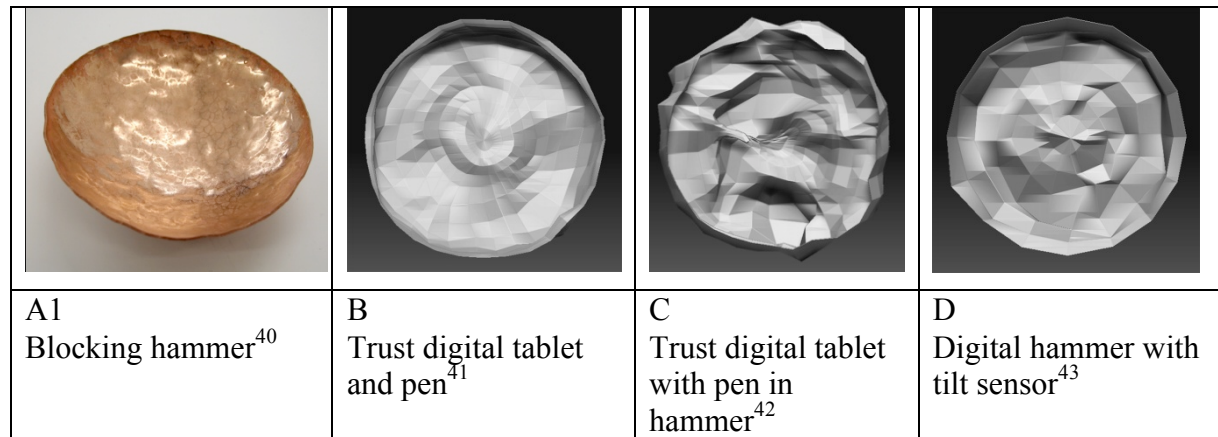


Figure 30, Blocking
Image by © Kathryn Hinton, 2009

Raising

After peening and blocking three courses of raising were undertaken and there was a noticeable difference in the results (figure 31). The main difference, similar to blocking, was the lack of a stake to hammer the digital interface device on. However unlike blocking where the digital material on screen could be hammered further into the Z axis creating a bowl shape the technique of raising requires the metal disc to be hammered over a steel stake compressing and forcing the metal inwards. This could not be achieved in a digital environment as the digital material is positioned in three-dimensional space in ZBrush® and as a result did not have a stake to support the mesh and was being raised on virtual air. This meant the mesh was being blocked again, but in the opposite direction and began to turn inside out. The irregularity of device D increased as the resolution of the mesh was increased and the material became finer which gave it more clay-like properties of malleability. As a result the hammer strikes affected localised mesh points creating ridges and grooves within the surface.

⁴⁰ See DVD, 8_Blocking_traditional, for film.

⁴¹ See DVD, 9_Blocking_tablet and pen, for film.

⁴² See DVD, 10_Blocking_tablet and nylon hammerhead, for film.

⁴³ See DVD, 11_Blocking_hammerhead with tilt sensor for film.

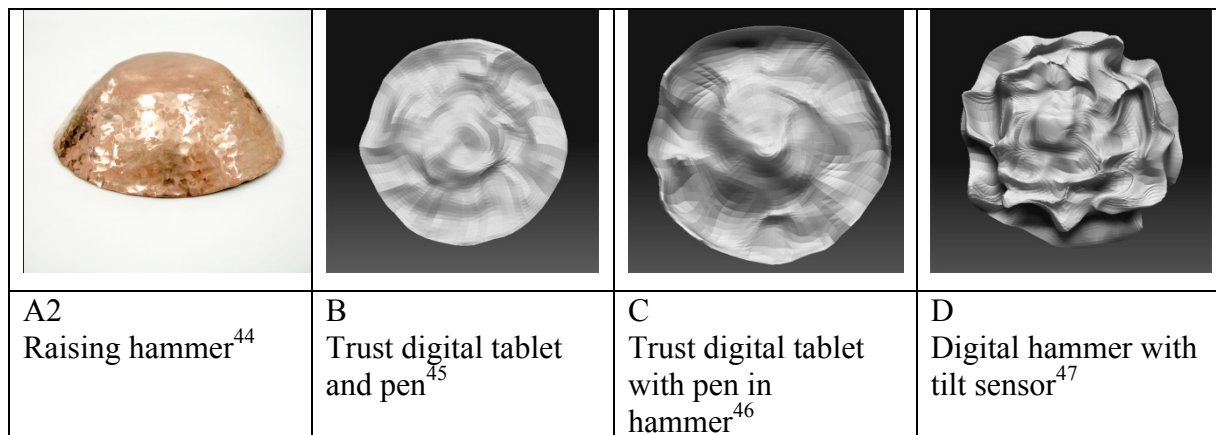


Figure 31, Raising
Image by © Kathryn Hinton, 2009

Planishing

The final stages involve planishing the surface of a hemisphere to smooth out any irregularities (figure 32). The copper bowl was planished over a mushroom shaped stake with a light-weight steel planishing hammer. The differences achieved by planishing hammers depend on the thickness of the metal and weight of the hammer. Like the raising process the technique did not transfer into the virtual environment as there was no stake to conform the mesh to. Tests were carried out in ZBrush® to increase the geometry of the digital mesh and decrease the cursor size to try and achieve an even finish. With light strikes of devices B, C and D it was hoped that a surface texture resembling planish marks would be achieved, however this did not occur. The function of the mushroom stake is to support the copper bowl as the hammer forced the metal to conform to the contours of the stake smoothing the surface. As there was no stake in virtual space to support the digital material dents and craters were hammered into the surface.

⁴⁴ See DVD, 12_Raising_traditional, for film.

⁴⁵ See DVD, 13_Raising_tablet and pen, for film.

⁴⁶ See DVD, 14_Raising_tablet and nylon hammerhead, for film.

⁴⁷ See DVD, 15_Raising_hammerhead with tilt sensor, for film.


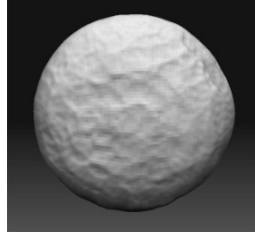
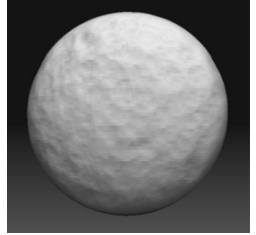
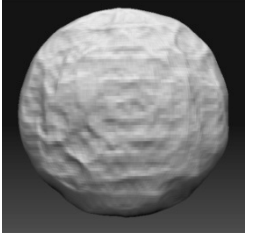
			
A3 Heavy planishing hammer ⁴⁸	B Trust digital tablet and pen ⁴⁹	C Trust digital tablet with pen in hammer ⁵⁰	D Digital hammer with tilt sensor ⁵¹

Figure 32, Heavy planishing
Image by © Kathryn Hinton, 2009

Results

The results from the research showed the main issues were concerned with the behaviour of the digital material. One advantage of the digital material is that it is not constrained by stressing and fracturing that can occur with metal. However the pixels of the digital object could be stretched to a point where it becomes difficult to manipulate them further. This could be rectified with the useful undo function in ZBrush®. Further research had to be undertaken to replicate the properties of metal in ZBrush®.

There were differences in the action of hammering as the environment and equipment were not the same. The traditional hammering of the copper discs was undertaken in a silversmithing workshop (figure 33). Vices were needed to hold the stakes and access to a forge was required to anneal the metal. In contrast the digital hammering was done in the lounge of a domestic home (figure 34). This highlights a major benefit a digital tool could have to help to promote silversmithing and jewellery enabling people to start making and learning the techniques without the commitment of renting a workshop and buying vast quantities of tools.

⁴⁸ See DVD, 19_Heavy planish_traditional, for film.

⁴⁹ See DVD, 20_HeavyPlanish_tablet and pen, for film.

⁵⁰ See DVD, 21_HeavyPlanish_tablet and nylon hammerhead, for film.

⁵¹ See DVD, 22_HeavyPlanish_hammerhead with tilt sensor, for film.



Figure 33, Traditional hammering in the silversmithing workshop at the Royal College of Art
 Image by © Kathryn Hinton, silversmithing workshop in department of Goldsmithing, Silversmithing, Metalwork and Jewellery, 2009, Royal College of Art



Figure 34, Digital hammering in the living room of a domestic home
 Image by © Kathryn Hinton, 2009

The physical effects of hammering were highlighted in the differences project as the traditional process of raising is noisy and ear protection has to be worn to save the maker from damaging their hearing. As the hammer interface device did not strike a metal surface the sounds was not high pitched and would not cause distress. The audio recordings also highlighted the difference in sound between the metal hammers with the disc of copper on the stake and the plastic digital hammer head striking the plastic of the digitising board.⁵² With the traditional method of raising craftsmen use the sound of the hammer strike to determine the correct position of the metal disc on the stake. A dull thud will indicate the disc of metal is not being struck on the stake. In the digital environment the sound of the hammer strike is less useful and the visual observations become more important. For future developments it may be possible to play a sound when the digital hammer strikes in the correct position.

Parallel differences

Once the initial research into the differences between traditional and digital hammering had been established the next stage was to hammer an object in a parallel real world and a virtual environment, combining the traditional raising processes previously documented. This would further explore the material properties and implications of the digital hammering process. Each stage was documented through photography to visually show the progression of the two

⁵² See DVD 23_Audio_traditional raising and 24_Audio_Digital_tablet and nylon hammer

objects to their final forms (figure 35- 44). An identical number of hammered courses were applied to the copper disc and digital mesh.



Figure 35, First round, Image by © Kathryn Hinton, 2009

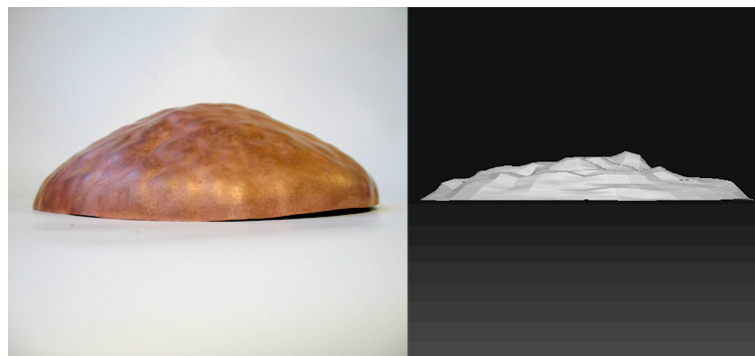


Figure 36, Second round, Image by © Kathryn Hinton, 2009

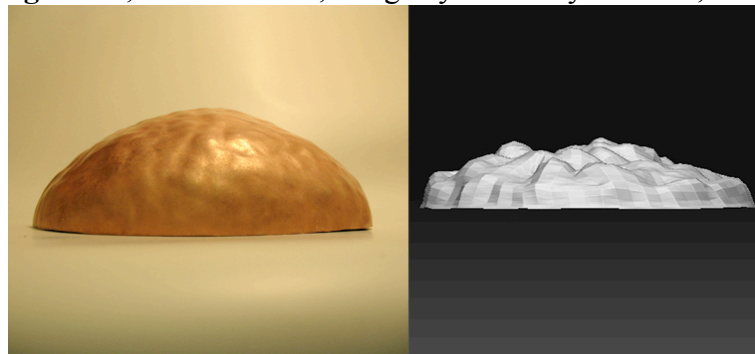


Figure 37, Third round, Image by © Kathryn Hinton, 2009

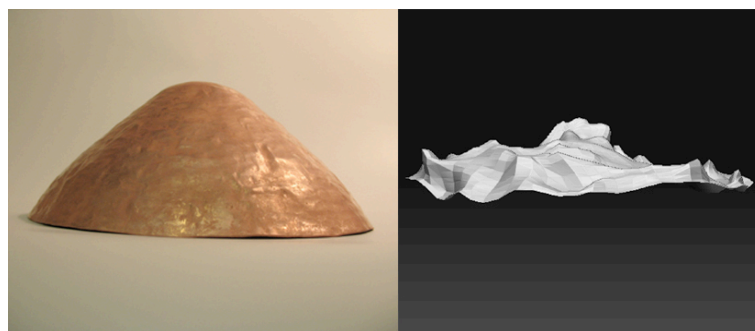


Figure 38, Fourth round, Image by © Kathryn Hinton, 2009

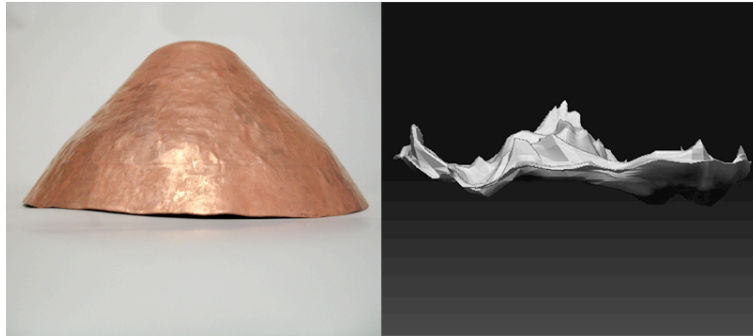


Figure 39, Fifth round, Image by © Kathryn Hinton, 2009

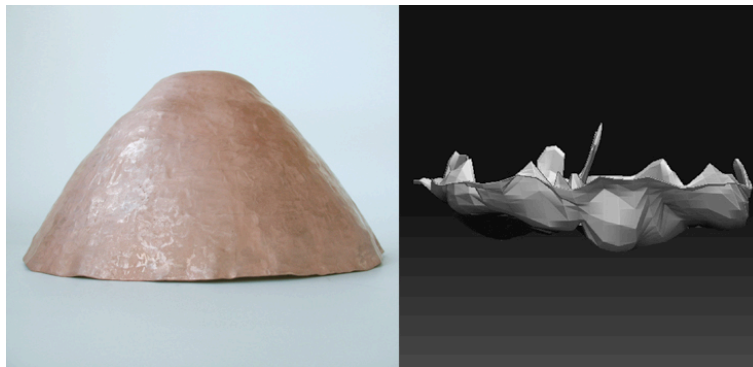


Figure 40, Sixth round, Image by © Kathryn Hinton, 2009

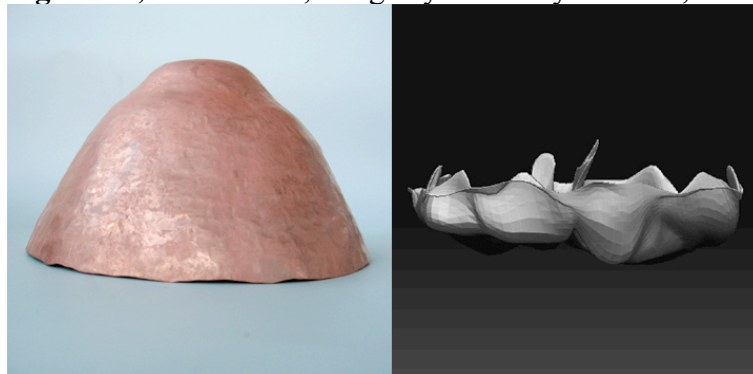


Figure 41, Seventh round, Image by © Kathryn Hinton, 2009

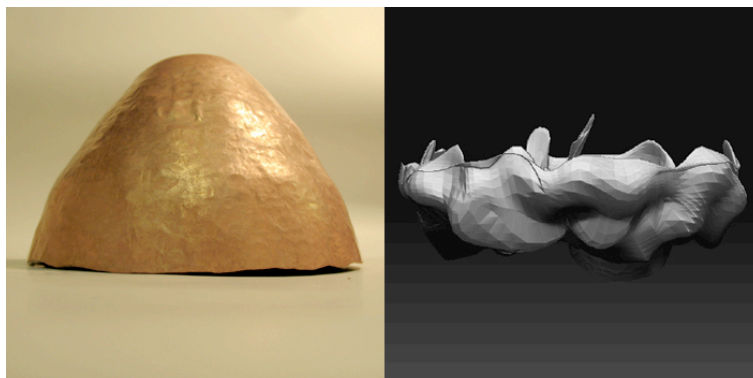


Figure 42, Eighth round, Image by © Kathryn Hinton, 2009

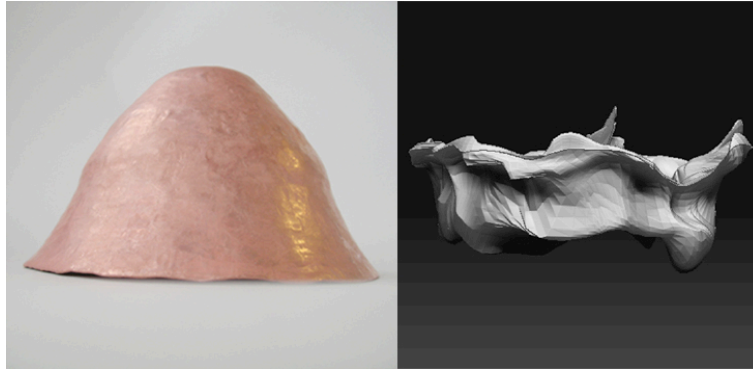


Figure 43, Ninth round, Image by © Kathryn Hinton, 2009

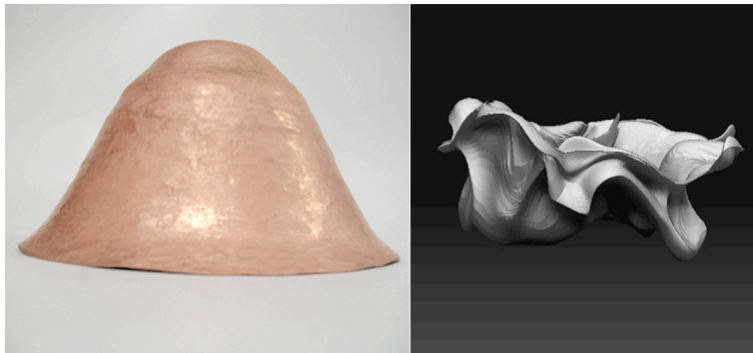



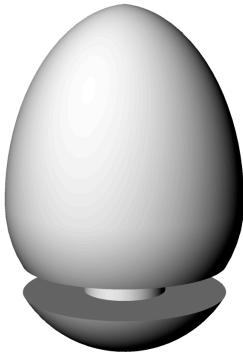
Figure 44, Tenth and final round; Image by © Kathryn Hinton, 2009

The differences highlighted in the previous project were exaggerated further as the hammering processes were combined together. The regimented and symmetrical form of the traditional raised object contrasts with the distorted form of the digital. This occurred as the digital object has no stake to conform to and defects picked up in one stage were taken through and hammered into in the following steps. Also as there was no stake to strike the digital hammer on which meant the blocking process was reversed and turned inside out as the material could not be formed over a stake. Although there were problems replicating the traditional form, I feel the warped digital object has more appeal as a new innovative object as it would be difficult to produce this through hand methods.

The idea of scale becomes an interesting issue to explore with regards to applying the silversmithing technique to create different sized objects and jewellery. The digital objects hammered in ZBrush® are not limited by the amount of material available, but only by the size of the computer screen displayed on and the set platform size of a rapid prototype machine. I plan to research this further when producing the pieces from screen into reality.

1.3 Development of hammer interface device

Although the digital hammer interface device is based on a traditional hammer, the main difference between the two is the amount of force applied: the digital hammer does not require as much as the traditional hammer. I considered whether the form had to resemble a traditional hammer as the interface tool could take on the characteristics of a prehistoric hammerstone (figure 39). The tactile element is still apparent and force can still be applied, however the sensitivity and precision applied through the wrist and handle is lost and it becomes a simple striking implement.

	
<p>Figure 45, A hammerstone used 2-1.5 million years ago by the habilines, thought to be the first human tool makers.</p>	<p>Figure 46, Rhino 3D rendering of a proposed hammerstone interface device. Image by © Kathryn Hinton, 2009</p>

The position and action of hammering with the hammer interface device, current at this point of the research, was unrealistic and awkward. By repositioning the three-dimensional mouse component within the hammerhead I was able to rectify this. With the new position I was able to strike using the hammer face and by lathing the hammer out of nylon⁵³ instead of rapid forming more weight was added (figure 47).

⁵³ See appendix 1 for technical drawing



Figure 47, Exploded view of nylon hammer with electronic components
Image by © Kathryn Hinton, 2009

However to be able to house the three-dimensional mouse the amount of nylon made the hammer head too heavy and it felt unbalanced. Further hammer-heads were rapid prototyped as the head did not need to be made out of metal as the weight is not a functioning requirement.

With the growing number of digital devices on the market it was inevitable that the question would arise about the need for a hammer device. Although an object could be shaped and smoothed using a digitising tablet and pen in ZBrush®, the action of using that combination does not resemble that of silversmithing. The previous chapter records exploitation of the differences that arise and the physical strain that can occur trying to imitate the action of traditional hammering with the digital tablet board and pen. Taking this into consideration I decided to explore the making experience by using both hands to control two computer mice in ZBrush®.

The hammer interface device, like the mouse, combines all the necessary hardware together in the hammer head. The software reads the hardware and translates the X and Y co-ordinates into the movement and also registers the mouse button clicks. However the accelerometer is always active making the controls difficult while striking. By using two mice the left hand would control the location in the X and Y axes and the second mouse would simulate the hammer strike by clicking the left mouse button (figure 48).



Figure 48, Testing the use of two computer mice in ZBrush®
Image by © Kathryn Hinton, 2009

Once the controls became familiar it was easy to use the left hand to move the cursor into position ready for the right hand to click the mouse button for striking the material. The coordination between both hands made the task of moving and striking the mesh smoother and more controlled (figure 49). However the repeated quick action of clicking the mouse button to simulate the hammer strikes would cause repetitive strain on the index finger. In ZBrush® it is possible to adjust the intensity of pressure in the Z axis. To control the points and create a more even mesh I changed the Z intensity from 25 to 18 (figure 50). However the action applied through the use of two mice was not the same as a traditional hammer and the mouse button click to simulate a strike did not have a pressure scale.

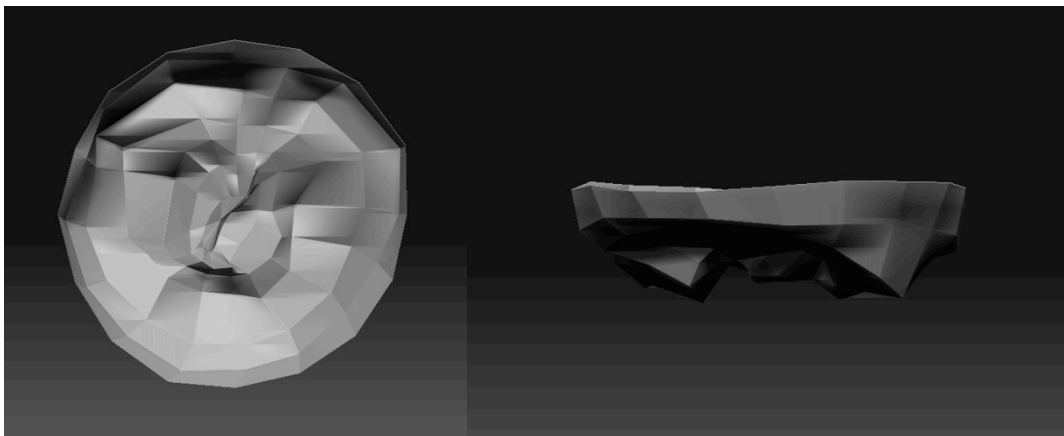


Figure 49, Front and side view of ZBrush® material manipulated by two computer mice.
Image by © Kathryn Hinton, 2009

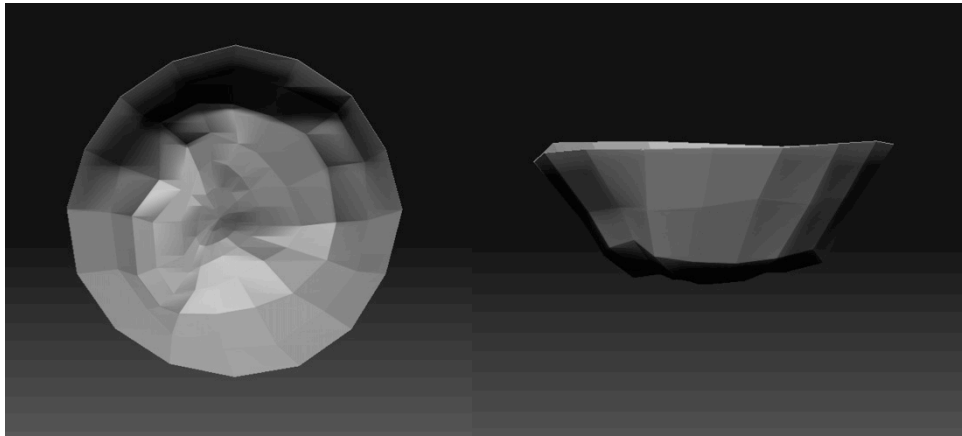


Figure 50, Front and side view of ZBrush® material manipulated by two computer mice with adjusted Z Intensity.
Image by © Kathryn Hinton, 2009

To create a realistic hammering device the electronic components within the hammer head would provide the location of the X and Y axis and register the pressure of the Z axis to represent the hammer strike. I decided to use Arduino⁵⁴, which is an open-source electronics prototyping platform to control sensors, motors, lights or other electronic input in a project. In conjunction with the Arduino software I used a Diecimila microcontroller board to control the hardware (figure 51).

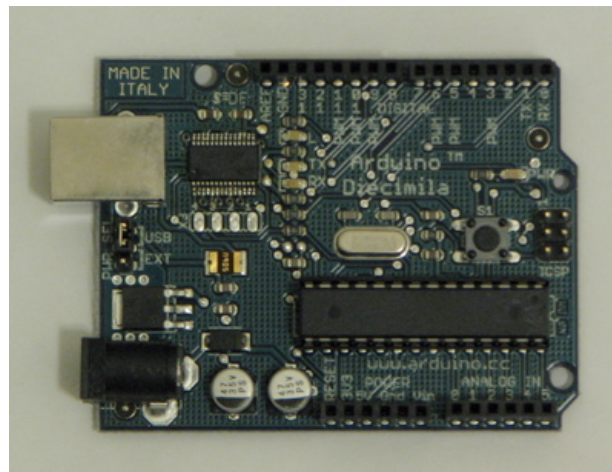


Figure 51. Arduino Diecimila microcontroller board⁵⁵

To achieve the location and pressure of the hammer strike I employed a 3 axes accelerometer, which measures the accelerated gravity of the X, Y and Z axes when tilted. Accelerometers are used in many different situations for reading vibrations and in gaming devices and mobile

⁵⁴ <http://www.arduino.cc/>

⁵⁵ <http://www.arduino.cc/en/Main/ArduinoBoardDiecimila>

phones to recognise a change in the orientation. I purchased a 3 axis accelerometer DE-ACCM3D (figure 52) from Total Robots⁵⁶.

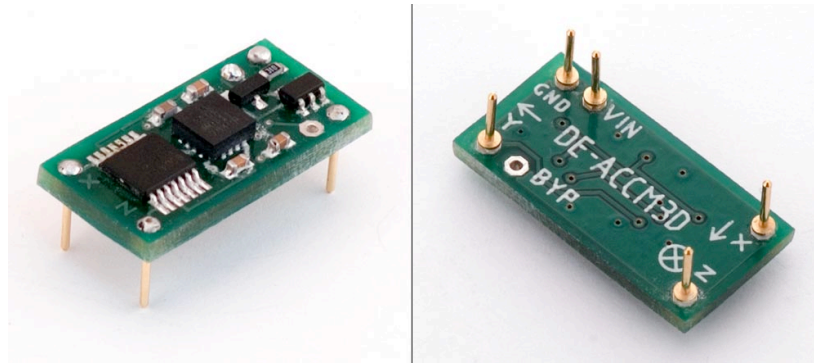


Figure 52, DE-ACCM3D 3 axis accelerometer

By attaching the accelerometer to the Decimila microcontroller board and running the Arduino source code for⁵⁷ an ADXL3xx accelerometer I was able to get a sequence of reading from each of the 3 axes. However to be able to use any of the data successfully required programming a mouse emulation driver to work with the Microsoft® Windows Operating System.

Motion capture is another method of recognising the location of the hammer through the use of Processing 1.0⁵⁸, an open source programming language that enables animations, images and interactive programs to be created and can be used with Arduino. By using a webcam and running the source code available from the Processing homepage⁵⁹ a bright area on the hammer can be picked up and followed around the computer screen. However this was not a mouse as it only operated within the processing environment and like the accelerometer needed a programmed driver to work in ZBrush®.

There were a few methods of registering movement in two-dimensions on the screen, but it was harder to try to establish a varying pressure in the Z axis. Pressure sensitive materials are available, such as Quantum Tunnelling Composite (QTC) and force sensing resistors (FSR) which work as conductors under applied force (figure 53). However there was a probability

⁵⁶ <http://www.totalrobots.com/>

⁵⁷ See source code in Appendix 2

⁵⁸ <http://processing.org/learning/libraries/brightnesstracking.html>

⁵⁹ See source code in Appendix 2

that the sensors would become unreliable after extensive use as they are attached to the hammer face and being struck directly onto a surface.



Figure 53, Force Sensing Resistor

After spending time researching and speaking to specialists in programming and software development it was apparent that it was unrealistic to develop a mouse driver in the time available to the MPhil.

To develop a pressure switch without having to write specialist software I created a selection of switches to test their efficiency and reliability when attached to the existing button on the MOD MMA7260Q 3-axis accelerometer board. I started by looking at a spring with a silver end housed inside a copper tube. Depending of the force of the strike the silver on the spring would reverberate off the sides of the surrounding copper tube to create multiple hammer strikes (figure 54). However this was not the case as there was not enough tension in the spring or space within the tube to keep the spring moving. Also the spring with silver head had the tendency to make contact if the hammer was moved sharply.

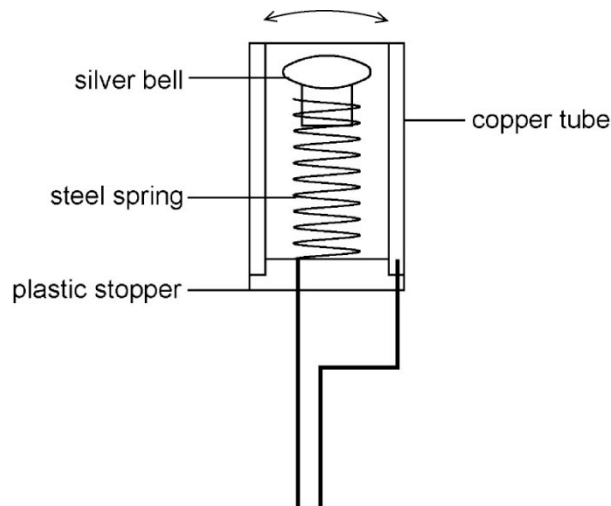


Figure 54, Spring switch
Image by © Kathryn Hinton, 2010

With the inaccuracy and unreliability of the spring switch noted I explored the idea of a sliding switch with separators (figure 55). The hammer face had a conductive copper end which passed over a central copper connector connecting with the outer switches separated by plastic spacers.

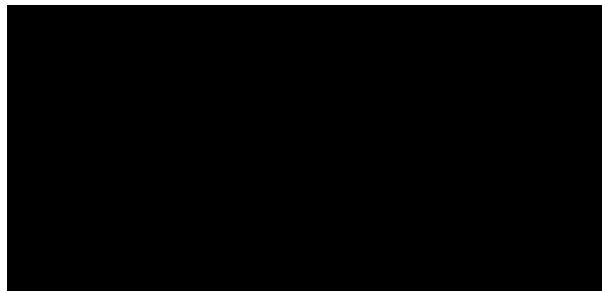


Figure 55, Switch with separators
Image by © Kathryn Hinton, 2010

It had become apparent that although the pressure is determined by the strike it was also affected by the movement of the hammer when striking. Taking this into consideration the final switch took the idea of a simplified sliding switch consisting of a tube and rod connection (figure 56). Depending on the force applied when struck the rod slid into the tubing making varying lengths of connection resulting in different ranges of pressure in ZBrush®.

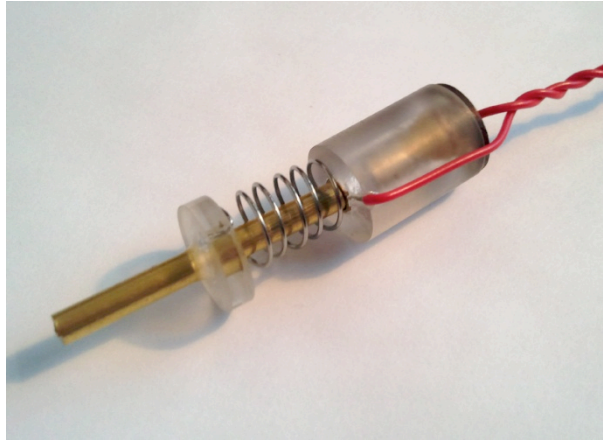


Figure 56, Slide switch
Image by © Kathryn Hinton, 2010

Once I had established the hardware to create the digital hammer I had to connect it to the computer. The MOD-MMA7260Q development board has a mini USB connection to the computer through a USB to mini USB wire. However if I had used this wire I would have to design an extra large hammer head and handle to be able to accommodate its bulkiness. To resolve the problem I used a double sided pre-sensitised copper-clad board⁶⁰ to create a printed circuit board (PCB). I redrew the wires from the USB cable into Rhino 3D and printed it onto a transparent acetate to exposure using a UV light box onto the pre-sensitised copper-clad board (figure 57). The lines connect through the board by drilling holes and riveting small sections of silver wire in place. I used the existing mini USB connector plug to with PCB but took the extra plastic and metal sheathing off so it was small enough to fit in hammer-head.

⁶⁰ <http://uk.rs-online.com/web/search/searchBrowseAction.html?method=getProduct&R=1595818#header>

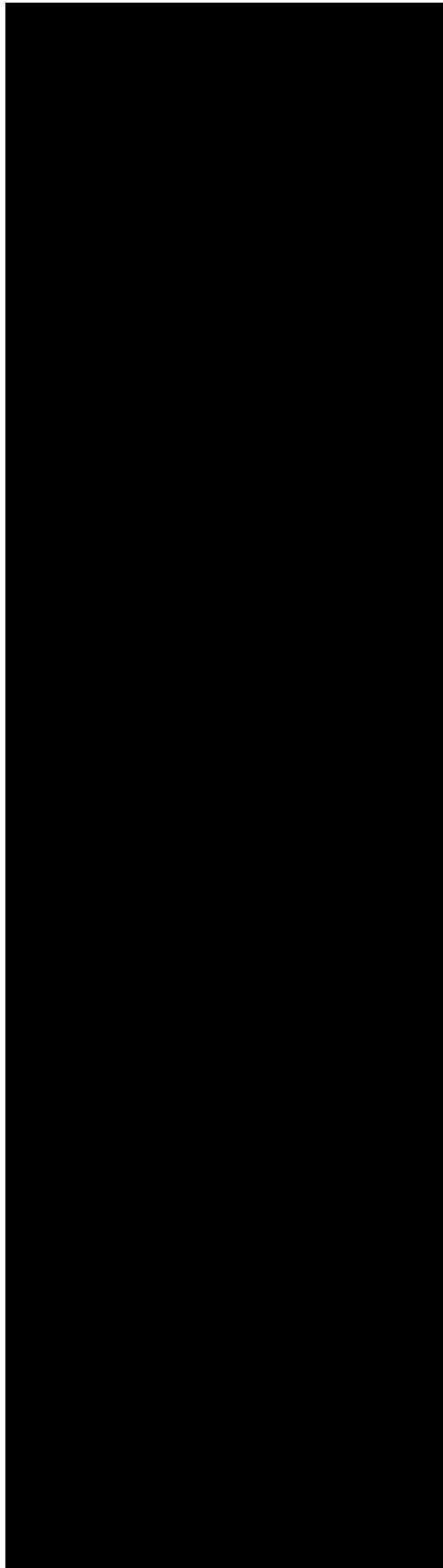


Figure 57, Layout for PCB board in hammer handle
Image by © Kathryn Hinton, 2010

To make previous hammer handles to connect the USB cable to hardware housed in hammer-head I drilled through the length of the shaft. However to create the final handle I drew the model in Rhino 3D to be CNC milled (figure 58). Handles are usually made out of hickory or ash, but I used maple as it is a hard wood with a close grain suitable for machining. Once the milled handle was finished the etched PCB board was screwed into place (figure 59).

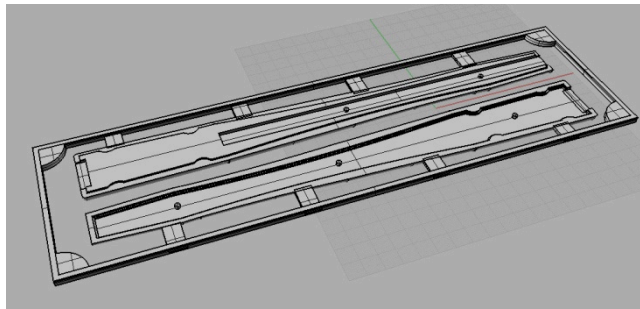


Figure 58, Rhino 3D model for CNC milling
Image by © Kathryn Hinton, 2010



Figure 59, Milled maple handle with PCB development board
Image by © Kathryn Hinton, 2010

However when the MOD MMA7260Q 3-axis accelerometer board was attached to the PCB it did not activate. The connections were checked to make sure there were no breaks in the copper circuit or the board had been wired the wrong way round with power going into the ground pin. As these were all intact I can only presume that there was a problem with the copper wires being exposed as the original USB cable had metal insulating wire running the length of wire as another method to ground the cable and device. To develop a working hammer interface device I ran the USB cable up the length of the hammer shaft and rewired

the top section to the existing mini USB connector plug so it would still fit inside the hammer-head.

To house the components in the hammer-head I used the dimensions of the MOD MMA7260Q 3-axis accelerometer board as a starting point to build the hammer-head around to create a well proportioned form. The model was drawn in Rhino 3D and built in white Stereolithography⁶¹ (SLA) resin (figures 60 and 61).

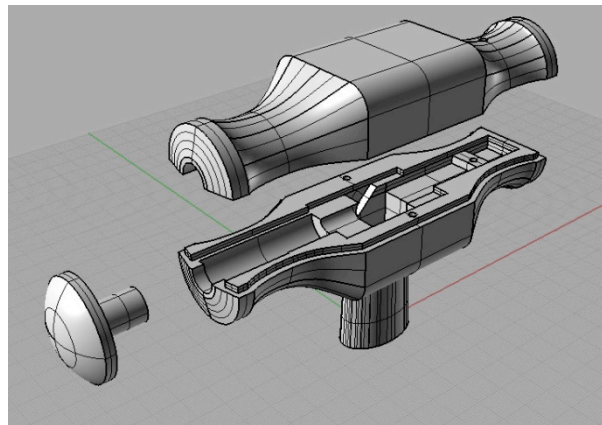


Figure 60, Rhino 3D model for rapid prototyping
Image by © Kathryn Hinton, 2010

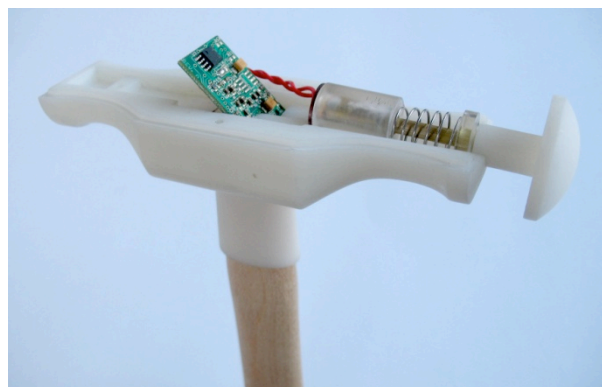


Figure 61, Hardware components in hammer head
Image by © Kathryn Hinton, 2010

The final hammer interface device was completed using the information from previous tests to differentiate between traditional and digital hammering (figure 62). The following chapters

⁶¹ Stereolithography (SLA) works using a UV laser to cure photosensitive epoxy resin. The liquid resin is built in layers turning solid when the laser touches the surface.

explore the other tooling used in the raising process and the possibility of the stake or material being used to create an input device.



Figure 62, Final hammer interface device
Image by © Kathryn Hinton, 2010

2. The craftsman's tool: the stake

The stake is an indispensable tool in the traditional raising process as it works in conjunction with the hammer to support the metal being struck. Raising and planishing stakes have different roles in the process of raising an object. The raising stake is usually T-shaped with a long shank to fit in a vice or mounted in a tree trunk and two arms of different radii to hammer onto. The disc of metal touches the stake at a certain point, supporting it as the metal is compressed down onto the surface of the stake (figure 63).



Figure 63, Raising stake
Image by © Kathryn Hinton, 2010

The metal piece also has to be planished to smooth the form where irregularities might have occurred in raising. To planish, the stake has to match the contours of the piece and, depending on the object many stakes might be used for different sections (figure 64).

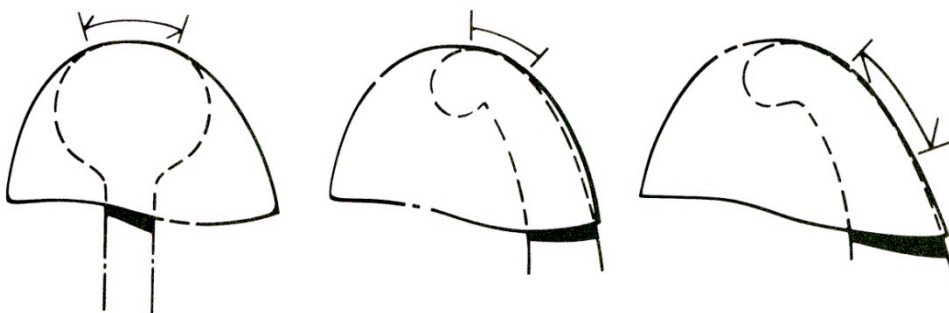


Figure 64, Different stakes for planishing contours of piece
Finegold, R. and Seitz, W. *Silversmithing*, Wisconsin: Krause Publications, 1983, p183

Cast iron is the most commonly used material. Wooden stakes can be used but they are not as hard-wearing as metal and are marked easily. They also absorb the force of the strike and do not offer the same amount of resistance needed to raise.

As the stake is an important tool in the traditional raising process I decided to undertake a project that would examine differences between a selection of stakes. By using the digital hammer interface device I was able to test whether the surface being hammered has an effect on the object produced and the possibility of a stake as an input device. Another important aspect explored was the individual and common-task roles of right and left hands' as I wanted to see whether the left hand could be included back into the process.

The basic selection of stakes represents the different surface areas to test the striking area and movement of the hammer. A mushroom stake (a domed hemisphere)⁶² and raising stake⁶³ were used along with a Z-Corp®⁶⁴ rapid prototyped object with irregular bumps on its surface to see if this would alter the hammering experience (figure 65).

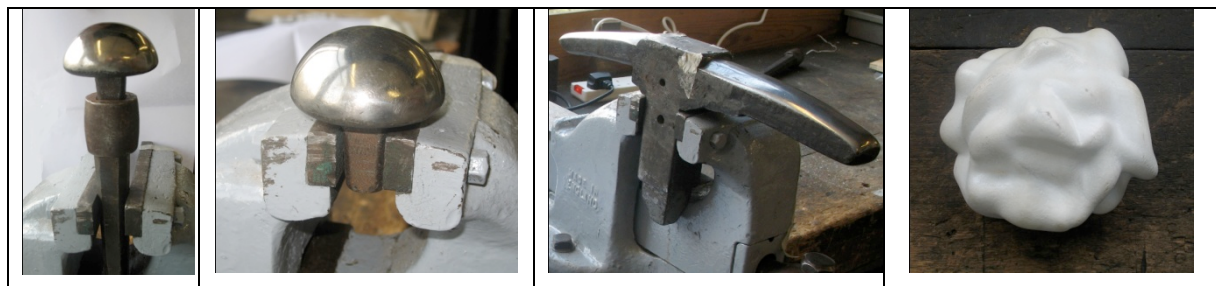


Figure 65, Mushroom stake in holder, mushroom stake directly in vice, raising stake, Z-Corp rapid prototyped stake
Image by © Kathryn Hinton, 2009

The mushroom stake was compared in the holder and held directly in the vice to see if the height was a factor. As the whole surface area of the mushroom stake was used it was more comfortable to use the stake directly in the vice. The mushroom stake in the holder was too tall and as it was forced my arm away from my side and my wrist was at an angle that did not make it easy to strike effectively (Figure 66).

⁶² See DVD, 26_Mushroom stake and 27_Mushroom stake in holder, for film

⁶³ See DVD, 28_Raising stake, for film

⁶⁴ A method of rapid prototyping from CAD models using ink jet printer heads to deposit liquid that bond powdered plaster.

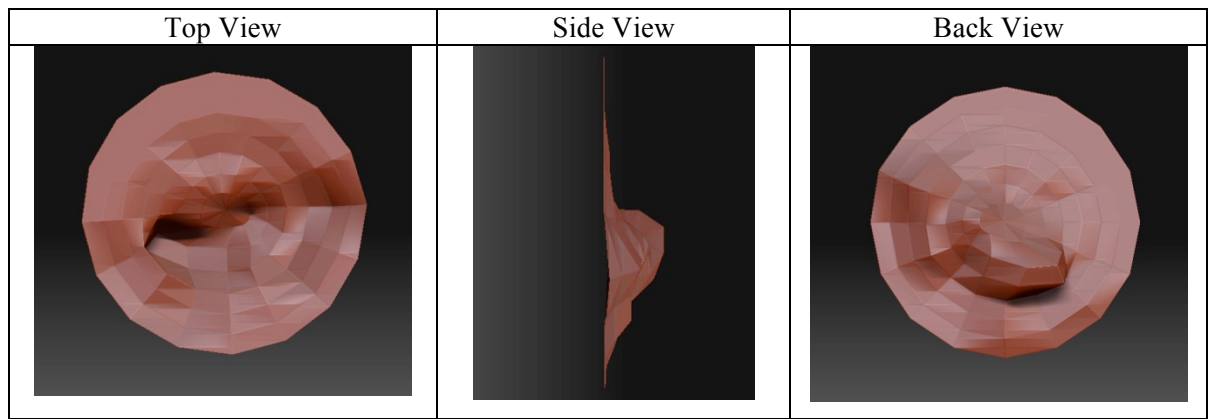
ZCorporation® <http://www.zcorp.com/en/home.aspx>

See DVD, 29_ZCorp_stake, for film

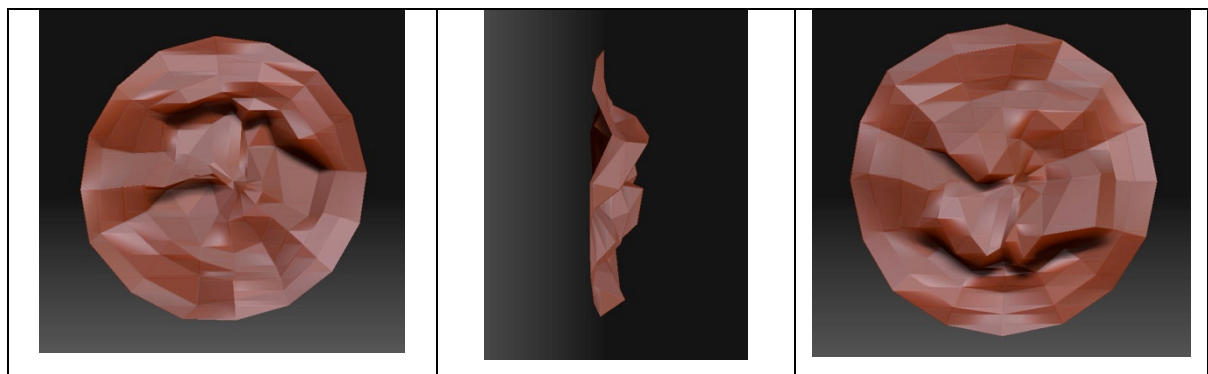


Figure 66, An example of an awkward stance for hammering
Image by © Kathryn Hinton, 2009

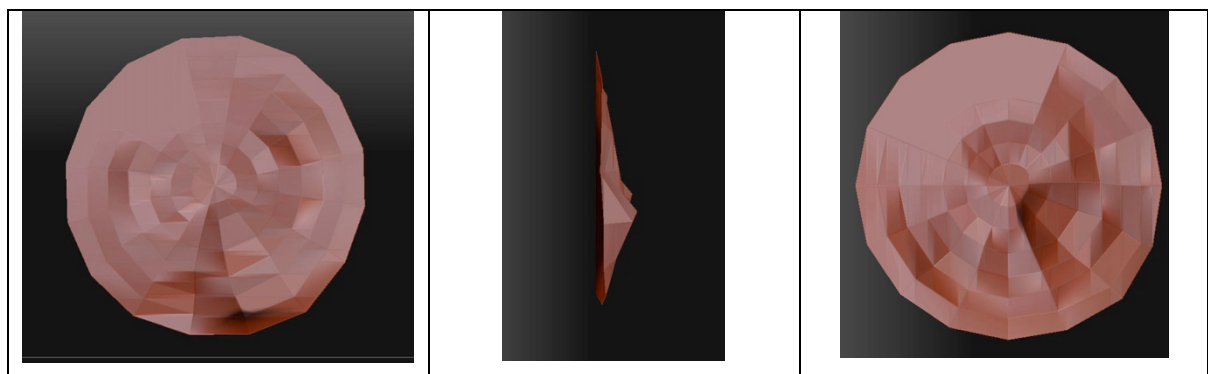
As I could not rotate the disc of digital mesh on screen, the hammer needed to have 360-degree movement over the surface of the stake to be able to locate itself in ZBrush®. The traditional raising stake was not successful, as the cursor would only position itself in the lower regions of the circular disc. This was due to the fact that the stake was slightly slanted and had a small narrow surface area to work on. After each strike the hammer needed to be repositioned. The rapid prototyped stake was included in the project as it had a 360-degree irregular surface to test whether the hammer could pick up the different surface extrusions. The random surface did not make it easy to hammer in an even, circular, motion as the various notches and depressions displaced the hammer strikes. This stake was not held in a vice like the others which meant the left hand had a role holding the stake steady on the bench. Figure 67 shows the different views of the hammered digital material on each stake.



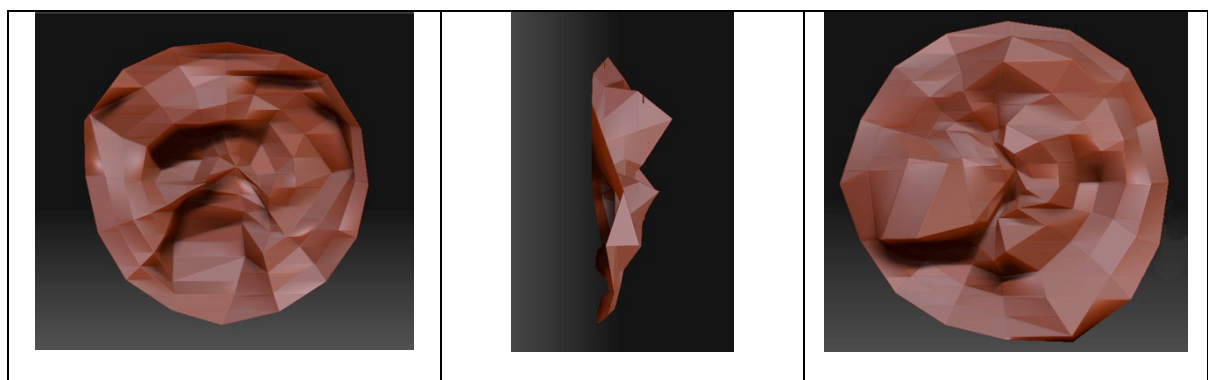
Mushroom stake in holder



Mushroom stake held directly in vice



Raising stake



Rapid prototyped irregular shaped stake

Figure 67, ZBrush® mesh hammered on different stakes
Image by © Kathryn Hinton, 2009

The different views describe the movement and action of striking with the digital hammer. The areas where there were less hammer strikes show the restrictions of that particular stake. The aim of this strand of research was to test benefits and limitations of the digital hammer interface device with a physical stake to see if it would provide support to enable consistent hammer blows resulting in an even hammered ZBrush® object. The images show that although the stakes offer resistance, it is the force with which the hammer strikes that determines the pressure on the material.

An issue highlighted by this strand was the lack of involvement of the left hand. The hand holding the hammer (in this case the right hand) has to direct the cursor to the desired striking location and also control the force applied. The slow movement of the cursor on screen combined with fast striking means individual points are being deformed as the hammer blows fail to move onto surrounding points quickly enough. With further hammering practice, movement and striking co-ordination this can be resolved. The left hand held the stake steady on the bench saving it from the stress and strain that it was subjected to when clutching the edge of metal disc against the stake when raising using traditional methods (figure 68).



Figure 68, Left and right hand working together
Image by © Kathryn Hinton, 2009

The mushroom stake used in this project had a small surface area with a steep profile. Using the information collected I created a wooden stake to test whether a shallower form would provide better movement for the hammer. This stake has a clamp so it can be attached to a table or bench (figure 69). The shallow curve of the stake enabled a more controlled

movement of the hammer interface device. However as the whole area of the stake was used it was awkward to manoeuvre the hammer to certain positions for striking.⁶⁵



Figure 69, Rhino 3D render of wooden stake
Image by © Kathryn Hinton, 2009

One of the main problems found when working the digital mesh in ZBrush® was the lack of a supporting stake in the virtual environment. An area for further development could be to investigate the possibility of introducing a fixed surface on which the virtual material can be hammered onto and shaped by varying degrees of pressure. A selection of varying shaped stakes could also be defined. Implementing would however require collaboration with software designers.

The following chapter explores the different proposed methods of development for a digital interface stake with a pressure sensitive element that reads the point of impact from the hammer.

⁶⁵ See DVD, 26_Wooden stake, for film

2.1 Hand stake

The traditional act of raising requires the craftsman to use both hands. Through the various experiments with different digital interfaces it became apparent that successful use of the digital hammer interface device could be achieved using one hand. In trying to engage both hands in the guidance and construction of an object I am continuing to explore the development of an approach that can immerse the maker more fully in the process.

To test the involvement of the left hand I used a fabric ball filled with hard beans to represent the stake while the right hand dealt the hammer strikes to the ball (figure 70). It was effective in creating a resistance and immersing the left hand back into the process, but the hammer strikes were still uneven (figure 71).

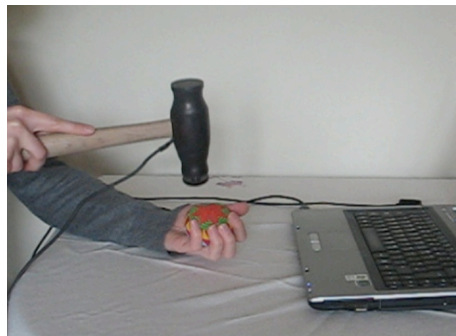


Figure 70, Ball held in left hand and struck by hammer held in right hand
Image by © Kathryn Hinton, 2009

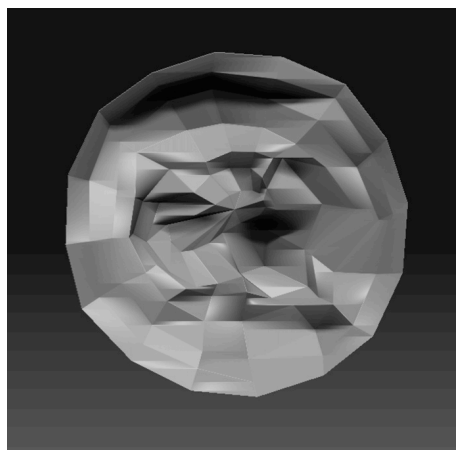


Figure 71, Uneven hammered disc
Image by © Kathryn Hinton, 2009

This experiment showed that although the left hand has been brought back into the process, the physical effects on the hand could cause problems. The left hand was kept tense to cushion the shock of the hammer strike and this caused strain after awhile. As the ball was spherical I instinctively wanted to move it around in my hand. I could utilize this feature and enhance the experience by making it possible to move the digital mesh on screen mirroring the movement of the ball. Further research is required in this area at a later date as two cursors would be required on screen at the same time, one would control the hammer;- one would control the hammer movement, the other the mesh.

As a result of the stake differences project it has become apparent that although the traditional stake is ineffective with the hammer interface device the application of a hand stake is integral in immersing the maker in the hammering experience. With this in mind the next stage of the research was to determine what form a hand stake could take and which materials would be most effective in reducing stress and vibration through the hand and arm.

When developing the hand stake I referred back to the difference test between the stakes as it presented the data to create a comfortable and supportive tool. The process of digital hammering has more similarities to the blocking process than raising. As there is no stake to conform to in ZBrush® the hammer strikes beat the digital mesh into the Z axis it does not matter for technical reasons if the hand stake is concave or convex comfort becomes more important (figure 72).

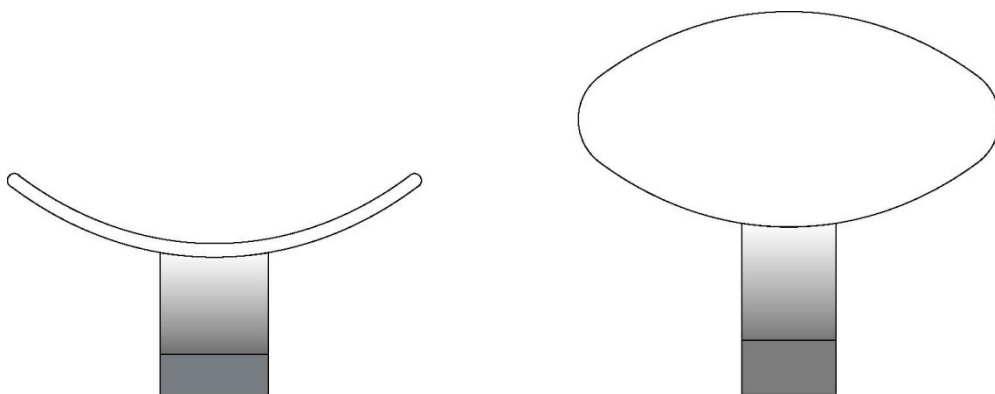


Figure 72, Proposed design for a hand stake
Image by © Kathryn Hinton, 2009

Previous experiments using a copper disc created a familiarity with traditional hammering through resistance and sound. However it was uncomfortable to hold as the vibration of the hammer strike could be felt. For this reason I decided to replicate the previous test to develop a bean bag by using materials such as polystyrene balls and lentils, which would absorb the hammer strike and also mould to the impression of the hand. The material had to give enough support to be able to create some resistance and enable the hammer strike to register.

To improve the comfort and support I made the ball larger, changing the contents and introduced a strap so it would not be necessary to hold the form tightly, eliminating the tension induced by gripping (figure 73).

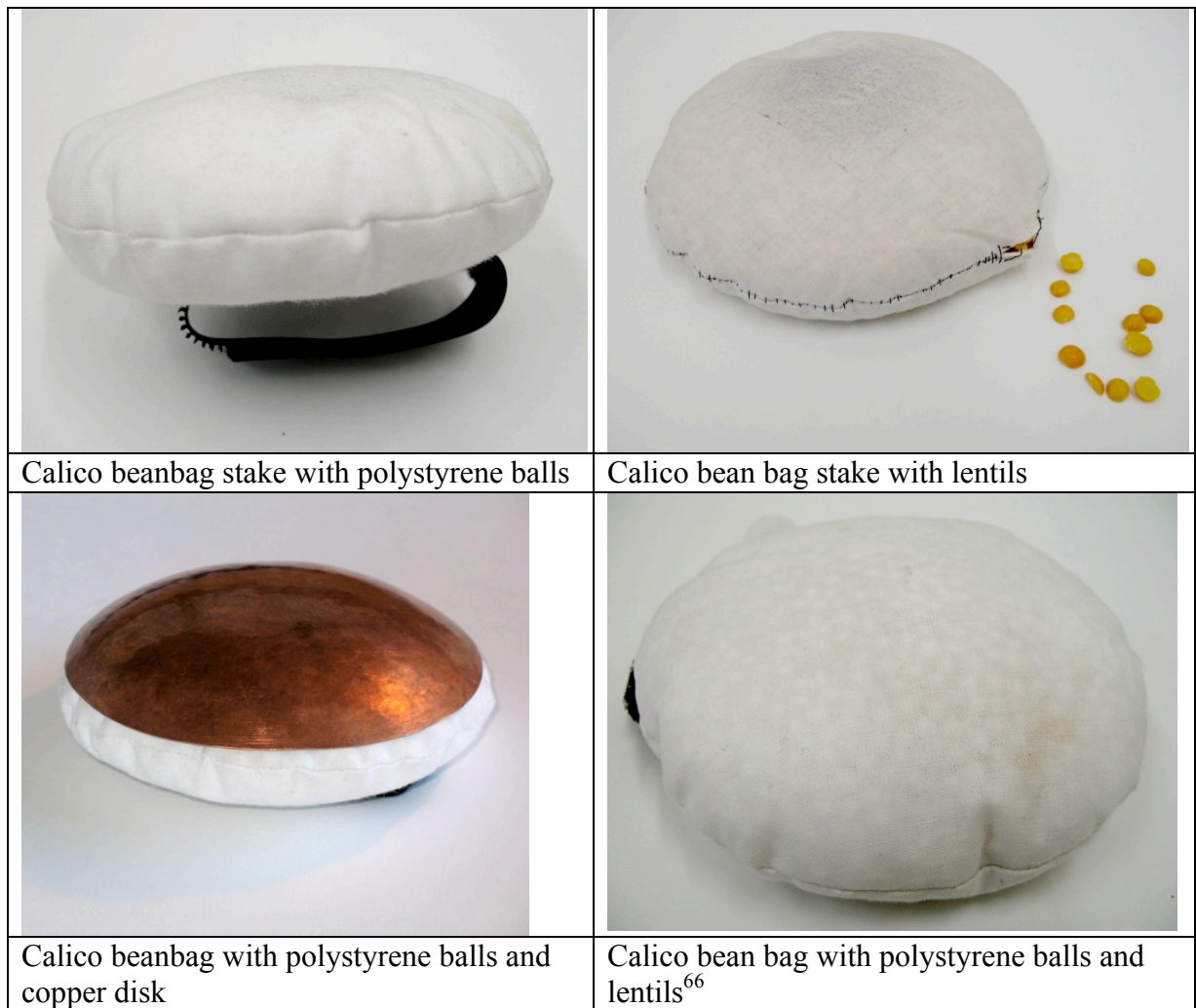


Figure 73, Hand stakes
Image by © Kathryn Hinton, 2009

⁶⁶ See DVD, 25_Hand stake, for film

The polystyrene balls were soft and comfortable in the hand, but when struck with the hammer they were too light and did not offer enough resistance under the force of the hammer blows. The lentils had the opposite effect as they were heavy and it was uncomfortable to hold up the weight of the stake after a while. The inevitable solution was to combine the polystyrene balls and lentils and although the weight of the lentils fell to the bottom of the hand stake, this did not appear to be a problem and achieved the desired affect as the resistance to the hammer strike was ideal. I also tried placing the copper disk onto the hand stake full of polystyrene balls and while the sound resembled the striking of metal, it was not essential to the process as I did not need to know what sound the metal made as I was not trying to find its correct position for hammering on a traditional stake.

Another approach would be to incorporate a digitising tablet into a stake and have the vertical and horizontal lines over the surface capture the location of the hammer and find the position on screen (figure 74). The main problem would be the size and curvature of the wires and the practicalities of keeping the wires at an equal distance apart. A possible method would be to cut the mesh out of copper vinyl or screen print the lines onto a flexible mesh or alternatively cut groves into the solid stake form and inlay the copper lines into the surface. However the drawback to this approach is that the size of the mesh limits the hammering area on screen as the overlaying horizontal and vertical lines corresponds to a certain point on the screen. Additionally ZBrush® does not react to the three-dimensional curvature of the mesh and would not pick up the shape of the contours on the stake form (figure 75).

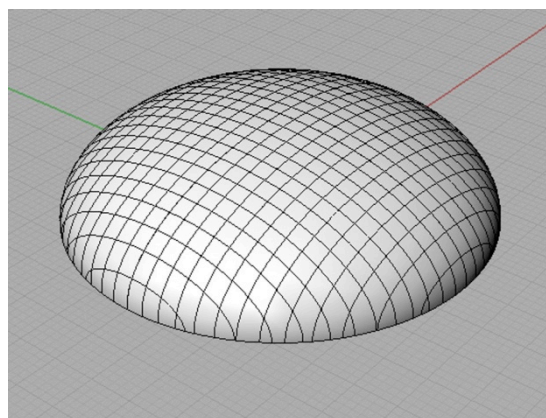


Figure 74, Stake with horizontal and vertical copper wires
Image by © Kathryn Hinton, 2010

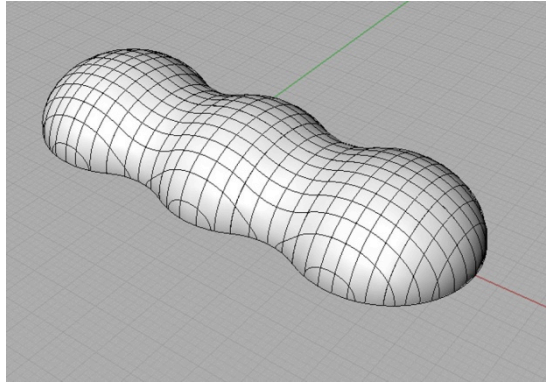


Figure 75, Example of shaped stake
Image by © Kathryn Hinton, 2010

Hammering onto a flat surface or a traditional stake held directly in a vice restricts the control and movement of the hammer interface device as the hammer has to travel over the whole 360-degree surface of the stake to locate imitate the digital disc on the computer screen. A hand held stake would be beneficial to the process as it moves in conjunction with the hammer interface device making the movement of the cursor smoother on the computer screen.

3. Metal

The essential part in the raising process is the forming of the metal between the hammer and the stake. This chapter will explore the properties of metal, its use and the possibility of a digital material acting as an input device for the location and pressure of the digital hammer strike.

Historically, metal objects developed as the malleable properties of their raw materials were exploited through hand working processes. Silver and gold became valuable resources as currency in trade, but were also seen as symbols of wealth and status. used to create hand crafted jewellery, objects and coins (figure 76).



Figure 76, The Rillaton and Ringlemere gold cups, Early Bronze Age 1800- 1600 BC, Rillaton, Cornwall and Ringlemere Farm, Kent. the British Museum.

Metals are also valued for their practical uses as they have attributes that can be drawn on for a wide range of both every-day and specialised applications. Iron is produced in vast quantities for building and engineering. Other base metals including copper and lead are highly conductive and cheap to use in electronic circuits. Precious metals, on the other hand, are more expensive and employed for more specialised applications such as dentistry where pliability and resistance to wear are required.

Some metals are prized for their malleable properties which define the ease with which they can be bent and beaten without breaking. They are also ductile and able to be melted and drawn. Metal behave in these ways as a result of the strong electron bonds between its atoms

and their arrangement which is typically close-packed as face centre cubic structures (figure 77)

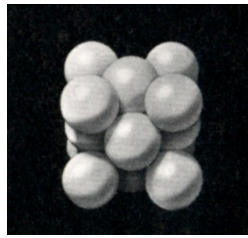


Figure 77, Face-centred cubic structure

When the metal is worked the atomic framework is distorted but the atoms compensate for this by moving along slip-planes in the crystal structure. As distortion continues, stresses and dislocations build up and the material may become harder and more brittle. The process of annealing can then be used to apply heat to the crystal lattice in order to relax the structure. The material is recrystallised as strain-free grains and the metal returns to a more malleable nature.

Alloys are created, when two or more metals are mixed, to enhance physical properties of the individual materials. For example, brass and bronze are alloys of copper to which varying amounts of zinc and tin have been added. Copper is added to fine silver to make sterling silver, a stronger metal.

The digital material is not as complex as traditional metals as it is controlled by variable amounts of mesh points. All points have the same basic properties. However, it is possible to change the mesh density and the amount of pressure the mesh responds to in the Z axis. This feature is represented in ZBrush® by a slider that ranges from 0 to 100. This software property led me on to explore the possibility of creating digital materials that could closely simulate specific metals. I hammered silver, copper and aluminium sheet and repeated the process using the hammer interface device in ZBrush® to determine the set range of intensities.

The use of traditional hand techniques to manipulate metal is still evident today as makers utilise the malleable properties of precious metals. Hiroshi Suzuki is one such silversmith that uses silver to realise his designs

*I do not really think of myself as a silversmith, but silver is my medium and it is what allows me to express my creativity. I am attracted to it because of its fluidity.*⁶⁷

The qualities of silver lend themselves to Suzuki's hammering style. He raises large discs of silver and works into the form to create objects with natural fluid lines (figure 78). The ductility of silver enables the metal to conform under each hammer strike.



Figure 78, Hiroshi Suzuki, Miyabi- Fire I, hammer-raised Fine silver, H 31cm x Ø 25.5cm
2006

With digital input it could be argued that amateurs with no previous silversmithing experience would not be able to hammer the digital mesh in ZBrush® without prior knowledge of metalworking. However as the digital material does not act like metal, once the amateur gets a feel of the hammer interface device and the way the digital mesh reacts they would be able to start working more effectively. The hammer is a recognisable tool and most people have a general understanding of the action of hammering. As the process is different

⁶⁷ Schroder, T. *Hiroshi Suzuki*, London: Scala Publishers Ltd., 2010, p6.

from traditional silversmithing they do not need to know about holding the metal in the correct position or which size and weight of hammer is correct to use. Also as the maker does not physically manipulate the metal they have to rely on other senses. This is a new method of working even for experienced silversmiths.

Like traditional raising I am able to start digital hammering with a flat disc of material. The disc of digital material available in ZBrush® offers the maker the opportunity to experience hammering in a digital world free of metal's physical properties and the issues that can occur. The disc I am working on in ZBrush® is made up of points radiating from the centre, this makes hammering uneven as the mesh is more condensed towards the centre (figure 79).

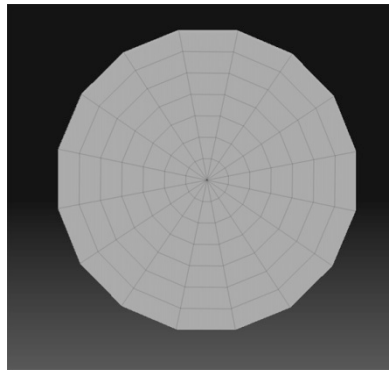


Figure 79, ZBrush® default mesh disc
Image by © Kathryn Hinton, 2009

The points of the digital mesh in ZBrush® expand as they are hammered reacting in the opposite way to the compression of metal when hammered (figure 80).

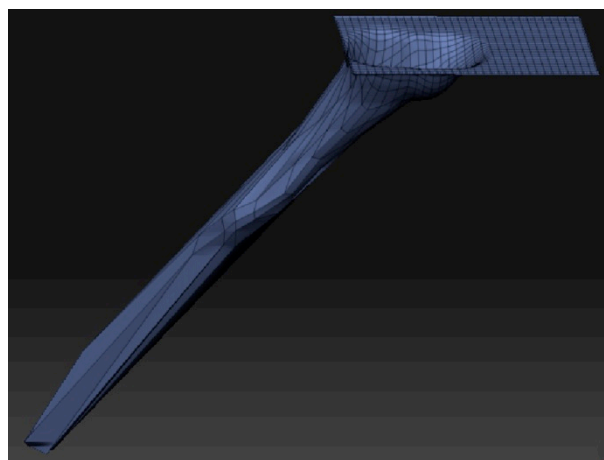


Figure 80, Stretched points of ZBrush® mesh
Image by © Kathryn Hinton, 2009

The mesh in ZBrush® can be sub-divided to create a finer mesh with more points, however if the mesh is divided too much it can result in a different material quality (figure 81). The sub-divided mesh has more points and fewer facets which create a material that resembles clay.

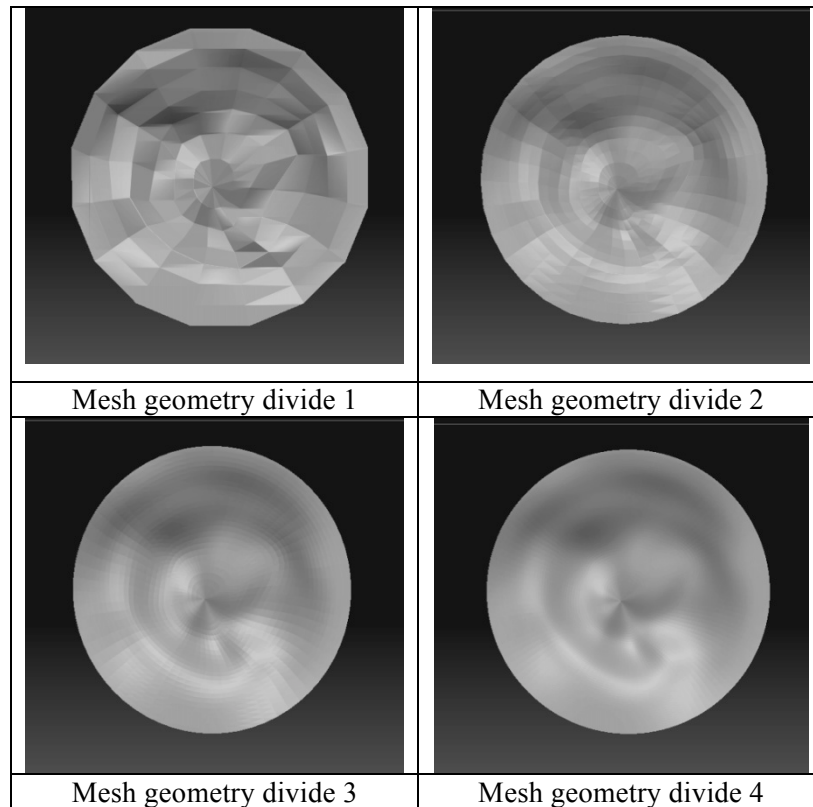


Figure 81, ZBrush® polygon mesh sub- divided
Image by © Kathryn Hinton, 2009

To solve the problem of a radiating mesh I imported a flat mesh from Blender⁶⁸, a free open source three-dimensional modelling programme. The software has a feature that enables the mesh to be sculpted similar to that of ZBrush® and when the mesh was imported into ZBrush® it reacted in the same way. This mesh comprises of regular grid points across the surface making it easier to control the mesh and keep it even (figure 82).

⁶⁸ <http://www.blender.org/>

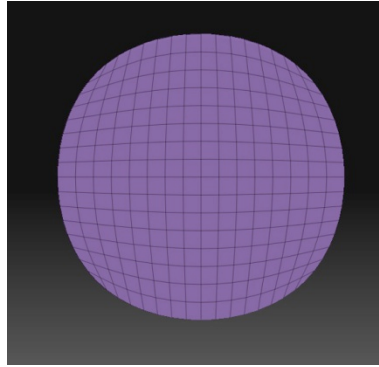
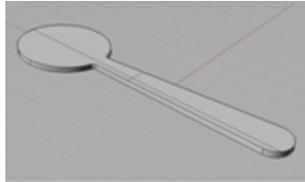


Figure 82, Blender mesh imported into ZBrush®
Image by © Kathryn Hinton, 2009

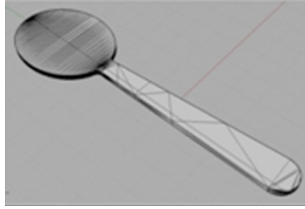
When working in ZBrush® the mesh has no measured thickness. This is assigned depending on the thickness required in the final output of the formed object. The lack of thickness enables me to push and shape the form without the worry of stretching and thinning metal as I know the physical object will have an even wall thickness. However it is possible to assign a thickness and hammer the mesh but it works like a double skin and if it is hammered too much it can go through the other mesh.

Through this project so far I have used a flat disc of digital material relating to the raising process. To further develop the process and explore the potential I looked into the idea of forging a spoon. By creating a polysurface⁶⁹ spoon blank in Rhino 3D I was able to draw the basic shape and convert it into a mesh form to import into ZBrush®, however the difference in mesh structure between Rhino 3D and ZBrush® meant I did not have enough points to manipulate (Figure). I then created a spoon mesh in ZBrush® and was able to dome out the spoon bowl, but as there was no stake to support the forging the handle distorted (figure 83).

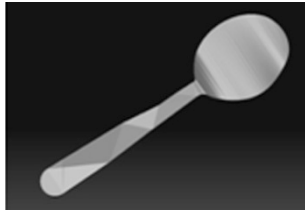
⁶⁹ A polysurface is made up of two or more surfaces joined together. A fully enclosed polysurface is also known as a solid



Spoon blank polysurface



Mesh form to import into ZBrush®



Lack of points to manipulate

Figure 83, Creating a digital spoon blank
Image by © Kathryn Hinton, 2009

The following chapter will explore the idea of a flexible material interface that can be held by the left hand over an existing stake to detect the location and pressure of the hammer.

3.2 Digital material development

In a previous project on my MA at the Royal College of Art I investigated the idea of a flexible material that could drape over stakes and be hammered. I looked at all different aspects of the raising process and revisiting this area to explore the possibility of further development. Previously I used a Trust tablet 1200- V2 digitising board as the basis for my project. Inside this tablet was a flexible polypropylene sheet with conductive horizontal and vertical lines that locate the position of the corresponding pressure of the pen (figure 84).



Figure 84, Exposed Trust tablet 1200- V2 digitising board
Image by © Kathryn Hinton, 2008

To be able to create different directions of flexibility within the board I choose to use fabric as it could drape over an object. I was able to create a template for the circuit by using a linen fabric that could be fed through an inkjet printer⁷⁰. The board design was printed onto this and a thin copper electrical wire was sewn through the fabric to create the board (figure 85).

⁷⁰ http://www.craftycomputerpaper.co.uk/products-Linen-inkjet-fabric-non-washable_03745.htm



Figure 85, Copper wire was sewn through fabric
Image by © Kathryn Hinton, 2008

The combination of material and sewn copper wire made the board quite stiff and although it was still flexible it needed to be held over the object (figure 86). The way the wire was sewn through the material made the board raised and the lines wavy, which made it difficult to capture the exact position of the digitising pen housed in a nylon hammer head. Although the board worked the main problem was controlling the cursor as it unpredictably jumped around on the computer screen. This occurred as the lines were not straight and the board was not reproduced to the exact size of the original digitalising board resulting in the co-ordinates of the X and Y axes being out of sync.

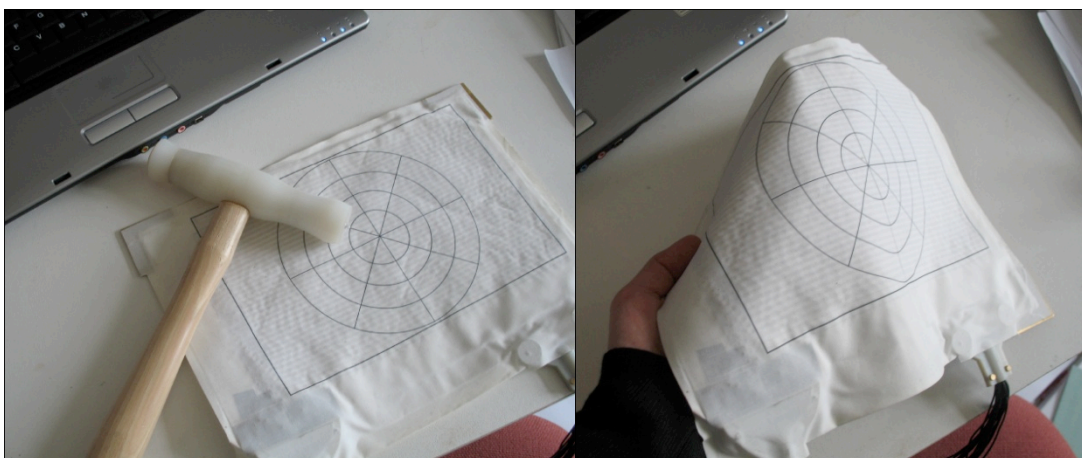


Figure 86, Sewn flexible material and the hammer with digitising pen
Image by © Kathryn Hinton, 2009

By creating a flexible material that can drape over a stake the maker becomes more involved in the experience as they can interact with the material they are beating. Through testing the flexibility I discovered there was no difference between the material being two-dimensional or shaped over a three-dimensional object. When the plastic casing was taken off the circuit board it became semi flexible and although the circuit board was forced over a curved surface the data received and used in ZBrush® did not change. The pens location in the X and Y axis and the directional pressure of Z react the same as if the board was still flat (figure 87).

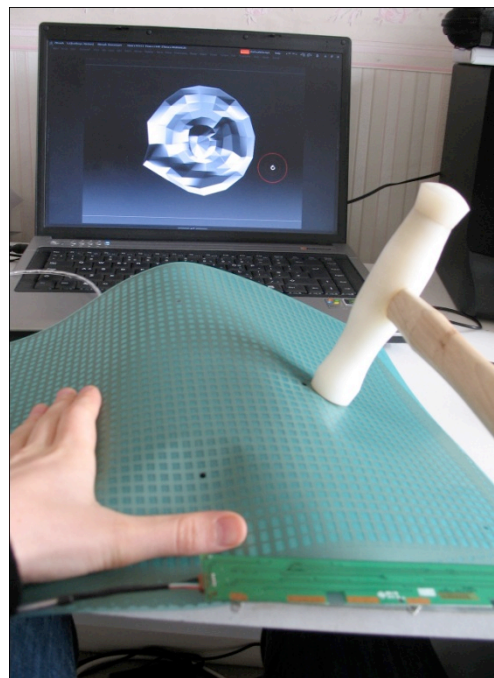


Figure 87, Testing the flexibility of the exposed polypropylene digitising tablet
Image by © Kathryn Hinton, 2009

The use of a flexible material to trace the form of a stake in a three-dimensional space would not be achievable through this process. However it may be beneficial to create a flexible material to use with the hammer interface device that gives a similar experience to traditional raising. The left hand would control the positioning of the material on the stake while the other hand struck with the hammer.

To recreate a flexible board the plastic between the horizontal and vertical lines was removed. After trying this idea out on a small section of the board I discovered that although the material became more flexible it was still too stiff to be used as it did not maintain its position (figure 88).



Figure 88, Squares cut from the tablet board to test flexibility
Image by © Kathryn Hinton, 2009

Although this method had problems an alternative idea to create a flexible input material would be to replicate the horizontal and vertical lines in copper encased in thin sheets of silicon for insulation (figure 89).

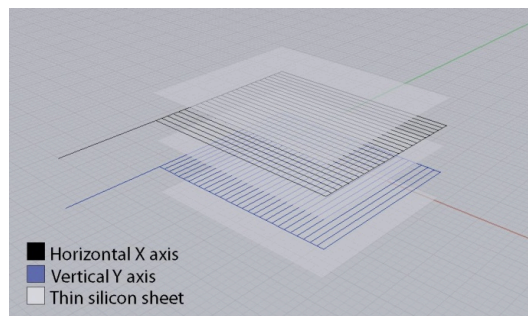


Figure 89, Proposed silicon material board
Image by © Kathryn Hinton, 2010

Another avenue for research is to use a conductive film as a force sensing resistor to capture the pressure of the hammer strike. The conductive film would be hammering into a metal depression in a tree trunk using a metal hammer-head creating the button strike. An accelerometer in the hammer head would locate its position and be communicated through the Arduino to the computer (figure 90).

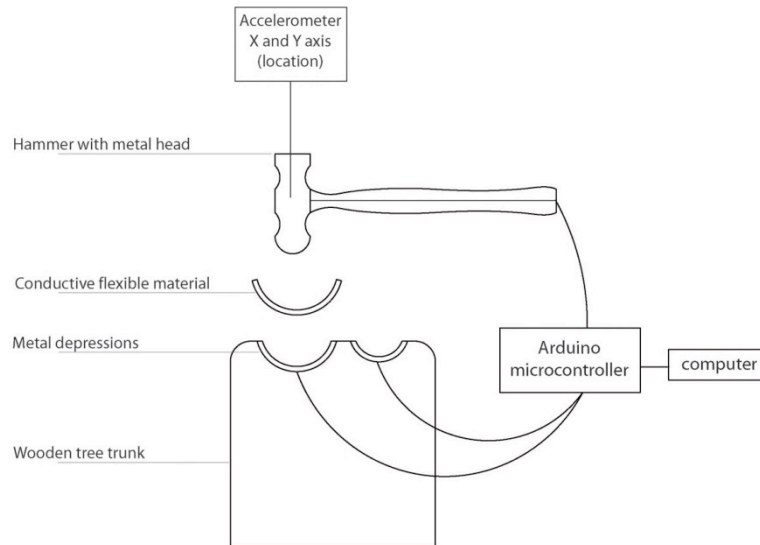


Figure 90, Development of an interface tool using Arduino and conductive material as a pressure sensor
 Image by © Kathryn Hinton, 2009

Like the development of a stake interface device there are too many parts required to make the material interface work. The hardware in the hammer interface device incorporates all the elements needed to capture the pressure and location. The fabric hand stake is included as it makes the movement and process of hammering easier.

With the completed development of a hammer interface device the following chapter explores the design possibilities. For the purpose of my research I will reverse the traditional method of designing with function in mind as my method of exploration is to first test the limits of the digital mesh without being limited by the function of the final object.

4. Design

Throughout my research I have concentrated on testing the differences between traditional and digital hammering and using the data gathered to create a tool to use within the digital realm. The next stage of my research is to use the hammer interface device to create new objects. The digital objects produced through the process of hammering are completely removed from my previous silver work as the tableware I make is predominately fabricated out of sheet metal. As a result I have had to adapt to this new method of working and embrace the organic forms I am able to produce. To understand the full potential of hammering the digital mesh I have to make without function in mind and push the possibilities of the material. New technology has often been met with scepticism as CAD and computer aided manufacture (CAM) are seen to distance the maker from materials and the process of making. Also as new technologies become available makers often get caught up in the novelty.

*a computer is not a craft in itself, it is a utilization of a tool, no matter how creative the outcome: the real skill in utilizing that tool is derived from traditional design knowledge.*⁷¹

Many makers are able to make this transition to working with CAD as they understand the stages of making and have the ability to visualise problems that may occur. However the lack of computer skills can hold the maker back as they do not understand how to realise their designs. This lack of knowledge is not as important when using the digital hammer interface in ZBrush® as the maker is not concerned with constructing using the tool palette within the program as they are just working with the single disc of material.

Digital craft has been adopted by many practitioners and should not be seen as a rejection of traditional craft, but as a new avenue to create exciting work using the many different tools and techniques available. Rhino 3D and ZBrush® are among many packages that have their own tool palettes to construct or manipulate the digital meshes. These pieces can then be manufactured through technologies such as rapid prototyping and computer numerical

⁷¹ Myerson, J. (1997) *Tornadoes, T-Squares and technology: can computing be a craft?* In: Dormer, P. (eds.) *The Culture of Craft: Status and Future* Manchester: Manchester University Press. p177.

controlled (CNC) milling⁷². Traditional making often works in conjunction with CAM as the work still needs to be finished by hand at the bench.

This is evident in Jeroen Verhoeven's Cinderella table as the piece was created using CAD taking the outlines of two eighteenth century tables and combining them to produce a morphed form (figure 91). The table was CNC milled in 57 slices, each cut out of 80mm thick plywood and assembled and finished by hand.



Figure 91, Jeroen Verhoeven, Cinderella table, Birch plywood 2005

More makers embrace the use of technology as they progress through college education where the equipment is readily available to experiment within different craft disciplines. The use of CAD/ CAM, as a tool for design and production, eliminates the benefits of certain materials and techniques. Silversmiths use the malleable properties of silver to transform a sheet of metal into a three-dimensional form. Rapid manufacture technologies open up possibilities of design and manufacture in different materials as the objects generated on screen are most often a prototype to be moulded and cast.

Geoffrey Mann uses rapid prototyping technology to realise his work. His piece entitled 'flight landing' from his long exposure series captures the motion of a bird in flight using stop frame cinematography. He then creates the physical pieces using CAD, rapid prototyping and kiln cast glass (figure 92).

⁷² Computer Numerical Control refers to machine tools programmable through a computer. Commonly used for accurate drilling or milling machine processes.



Figure 92, Geoffrey Mann, Flight landing,
Long Exposure series
700 x 350 x 350 (mm)
Mfr. Glass

The Devon Guild of Craftsmen recognised the opportunities presented by new technology and with Innovate- Centre for Creative Industries, a University of Plymouth Centre of Expertise⁷³, curated a touring exhibition in 2006. A selection of craftsmen who utilise technology within their craft discipline displayed their processes of design and manufacture.

Rhino 3D starts with 4 viewport windows which display the X and Y axis on a grid plane (figure 93). The tool palette on the left side of the screen enables the designer to start constructing their desired form. This method of working can be daunting as there is no material to visualize and start working into. The designer also has to understand the functions of the different digital tools. However in ZBrush® there is only one window with a black area to import mesh into (figure 94). As I am looking at the possibilities of the individual mesh I start with a disc of material that I hammer into with no other components added.

⁷³ <http://www.research.plymouth.ac.uk/creativeindustries/home/>

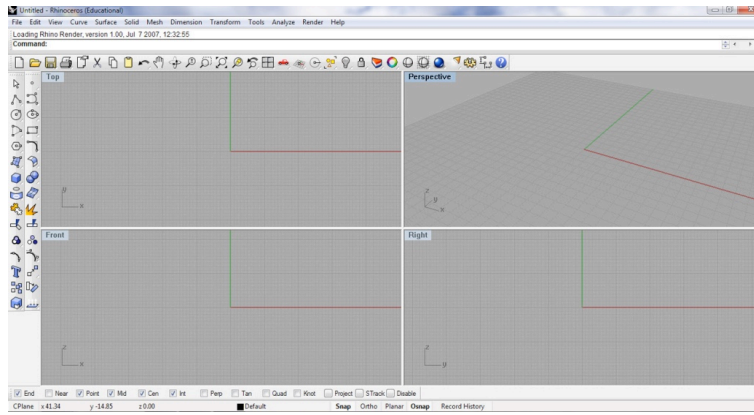


Figure 93, Rhinoceros 3D 4 default viewports
Image by © Kathryn Hinton, 2010

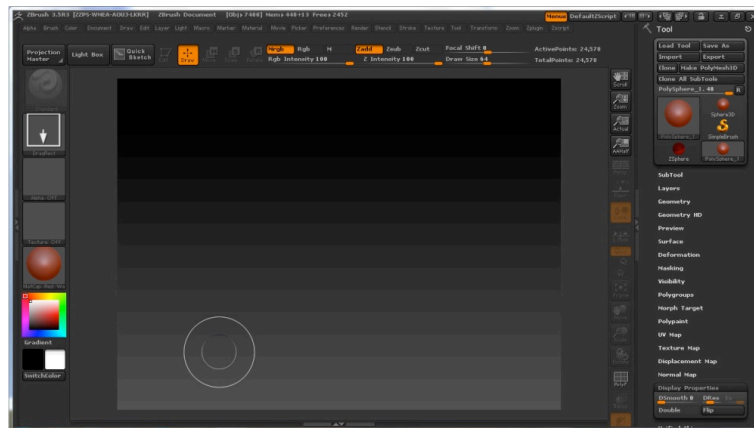


Figure 94, ZBrush® interface
Image by © Kathryn Hinton, 2010

ZBrush® has its own tool palette with many features to enhance the surface of the mesh from smoothing to adding textures. My research looks at using a default mesh with the hammer interface device to see how the material can be manipulated. Radial symmetry is a feature in ZBrush® that creates a range of circular points which all imitate the highlighted cursor (figure 95). These points can be increased from 4 to 100 depending on the amount required.

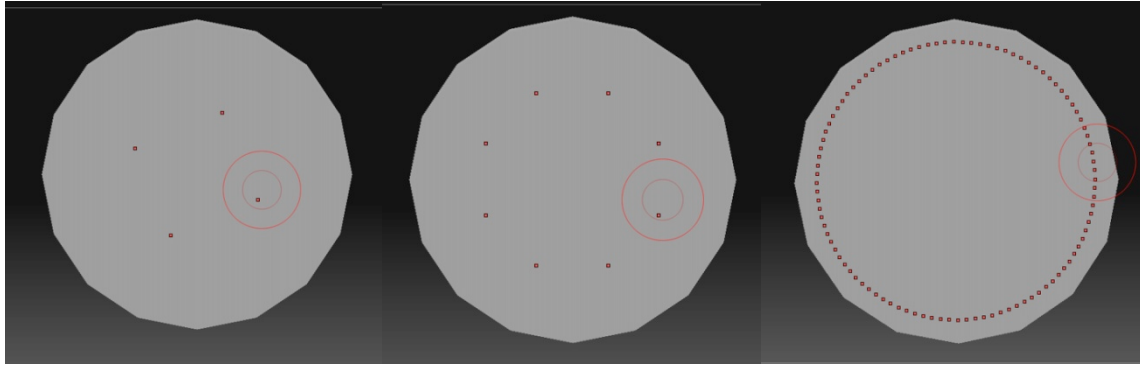


Figure 95, radial symmetry 4, 8, 100 points
Image by © Kathryn Hinton, 2009

The use of 100 points is effective with a very fine mesh to create intricate detail. However using 100 points on the simplest mesh would be ineffective as there are fewer points to manipulate. Below is a test undertaken between hammering with a single point and hammering with radial count turned up to 42 to see if radial symmetry takes away from the experience of hammering with a single primary cursor (figure 96).

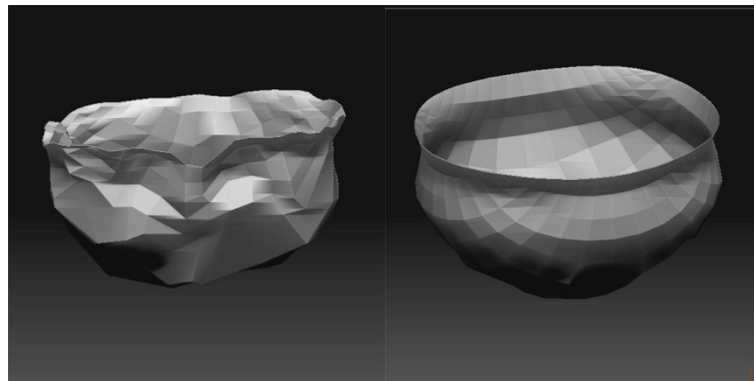


Figure 96, Hammering mesh with single cursor point and a radial count of 42
Image by © Kathryn Hinton, 2009

Radial symmetry creates a much smoother surface as the radial count works in a circular motion with each point replicating the movement and pressure of the hammer strike. However radial symmetry does not convey the process of digital hammering as the mesh is not beaten in individual points. This method relates more to the process of spinning where a metal disc spins on a lathe and the maker uses a long rounded steel tool to push the metal over a former. Although the digital mesh is not spun over a former the amount of radial points correspond to the spinning motion.

Like Charles Robert Ashbee and the silversmiths of the Arts and Crafts movement I am interested in showing the making process through the mark on the surface of the final piece. ZBrush® enables me to achieve the desired result of highlighting the uneven mesh to show the hammer marks through the deformed facets.

When raising an object I start by sketching possible designs and forms and then calculate the amount of material I will need to achieve the size. The usual calculation is to multiple the widest point by the tallest and add a small percentage for trimming up the top. This method of designing and making is reversed from digital hammering as there is no size assigned to the mesh until it is ready for output. Also as I am testing the properties of the mesh I have been hammering straight into the mesh without a proposed design in mind.

Taking the traditional method of designing and making I undertook a test to discover how closely I could control the hammer interface device and mesh to replicate the design of a traditionally raised object. I set myself a brief to design a simple symmetrical vessel that could be raised out of fine silver (figure 97). Once I had decided of the form I raised and planished the form. I kept the planished marks as the final finish to be able to compare to the digital vessel (figures 98 and 99). I replicated the process of hammering with the hammer interface in ZBrush® and took notes throughout the test to be able to compare the different processes⁷⁴.

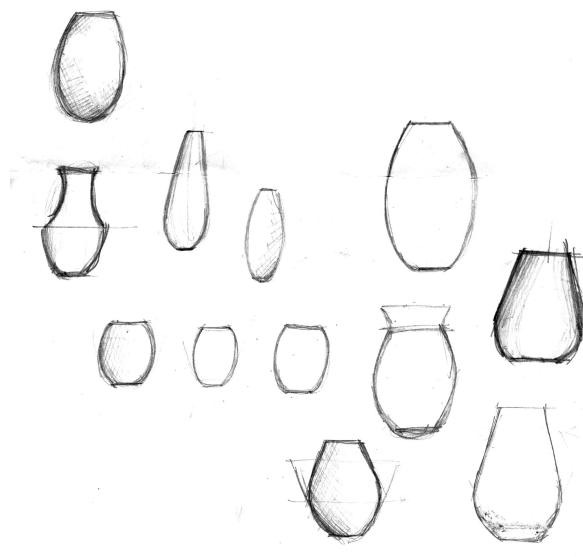


Figure 97, Symmetrical vessel design sketches
Image by © Kathryn Hinton, 2009

⁷⁴ See appendix 4 for comparisons



Figure 98, Raised fine silver vessel
Image by © Kathryn Hinton, 2009

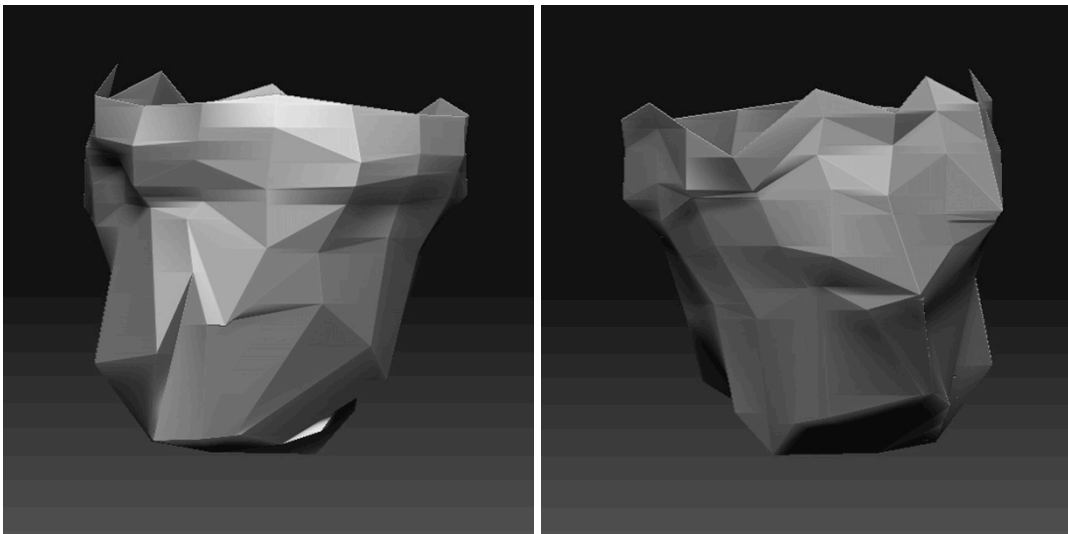


Figure 99, Different views of digital vessel
Image by © Kathryn Hinton, 2009

One of the main strengths of ZBrush® is the ability to design without the restrictions of material cost. While hammering I was able to rectify mistakes by reloading model saved a point before the mistake or revert through the individual hammer strikes by pressing ctrl + z on the keyboard. Below is a selection of images showing the different attempts at creating a circular bowl with a square inside (figure 100).

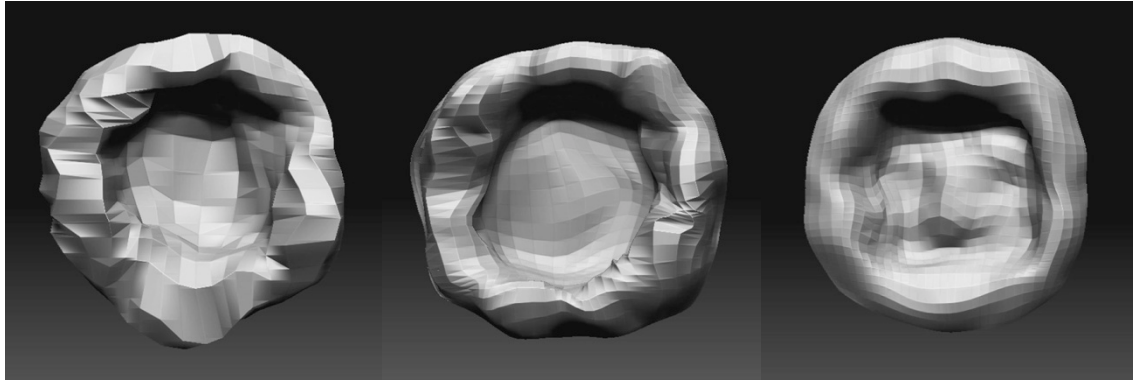


Figure 100, A selection of mesh attempts for circular bowl with square inside
Image by © Kathryn Hinton, 2009

Masking and the ability to add texture to the mesh surface are features that could benefit the design process when hammering in ZBrush®. Masking enables part of the work to be covered while the highlighted area is worked into. This function can be used to add further detail into particular areas. Many silversmiths add texture to the surface of the metal to add an extra decorative element or as a practical element to help with grip. Gerald Benney was a silversmith who known for his characteristic texturing by using a hammer with grooves shaped into the face he was able to apply an even texture to the surface of his pieces (figure 101). It is possible to apply texture to the hammered mesh in ZBrush® using alphas⁷⁵.

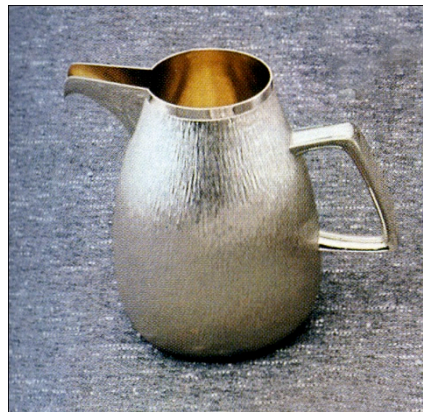


Figure 101, Gerald Benney sterling silver jug

An alpha can be made by creating a greyscale two-dimensional image and importing it into the ZBrush®'s alpha palette (figure 102). To be able to pick up the definition of the texture the mesh has to have a high level of geometrical resolution (figure 103). As the texture only

⁷⁵ An alpha is a greyscale image that controls the shape of the brush to deform and add depth to the mesh.

slightly deforms the surface it might not be possible to achieve the same results once the object is output.



Figure 102, Alpha
Image by © Kathryn Hinton, 2010

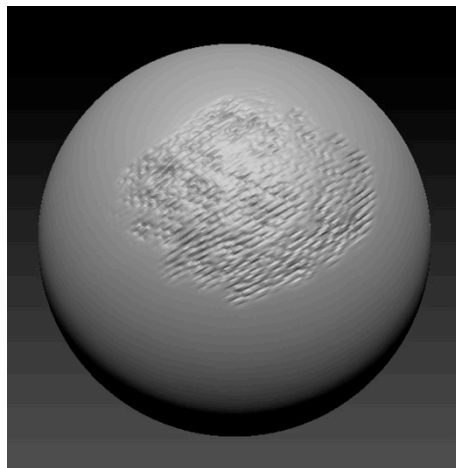


Figure 103, Texture on ZBrush® sphere
Image by © Kathryn Hinton, 2010

The digital realm opens up the possibility to explore the idea of scale as there is no predetermined size to the objects being hammered. The restrictions are dependant on the process used to output the final pieces. The following chapter explores different methods of production to determine the most effective process to incorporate with the hammer interface device.

5. Output

The final stage of digital hammering is to realise the piece in a physical material. There is a wide selection of output destinations: from different additive manufacture processes such as selective laser sintering (SLS)⁷⁶ and fused deposition modelling (FDM)⁷⁷ to subtractive methods, such as CNC milling. In this chapter I will look at processes associated with both areas to discover the best means to output results from this research.

Although the hammer can be used to make an object there is still the problem of realising the piece in a physical material. The action of hammering is used with the hammer interface device to manipulate the mesh in a digital realm but the action is not represented in the manufacture process. New technologies used to create physical objects either add material or cut it away but do not manipulate the material already there.

Some tools are by their nature more individual and 'expressive' than others. For example, a hammer is unequivocal in expressing what it does best: bashing things. But some modern tools do not overtly express their function.⁷⁸

A future project to further develop the hammer interface device would explore the idea of creating a tool that takes the digital data and directly hammers a sheet of metal into the desired form. Instead of cutting, a computer numerical controlled press would apply regulated pressure through a hydraulic press alongside a CNC style moveable tool bed driving the X and Y axes for location. However the disc of metal would have to be securely held and also able to be removed during the process for annealing for an accurate model to be made.

In most cases it is not necessarily quicker to create an object using rapid manufacture, as opposed to more traditional hand-wrought processes, as the build or milling times differ depending on the resolution required on the surface of the piece and can be very long. There

⁷⁶ Selection Laser Sintering is the process by which particles of powdered materials are fused by a high powered laser. The laser selects the areas to work on from the CAD model to form each layer. Once a layer has been created the bed drops for a new layer to be adhered to the existing one.

⁷⁷ A plastic material is fed off a coil through a heated nozzle and extruded in layers to make up the model.

⁷⁸ Dormer, P. (1990) *The Meanings of Modern Design towards the Twenty-first Century*. London: Thames and Hudson Ltd. p20.

is also a commonly-held misconception that once the initial set up on the machine has been done it can be left to run. This is not the case as it has to be checked and adjustments made on the programme, if and when necessary. One of the main benefits of rapid prototyping is in creating objects that are difficult, or impossible to make, using hand processes. There are many different types of materials that can be used to rapid prototype and some serve makers better than others as they can be built in wax and cast straight into metal. Grant MacDonald is a traditionally trained silversmith who has accepted new technology and uses these new techniques alongside his long-established silversmithing practice⁷⁹.

*For me, the excitement of new technology is the new opportunities in design it gives designers.*⁸⁰

MacDonald creates models on the EnvisionTEC Perfactory[®] system⁸¹ using a resin that completely burns away in the lost wax casting process⁸² to produce a clean piece in precious metal (Figure 104).

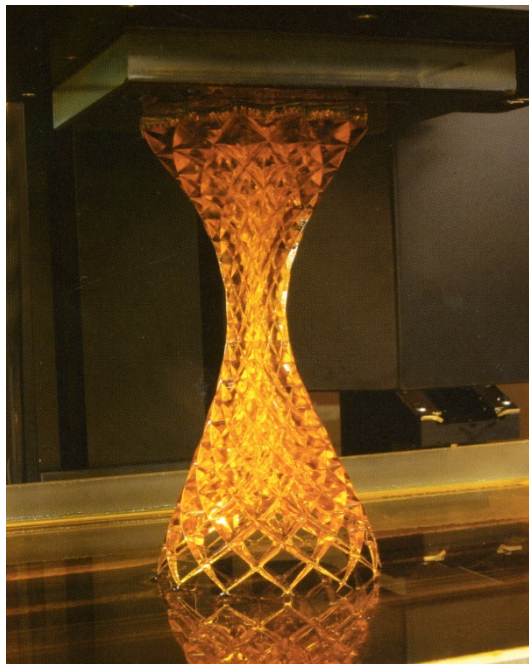


Figure 104, Grant MacDonald, EnvisionTEC Perfactory[®] Model.

⁷⁹ Corti, C. (2005) Investing in Technology Grant MacDonald –Silversmith. The Goldsmiths’ Company Technical Bulletin. The Technology and Training Department, Issue 2, p 3.

⁸⁰ Corti, C. (2005) Investing in Technology Grant MacDonald –Silversmith. The Goldsmiths’ Company Technical Bulletin. The Technology and Training Department, Issue 2, p3.

⁸¹ <http://www.envisiontec.de/>

⁸² Lost cast wax casting is the process by which a material is burnt out of a mould to leave a cavity for the molten metal to be poured into. Many materials can be used as an initial model for moulding but wax is most commonly used as it cleanly burns out.

The EnvisonTEC system is one of many that offer designers different materials to output their ideas. A process with considerable potential for jewellers and silversmiths is Direct Metal Laser Sintering (DMLS). This process builds models in layers of powdered metals and fuses them together using high-powered lasers reducing the stages of production (Figure 105). This could be a fast cost- effective method to produce objects instead of casting or machining. However although labour costs are reduced it is still an expensive process for individual craft makers.

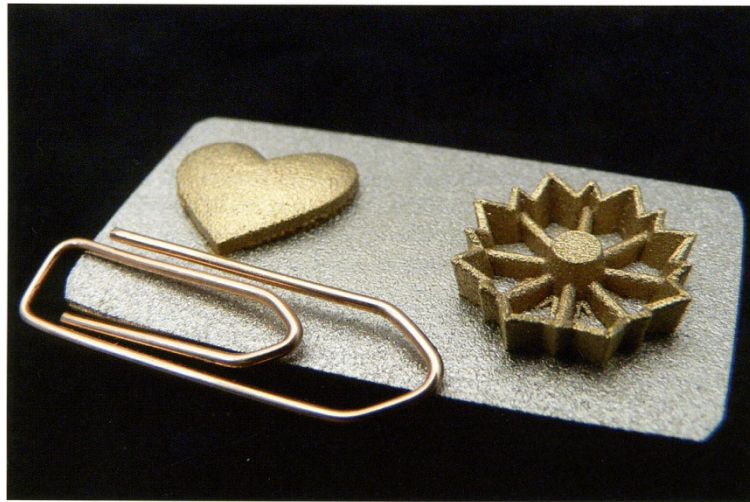


Figure 105, Electro Optical Systems, Direct Metal Laser Sintering in precious metal.

For this research project I have built wax models on the departments Solidscape[®] Rapid Prototype machine⁸³. Having this technology available has enabled me to experiment and output the digital objects into a physical material as its qualities change with the material (figure 106). Often the qualities of rapid prototyping are kept as an element of surface decoration. As I am interested in highlighting the hammer marks in the mesh I am outputting the objects with low mesh geometry to create a faceted surface. However if the resolution of the Solidscape[®] build is low, stepped lines appear on the model, which is something I am keen to avoid. Unfortunately during the build the machine crashed and stopped, when it restarted the next layer of wax was slightly out, creating a step. The model had to be rebuilt before it was cast in silver.

⁸³ <http://www.solid-scape.com/index.html>

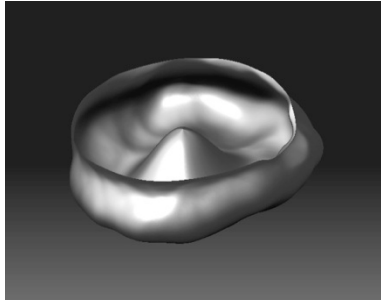


Figure 106, Digital ZBrush® mesh, Solidscape wax, cast sterling silver
Image by © Kathryn Hinton, 2010

Rapid prototyping is a valuable resource for small scale jewellery. However, as the Solidscape® is charged on the height of an object and the length of the build time it is not cost effective to create large objects.

The scale of objects is restricted by the outputting process. To achieve larger objects I had to look at other methods available. To produce the digital objects in silver on the MA at the Royal College of Art I used the electroforming process⁸⁴. For this research project I looked at other processes as electroforming was time consuming, had many stages of production which increased the risk of failure. The images below show the different stages of development from the digitally hammered object in ZBrush® through to the finished silver electroformed piece (figure 107). I started by rapid prototyping the digital file in Z-Corp® material, a three-dimensional printing process which bonds powdered plaster to create affordable objects. The Z-Corp® piece had a rough surface that needed to be sanded and smoothed. By making the surface as smooth as possible I would then get a perfect silicon mould to make multiple waxes with the same quality. Green casting wax was poured into the silicon mould, however due to the viscous of the wax small air bubbles formed on the surface. They had to be repaired and filled otherwise they would be picked up in the electroforming process. There were also problems in the electroforming stage as if the current was too low it would not cover evenly and if was too high small growths formed on the surface.

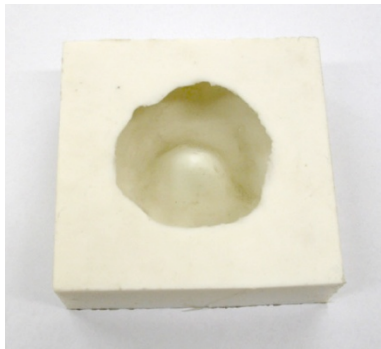
⁸⁴ Electroforming is the process where metal particles are passed through an electrolytic solution onto a form that is conductive through paint containing metal particles or the original object is metal.



ZBrush® digitally hammered object



Rapid prototyped Z-Corp® model



Silicon mould



Green casting wax with air bubbles



Silver electroformed bowl

Figure 107, Stages to realise physical object in silver
Image by © Kathryn Hinton 2008

The high cost and unpredictability of electroforming lead me to explore CNC milling as a possible method of production. Many artists and designers are already utilising the opportunities presented by CNC milling. Drummond Masterton⁸⁵ is one such designer who researches the cutting path of the CNC milling machine and develops a method of controlling the movement to cut patterns while also cutting the three-dimensional form (figure 108).

*My design process seeks ways in which I can combine, manipulate and subvert standard CAD toolsets, parameters in CAM software and first hand knowledge of CNC devices, in order to develop methods that are capable of producing unique objects.*⁸⁶

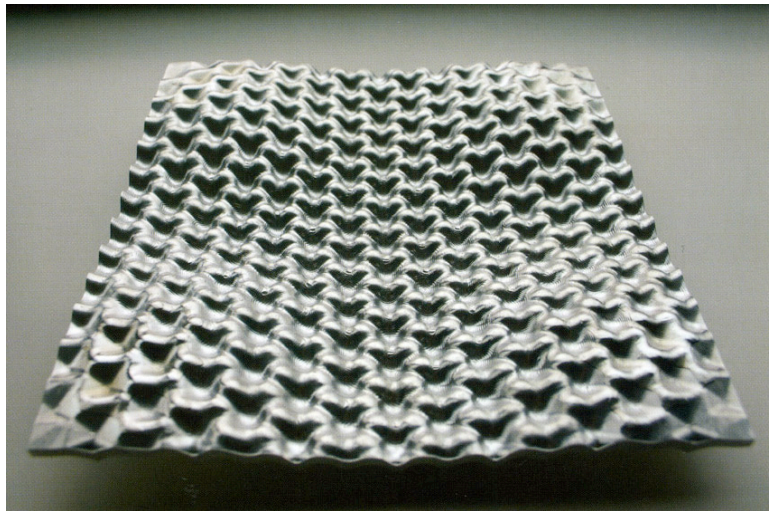


Figure 108, Drummond Masterton, Hexabubble Bowl, Aluminium, h: 25mm w: 175mm d: 175mm, 2005.

Masterton works directly into aluminium to create his large pieces, reducing the production processes. However as I planned to use the CNC milling machine to create large silver pieces it was not cost effective to work straight into a block of silver. To achieve the finished pieces I explored the idea of CNC milling a press-forming mould to fly press a sheet of silver into and also another method of CNC milling wax that would be cast into sterling silver. The restriction associated with 3 axes CNC milling means undercuts are not permitted as the cutting tool would not be able to get into them. This has implications when hammering in

⁸⁵ <http://www.autonomic.org.uk/team/dm/index.html>

⁸⁶ Wynne, S. & Woolner, M. (2006) Interface Exhibition Catalogue, A Devon Guild of Craftsmen and Innovate-Centre for Creative Industries, a University of Plymouth Centre of Expertise, Exeter: Ashley House. p33

ZBrush®, so I am constantly aware of the form and the need to maintain all areas as accessible to a CNC cutting tool.

In investigating these areas I used a Datron M9⁸⁷ 3 axes CNC milling machine, controlled by Mastercam⁸⁸ software. The machine was located within the department. To create a press-forming tool I programmed the Datron to mill the CAD file in Sikablock⁸⁹ made of fine polyurethane material. For industrial press tools or tooling that is going to be frequently used a female and male former is usually milled out of steel or aluminium. This press tool was created to test whether a 0.6mm copper sheet would take the definition of the mould (figure 109).

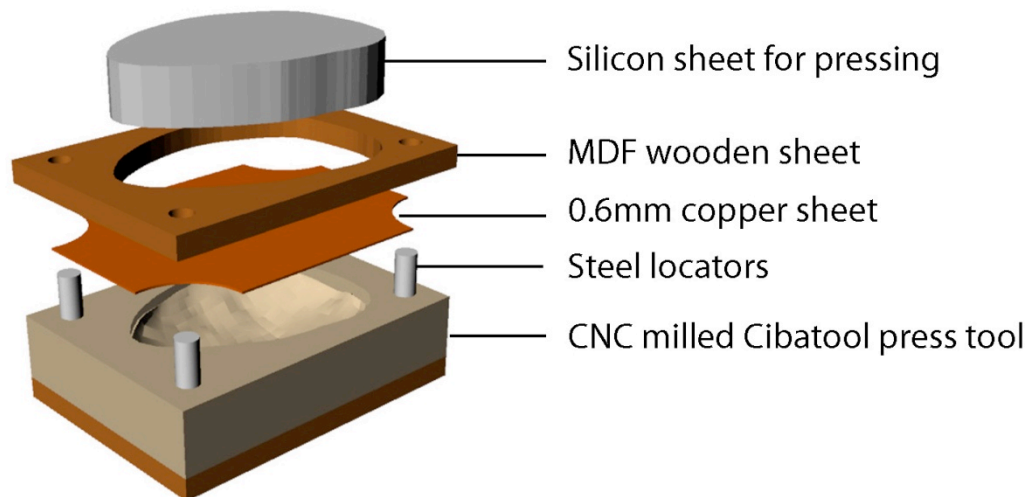


Figure 109, Exploded CAD rendering of press forming tool
Image by © Kathryn Hinton 2010

As I was gradually pressing the form with a manual fly press I had to anneal the copper sheet to make it malleable for further working. The copper sheet creased a little at the edges as the MDF sheet was not strong enough to hold the metal flat (figure 110). The main aim of this test was to determine whether I could work directly into sheet material as this would keep the cost and stages of production to a minimum. However using these materials for tooling was not as effective as I hoped as the copper did not pick up the definition of the mould.

⁸⁷ <http://www.datron.com>

⁸⁸ <http://www.mastercam.com/>

⁸⁹ Sikablock is available in epoxy or polyurethane blocks modelling or tooling board. It comes in different grades and can be CNC milled.
<http://www.johnburn.co.uk/product.php?grpId=375>



Figure 110, Copper pressing
Image by © Kathryn Hinton, 2010

The next stage of development was to use the same process but to mill the form in wax. There was a slight change with the CAD model as both sides were being CNC milled, tabs had to be added to support the model and keep it connected to the outer wax frame (figure 111).

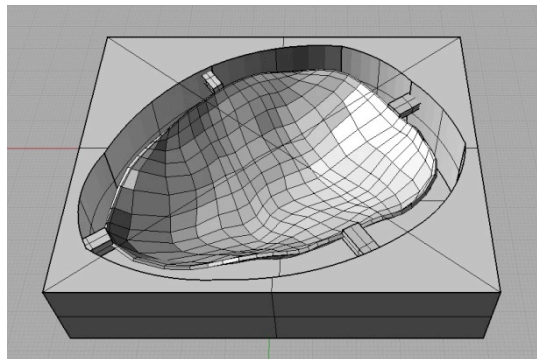


Figure 111, Rhino 3D modelling for CNC milling
Image by © Kathryn Hinton, 2010

Blue medium carving wax was used as it is suitable for machining and could be melted into the required block size (figure 112). The excess material can be recycled and melted back into a new block after it has been milled. However there is no guarantee that the wax would be clean as other jobs had been done on the CNC machine that involves metal. These metal imperfections encased in the wax block would not burn away in the mould and could be included in the final cast object.

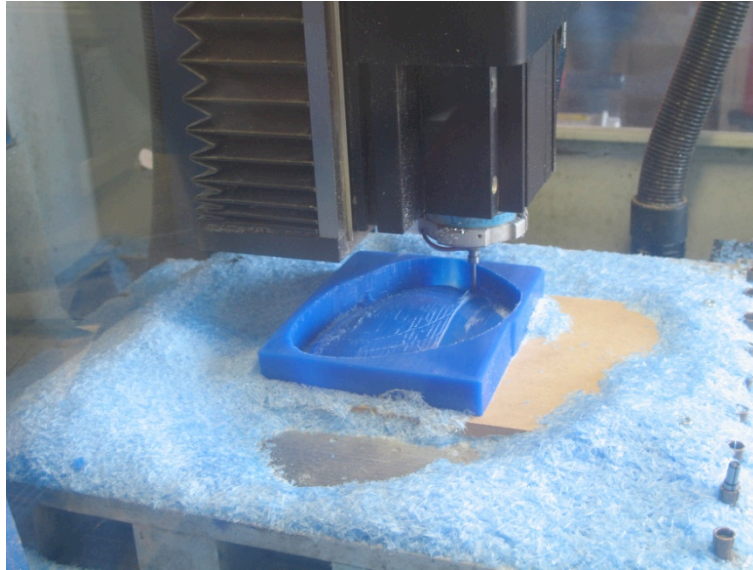


Figure 112, Wax milled on Datron M9 CNC milling machine
Image by © Kathryn Hinton, 2010

The final wax object had to have a suitable thickness of approximately 1.2mm to create a good flow of metal during casting. However there were problems with the milling as the final object was too thin causing a section to shear off the edge (figure 113). This was probably caused by miscalculation when turning the piece over.



Figure 113, Front and back view of milled wax
Image by © Kathryn Hinton, 2010

The Datron M9 CNC milling machine has a large bed size (350mm x 350mm x 200mm) making it possible to produce large wax objects with high surface definition, depending on the size of the cutting tool used. However the object still needs to be cast in metal which brings its own restricts with the flask size to hold the object. Being able to study at the Royal College of Art enables me to utilise the wide range of equipment and services available.

However one of the aims of my research is to use this process to create objects in a studio craft environment. Although it would be possible to outsource rapid prototyping and CNC milling the costs involved suit industrial manufacture and not studio crafts. For this reason I have been exploring the possibilities of alternative affordable machinery that could be used in conjunction with the hammer interface device.

A1 Technologies⁹⁰ have developed RapMan⁹¹ an affordable prototyping system based on fused deposition modelling using different plastics, such as polypropylene and high density polyethylene (figure 114). Although this is an affordable machine the resolution of the models might not be able to replicate the quality I require to show the definition of the digital objects without some degree of interference from the machines own build lines.

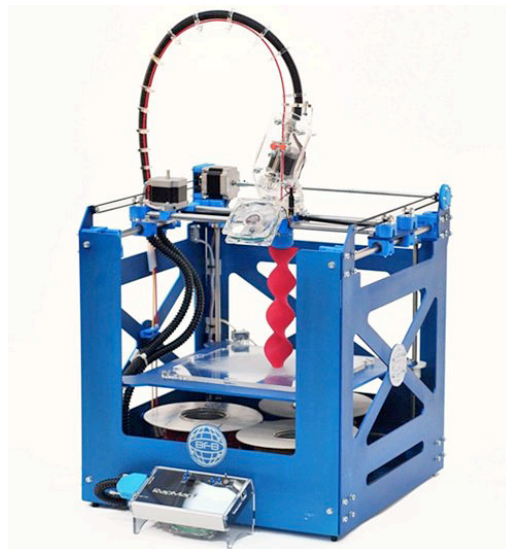


Figure 114, RapMan Pro from A1 Technologies

In the course of the research I came across a 3 axis CNC router from RoutOut CNC⁹² designed to mill wood, plastic and other materials (figure 115). Although the machine is not as sophisticated as a Datron M9 it would be suitable for milling the wax models I require for casting. Both these machines are priced just under £2000, which makes it expensive for an individual craftsman, but outsourcing rapid prototyping can be just as expensive for one off models.

⁹⁰ <http://www.a1-tech.co.uk/index.asp>

⁹¹ <http://www.rap-man.com>

⁹² <http://www.routoutcnc.com>



Figure 115, RoutOut CNC, 3 axis Z90 CNC Router

Throughout my research I have kept the designing and making directly related to the processes involved in silversmithing. For this reason I have been exploring the possibilities of creating objects in silver. However as the digital material in ZBrush® is not restricted by any specific material properties the final objects can be produced in any material. A future project will explore the idea of different materials being used to create the digital objects. These could include porcelain or ceramic pieces cast in moulds and plastic that is injection moulded using a CNC milled aluminium mould. As modern technology develops and new processes become affordable, artists and designers can utilise the tooling in their own practice to explore the possibilities to create new objects in a wide variety of materials.

Conclusion

The research examined the potential of a hammer interface device that simulates a traditional tool, integrating traditional silversmithing techniques and CAD. Haptic interfaces currently available are not sympathetic to simulating physical actions typical of traditional crafting methods. The ability to touch and shape the material is lost when the maker's tool becomes a computer mouse or digitizing pen. Although haptic devices offer force feedback most are not currently sufficiently developed to imitate real feeling. My research was not designed to try and replace traditional skills, but build on their foundations to create an alternative tool. The use of CAD and haptic devices enable the craftsman to have more choice and create designs that would not be possible through traditional methods.

As I approached the research as a maker I was able to use my experience and knowledge of traditional silversmithing to test and develop a device that resembled a traditional tool. By creating a familiar tool the maker would be immersed back into the process where they could inject an element of hand making through using the hammer interface device to design in the digital realm.

Through various tests and projects undertaken throughout the research I was able to highlight the properties of silversmithing and the unique skills metalwork requires. I explored the differences between traditional and digital raising, such as, stance, the physical action of hammering and tooling required. To enable me to highlight specific areas of the raising process I separated the individual stages and documented the process through film, photography, sound and written notes to discover the exact physical differences. After raising each stage traditionally in copper sheet I then repeated the process with the different hammer interface devices in their current states of development with the digital mesh in ZBrush®. By reflecting on the detailed findings I was able to develop the final digital interface device to create a more realistic experience.

The results highlighted differences with the force of striking as the same amount of force was not required to hammer digitally as it was to hammer traditionally. This opens up the possibility for makers who suffer from repetitive strain injury induced by traditionally hammering to be able to make using the hammer interface device. Another difference with the digital hammer was that there was no physical metal for the left hand to hold while

hammering. This removes the feeling of striking metal and new senses such as sight become more important as the digital mesh does not require the maker to listen to whether the metal is being struck on the correct part of stake. The left hand's role had been reduced to pressing buttons on the keyboard when required or resting by my side. It became apparent that to immerse the maker fully in the process and relate it to traditional method of silversmithing the left hand had to be included back into the process. To achieve this I created a hand stake, made out of soft fabric filled with polystyrene balls and lentils which absorbed the force of the strike while also acting as a support. As the hand stake is not fixed to a vice the left hand works in unison with the hammer to move the cursor around the screen making it easier to control the manipulation of the digital mesh. The stance and action of hammering changes as I no longer looked at where I was hammering on the hand stake, but concentrate on the position and movement of the cursor on screen, adjusting the hammer and stake accordingly.

The hammer interface device offers the opportunities to experience an element of silversmithing without the physical strains experienced by prolonged hammering. The loud noises associated with hammering metal are eliminated as the hammer interface device strikes the soft hand stake. The stance taken when digitally hammering is more relaxed as the maker can be seated at a table or standing without having to hold a heavy hammer.

The major difference between traditional raising and the digital simulation of raising I have developed is the absence of a stake in ZBrush® for the mesh to conform to. As the digital disc in ZBrush® exists in three-dimensional space the manipulation of the material more closely resembled blocking. A future project could involve including a solid object into the programme that acts as a stake which the digital mesh can be hammered onto to be able to control the points of the mesh and create an even object. This would require further research into the programming and software development.

The tests and projects throughout the research were also important in confirming the hammer as the best method of digital input. I explored the hammer, stake and metal as the basics of the project. They are the three fundamental elements in the raising process, which is one of the main silversmithing skills. Although I did not have time to learn and use coding and software programming I was still able to adapt existing technology and use the resources available within the Goldsmithing, Silversmithing, Metalwork and Jewellery department at the Royal College of Art to develop a tool that could be used with CAD.

As my research relates to silversmithing I have investigated the properties of metal and the resemblance the digital mesh had to it. The digital material also offers the benefits of a simple adjustable malleable mesh that is not constrained by the properties of metal. The maker does not have to worry about annealing to combat stress and cracking caused by working the metal. The digital mesh has no physical properties pertaining to any one specific material so coupled with the processes of manufacture the object could be produced in any material. This opens up the possibilities for the hammer interface device being adopted by other craft disciplines to use it. A future project will involve exploring the possibilities of producing the digital objects in different materials as moulds can be created through CNC milling and rapid prototyping which then could be used to slip cast ceramic or used to inject plastics.

The hammer interface device could be adopted into other creative practices where makers would be able to approach the tooling with their own individual knowledge and create objects or pieces that do not resemble silverware. For example the hammer could be used by an interior designer to create large scale architectural structures where interiors could be hammered to create different curves and surfaces, such as a wall in a building (figure 116).



Figure 116, Computer render of faceted surface superimposed onto interior as example of applications for hammer interface device in interior architecture.

The potential to design using the hammer interface design in ZBrush® is restricted by the limitations in the output process. I explored three different methods which were rapid

prototyping and casting, CNC milling and casting and press forming to test the possibilities of creating large objects in metal. Through the research it became evident that each of the processes had an element of risk, as problems could occur with the build of the wax on the Solidscape® rapid prototyping machine or during casting. Also rapid prototyping the wax objects on the Solidscape® machine was expensive due to build time and size, as a result it is more practical to produce small objects. Whereas CNC milling can produce larger objects the process is restricted by the forms it can produce as the 3 axis machine cannot mill undercuts as the tooling is unable to reach those points. A strategy to resolve this would involve milling the object in parts and soldering the form together afterwards.

The use of the hammer interface design, although modelled on the techniques of silversmithing, would also be valuable as a tool for jewellery, silversmithing and large scale sculpture. The digital hammering experience supports the possibilities of different sized of objects as the digital mesh has no assigned size it is as big or small as the screen it is on. The cost involved in outputting the physical objects is also a limiting factor when applied to individual studio craft practice. The use of affordable machinery aimed at hobbyists might resolve this problem but the machines capabilities would not be as sophisticated as more expensive industrial machines. However investing in a machine would be cheaper in the long run than having large individual pieces rapid prototyped or CNC milled by subcontractors.

Although there are problems associated with individual methods of output, the objects that can be produced would be very difficult to make by hand. One of the aims of the research was to express visually the making process. Utilising the characteristic deformed facets of the mesh does this while at the same time referencing the traditional marks left by steel hammers.

This research project has highlighted the involvement creative artists and designers have with modern technology and the amount of potential there is for craftsmen to combine traditional skills with developing technologies. The use of the hammer interface device enables makers to use a familiar tool to make in a digital environment with the freedom to strike the material without having to stop and navigate the tools in a software application. The simple controls offered by the hammer interface device present a tool that does not require detailed training or knowledge to use. For these reasons it can be adopted by a range of people from experienced silversmiths to hobbyists and amateurs. It also became apparent that the hammer interface device did not need a large amount of tooling to use. The hammer interface device

could be used in the home without the need for a silversmithing workshop. The research has the potential to be developed further with the idea of digital tooling expanded into other areas of silversmithing, such as engraving and chasing, to create a digital workshop.

The hammer interface device enables the craftsman to design and hammer freely as they are not stopping to anneal the piece or adjust and change stakes in the vice, they can continue hammering until the object is resolved. If mistakes are made in the digital mesh they can easily be rectified by stepping back or reloading the saved piece. The craftsman is immersed in the process as they hold the tool in their hand and physically manipulate the mesh by striking, although it is not the traditional way of making, the maker gets a sense of hammering as they are controlling the movement of mesh through their own striking.

Modern technology has enabled artists and designers to realise complex designs that would be difficult to make using hand processes. Individual craft disciplines have to embrace modern technologies alongside their working practice to keep up with other areas of design in developing new and exciting work.

Glossary

Alpha

An alpha is a greyscale image that controls the shape of the brush to deform and add depth to the mesh in ZBrush®

Bluetooth

Bluetooth provides short range wireless communication between the computer and portable or fixed devices.

Blocking

Blocking is the method by which a bowl shape is formed using a rounded steel or wooden blocking hammer in either a sandbag or a recess in a wooden former usually a section of tree trunk.

CAD - Computer aided design

Is the use of computer software to design three dimensional objects in a virtual environment on the computer.

CAM - Computer aided manufacture

Is the common term to describe the process of controlling machine tooling through the use of computer software.

CNC - Computer Numerical Control

Refers to machine tools programmable through a computer. Commonly used for accurate drilling or milling machine processes.

Electroforming

Electroforming is the process where metal particles are passed through an electrolytic solution onto a form that is conductive through paint containing metal particles or the original object is metal.

FDM- Fused Deposition Modelling

A plastic material is fed off a coil through a heated nozzle and extruded in layers to make up the model.

Haptics

Haptic refers to the sense of touch. Haptic technology refers to interface devices that immerse the user through the sense of touch.

Hydraulic press

A hydraulic press applies varying amounts of force by using a lever to apply pressure to liquid in a cylinder that produces a compressive force upon the work.

Lost wax casting

Is the process by which a material is burnt out of a mould to leave a cavity for the molten metal to be poured into. Many materials can be used as an initial model for moulding but wax is most commonly used as it cleanly burns out.

NURBS - Non-Uniform Rational B-Splines

Representing curves and surfaces making up mathematical models created in CAD software.

Peening

Peening involves hammering a disc of metal with an even thickness on a flat metal surface using a hammer with a slightly domed face. This stretches the disc of metal to thicken the outer edge.

Planishing

Planishing is the final hammering process to create a smooth, even finish on the surface of a metal piece

Polysurface

A polysurface is made up of two or more surfaces joined together. A fully enclosed polysurface is also known as a solid.

Raising

A process of making a seamless form by compressing a disc of metal against a metal stake with a raising hammer.

SLA - Stereolithography

Stereolithography (SLA) works using a UV laser to cure photosensitive epoxy resin. The liquid resin is built in layers turning solid when the laser touches the surface.

Sikablock

Sikablock is available in epoxy or polyurethane blocks modelling or tooling board. It comes in different grades and can be CNC milled.

SLS- Selective Laser Sintering

Selection Laser Sintering is the process by which particles of powdered materials are fused by a high powered laser. The laser selects the areas to work on from the CAD model to form each layer. Once a layer has been created the bed drops for a new layer to be adhered to the existing one.

VR - Virtual Reality

Virtual reality is a computer hosted environment. The viewer can immerse themselves in real or imaginary worlds created on the computer screens or through stereoscopic equipment.

USB-HID

USB-HID refers to the USB device class that represent human interface devices such as computer mice, keyboard and game controllers.

Z-Corp®

A method of Rapid Prototyping from CAD models using ink jet printer heads to deposit liquid that bond powdered plaster.

Appendix 1

Diagrams

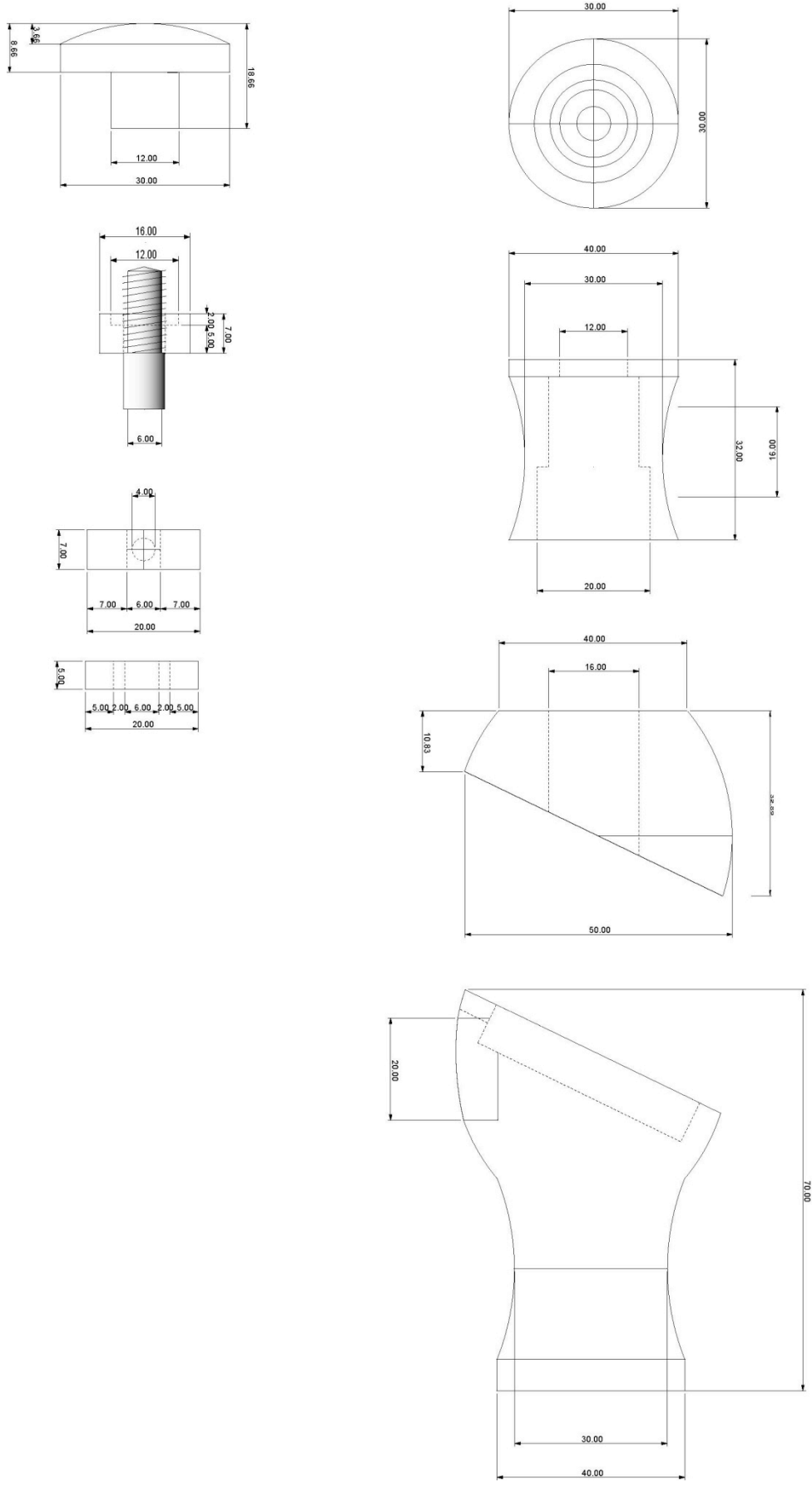


Figure A1, technical drawing nylon hammer head

Appendix 2

Codes

Code1. Arduino source code for an ADXL3xx accelerometer

```
/*
ADXL3xx

Reads an Analog Devices ADXL3xx accelerometer and communicates the
acceleration to the computer.

analog 0: accelerometer self test
analog 1: z-axis
analog 2: y-axis
analog 3: x-axis
analog 4: ground
analog 5: vcc

created 2 Jul 2008
by David A. Mellis
modified 26 Jun 2009
by Tom Igoe
*/
// these constants describe the pins. They won't change:
const int groundpin = 18;      // analog input pin 4 -- ground
const int powerpin = 19;      // analog input pin 5 -- voltage
const int xpin = 3;           // x-axis of the accelerometer
const int ypin = 2;           // y-axis
const int zpin = 1;           // z-axis (only on 3-axis models)
void setup()
{
  // initialize the serial communications:
  Serial.begin(9600);
  // Provide ground and power by using the analog inputs as normal
  // digital pins. This makes it possible to directly connect the
  // breakout board to the Arduino. If you use the normal 5V and
  // GND pins on the Arduino, you can remove these lines.
  pinMode(groundpin, OUTPUT);
  pinMode(powerpin, OUTPUT);
  digitalWrite(groundpin, LOW);
  digitalWrite(powerpin, HIGH);
}
void loop()
{
  // print the sensor values:
  Serial.print(analogRead(xpin));
  // print a tab between values:
  Serial.print("\t");
  Serial.print(analogRead(ypin));
  // print a tab between values:
  Serial.print("\t");
  Serial.print(analogRead(zpin));
  Serial.println();
  // delay before next reading:
  delay(100);
}
```

Code2. Source code for video capture in Processing 1.0

```
import processing.video.*;

Capture video;

void setup() {
  size(640, 480); // Change size to 320 x 240 if too slow at 640 x 480
  // Uses the default video input, see the reference if this causes an
  error
  video = new Capture(this, width, height, 30);
  noStroke();
  smooth();
}

void draw() {
  if (video.available()) {
    video.read();
    image(video, 0, 0, width, height); // Draw the webcam video onto
    the screen
    int brightestX = 0; // X-coordinate of the brightest video pixel
    int brightestY = 0; // Y-coordinate of the brightest video pixel
    float brightestValue = 0; // Brightness of the brightest video
    pixel
    // Search for the brightest pixel: For each row of pixels in the
    video image and
    // for each pixel in the yth row, compute each pixel's index in the
    video
    video.loadPixels();
    int index = 0;
    for (int y = 0; y < video.height; y++) {
      for (int x = 0; x < video.width; x++) {
        // Get the color stored in the pixel
        int pixelValue = video.pixels[index];
        // Determine the brightness of the pixel
        float pixelBrightness = brightness(pixelValue);
        // If that value is brighter than any previous, then store the
        // brightness of that pixel, as well as its (x,y) location
        if (pixelBrightness > brightestValue) {
          brightestValue = pixelBrightness;
          brightestY = y;
          brightestX = x;
        }
        index++;
      }
    }
    // Draw a large, yellow circle at the brightest pixel
    fill(255, 204, 0, 128);
    ellipse(brightestX, brightestY, 200, 200);
  }
}
```

Appendix 3

Tables

The following notes were taken during the differences project to explore the process of raising using traditional hammers and the various hammer interface devices in their stages of development.

	Traditonal - Blocking
Physical differences	Metal hammer, wooden handle, long head, A domed face on each end, using hollow depressions in of tree trunk.
sensitivity	Metal is malleable under force of metal hammer
Stance	Sat down, arm at right angle, shoulders relaxed, elbow kept tucked in.
Grip	Tight but relaxed, trying to let hammer head do the work.
Annealed	1
Physical Activity	Using upper arm, lower arm muscles felt tight. Wrist and hand (grip) was controlling hammer blows.
Beat metal onto	Tree trunk
Sound	Hollow sound as the metal took the form of curve in tree trunk. Wasn't always hitting something underneath.
Film	yes
Time	5mins
Rounds	Began in small hollows, using the larger one to even the bowl up.
Dimensions of Hammer	100m tapered head, 50mm diameter face, 300mm handle length.
Dimensions of piece	20mm x 94mm x 94mm
Thoughts while hammering	Thinking of the rhythm and sound.
Environment	Quiet, Artificial light, Monday morning raining outside – grey and dull. Low hum of ventilation system.
Note	

	Traditional – Peening with metal hammer
Physical differences	Hammer head steel, Face slightly domed.
sensitivity	Regular consistent strikes, not large amount of force needed as hammer head was heavy.
Stance	Moved tree trunk so hollow being beaten into was square with the body. Sitting down, back straight.
Grip	Tight grip as hammer is heavy
Annealed	1
Physical Activity	Not too strenuous as copper is soft and hammer heavy.
Beat metal onto	Wooden tree trunk
Sound	Hollow to solid as it pushed metal down.
Film	yes
Time	6.20mins
Rounds	3
Dimensions of hammer	150mm hammer head x 20mm diameter of face x 160mm handle length
Dimensions of Piece	20mm x 98mm x 98mm
Thoughts while hammering	Trying to concentrate on rounds, where I began and making strikes even.
Environment	Workshop, Quiet and low dull ventilation noise.
Note	

	Traditional - Raising with raising hammer
Physical differences	Hammer has double end. The head is rectangular in shape, wide with a narrow face.
sensitivity	Light to harder strikes as more force needed.
Stance	Sitting down, arm right angle, shoulder relaxed, elbow tucked in.
Grip	Holding copper firmly against stake. Vibrations from copper disc felt through hand. Hammer held copper tight.
Annealed	2 (first anneal after being blocked with wooden hammer)
Physical Activity	Hammer strikes consistent and light to heavy force needed towards edge.
Beat metal onto	Raising stake
Sound	Hollow sound to ting sound as metal and hammer make contact on stake.
Film	yes
Time	4mins
Rounds	3
Dimensions of Hammer	105mm x 27mm (face) x 290mm handle
Dimensions of piece	23mm x 94mm x 94mm
Thoughts while hammering	Trying to find best position to beat copper disc on stake.
Environment	Hammer workshop, 19/11/08 at 11am Workmen in other rooms.
Note	Small discs hard to raise as hammering affects most of surface area.

	Traditional – Light planish with light planishing hammer
Physical differences	Light steel hammer head. Thin wooden handle, tapered in at top – flares out towards the base of handle where it is held.
sensitivity	Light strikes.
Stance	Standing, legs a little apart. Arm and shoulders relaxed, elbow tucked in.
Grip	Light grip at base of hammer, fingers grasped around but occasionally index finger rests on top to support the blows.
Annealed	1 (before blocked with wooden blocking hammer)
Physical Activity	Light striking – nice light weight to hammer – easy to control. Holding disc on stake head with whole hand and moving around. Hammer hit stake at same point each time. Strikes beaten out from centre of disc.
Beat metal onto	Domed stake head
Sound	Light tings, but often a hollow sound as uneven surface finds the stake underneath and hammer blows smooth bowl out. File (folder D, DS00040)
Film	yes
Time	13.05mins
Rounds	1
Dimensions of Hammer	80mm x 20mm (diameter face) x 280mm length handle
Dimensions of piece	22mm x 94mm x 94mm
Thoughts while hammering	Trying to find spot where it makes nice sound and keep it in position while moving the disc of copper.
Environment	Hammer workshop 21/11/08 – 10.15am, hum of ventilation. Cold draft (cold hands).
Note	Mark centre as I will be striking out in rounds and up and down direction to keep even.

	Digital – Blocking with tablet and pen
Physical differences	Sitting in sitting room at home with laptop and tablet in front. Pen is the shape and size of a normal pen. Tablet is A4 and sits flat on the table surface.
Sensitivity (ZBrush® settings)	Z intensity 25 – geometry lowest at 1 subdivision. Focal shift 0, Draw size 64.
Stance	Sitting on a chair against table. Computer and tablet on table.
Grip	Little grip just holding – resting pen in hand while navigating. Stronger grip comes when pressing down for pressure.
Annealed	N/A
Physical Activity	Holding pen over tablet to locate. Push down lightly to manipulate virtual material. Quite hard to keep each strike constant, feels like clay. Left hand has no use but hitting keys, rests at the side while hammering.
Beat metal onto	Pen beat onto tablet, Material beat in virtual space.
Sound	Striking of pen of board (plastic on plastic) – careful considered striking, not in quick succession.
Film	yes
Time	1.15 mins
Rounds	1
Dimensions of Hammer	N/A
Dimensions of piece	Infinite but on screen, 12.5cm diameter x 1cm
Thoughts while hammering	Just watching screen – trying to keep sensitivity consistent and striking points of virtual disc.
Environment	Sitting room at home. Heating on but still cold (hands cold) 27/11/08 – 10.10pm dark outside
Note	

	Digital – Peening with tablet and pen
Physical differences	Pen and tablet working on the flat surface of the board
sensitivity	Round 1; z intensity 25, Draw size 60, Round 2; z intensity 30, Draw size 50, Round 3; z intensity 35, Draw size 40,
Stance	Sitting at table, legs crossed. Relaxed stance just as if writing.
Grip	Light around pen when manoeuvring. Tight hold while striking on board. Grip half way up pen, pressure on tip. Thumb and finger meet.
Annealed	N/A
Physical Activity	Beating material in 3 rounds from middle of material to edge changing the settings and geometry on each round. To keep an even consistent round begins to strains the arm muscles.
Beat metal onto	Pen beats onto tablet Piece beats onto virtual space
Sound	Tapping consistent and quick
Film	yes
Time	4mins
Rounds	3
Dimensions of hammer	N/A
Dimensions of Piece	14cm diameter x 2.2cm deep
Thoughts while hammering	The smaller draw size and lighter intensity the harder it gets as the surface is more irregular and harder to control. Focusing strikes it becomes bumpier. The higher geometry gets the more detailed the surface is creating localised hammer strikes.
Environment	Sitting room – Sunday afternoon. 30/11/08, 4.20pm. Lights on, dark outside.
Note	Can not traditionally peen material as the virtual disc has no thickness while hammering. Thickness is assigned later. Also working in z axis so not thinning. The material is not being trapped between metal so can not be stretched.

	Digital – Raising with tablet and pen
Physical differences	Flat tablet board A4, plastic pen, lightweight.
Sensitivity (ZBrush® settings)	Z Intensity 35, focal size 0, Draw size 30, geometry subdivision 1.
Stance	Sitting at the table with laptop and tablet in front. Right hand holding pen. Hovering over board and pushing down hard to create strikes. More pressure than originally thought needed to beat material. More striking as subdivision of geometry is 2, more like clay.
Grip	Light, the same sensation as holding a pen ready to write. The force at which pressure is applied depends on the Z intensity.
Annealed	N/A
Physical Activity	Hovering pen over board to get location and striking on the virtual points. Also moving disc around in virtual space to raise.
Beat metal onto	Pen beaten onto tablet Piece beaten in virtual space.
Sound	Random tapping as pen beats the material on the tablet and screen.
Film	yes
Time	1.30mins
Rounds	3
Dimensions of Hammer	N/A
Dimensions of piece	Infinite, but on screen 12.5cm diameter x 1.5cm
Thoughts while hammering	Not sure which direction material is moving when struck as can't feel the disc, the view is straight on.
Environment	Sitting room at home, Sunday afternoon, raining outside – 30/11/08 at 3pm.
Note	

	Digital – Light planish with tablet and pen
Physical differences	Pen held upright and tapped on the board to create marks. Striking at different pressures but not lifting pen like hammer.
sensitivity	Z Intensity 8, Focal shift 0, Draw size 64. Standard brush, Alpha 6
Stance	Sitting in front of tablet which is A4 in size with laptop positioned behind.
Grip	Light but tight while striking.
Annealed	N/ A
Physical Activity	Holding pen, beating onto tablet in rhythmic form. Left hand does nothing until hot keys need to be pressed. Shift on keyboard used most as this rotates the piece on screen while planishing.
Beat metal onto	Virtual space Pen on board.
Sound	Tapping as striking board/ Plastic sound
Film	yes
Time	1.30mins
Rounds	1
Dimensions of Hammer	N/A
Dimensions of piece	11.5cm x 2.4cm deep
Thoughts while hammering	Intrigued by pattern created, not really like planishing as piece is solid.
Environment	Sitting room, light on, 09/12/08 3.45pm
Note	idea of planishing is to smooth metal between hammer and stake, but there is no stake to hammer onto, so I am creating dents.

	Digital – Heavy planish with tablet and pen
Physical differences	Pen used with tablet, striking board or pushing pen down to apply pressure. Not lifting too far in the air to strike down.
sensitivity	Z Intensity 16, focal shift 0, Draw size 64, standard brush Alpha 6.
Stance	Sitting at table, board and laptop in front.
Grip	Light, but tight and tense while applying pressure.
Annealed	N/A
Physical Activity	Working round in circles to strike virtual material.
Beat metal onto	Virtual Space Pen onto board
Sound	Tapping plastic on board, sounds like hammer marks.
Film	yes
Time	1.04mins
Rounds	1
Dimensions of Hammer	N/A
Dimensions of piece	On screen 11.5cm x 2.5cm
Thoughts while hammering	The fact it has no stake and deforms makes the process unpredictable and more interesting.
Environment	Sitting room, dark outside. 09/12/08 4.15pm
Note	Would texture created on the surface come out in the rapid form machine?

	Digital – Blocking with tablet and nylon hammer
Physical differences	Pen is housed inside nylon hammer head. The board is the same but used at a sloping angle.
sensitivity	Z intensity 25, Focal shift 0, Draw size 64. Round 1 & 2 Geometry 1, Round 3 Geometry 2
Stance	Sitting uncomfortably with board laying flat, so I tilted it up. Hammering arm straight with board
Grip	Loose grip of hammer holding at the end of the hammer handle.
Annealed	N/A
Physical Activity	The pressure comes from striking hammer face on surface of board. Have to lift hammer quite high to get strike unlike pen which was light taps not far off the board.
Beat metal onto	Virtual Space Striking board
Sound	Loud bangs, plastic sound as hammer hit board.
Film	yes
Time	3 mins, 1 min each round
Rounds	3
Dimensions of Hammer	30cm x 10cm
Dimensions of piece	On screen 12cm x 1.5cm after round 1, 13.5cm x 5.5cm after round 3
Thoughts while hammering	
Environment	Sitting room, heating on 09/12/08 at 5pm
Note	

	Digital – Peening with tablet and nylon hammer
Physical differences	Pen housed inside hammer head, Board flat but worked on at a slanted angle.
sensitivity	Z Intensity 25, Focal size 0, Draw size 64, Geometry divided every round.
Stance	Sitting in front of board with laptop behind. Board at a tilt, arm tucked in, shoulder a little high as chair-back in way of elbow while hammering.
Grip	Light, muscle in lower arm used.
Annealed	N/A
Physical Activity	Beating round, hammer hitting harder as Z Intensity lower.
Beat metal onto	Virtual space Hammer onto board.
Sound	Loud sound as hammer taps board.
Film	yes
Time	1.40mins
Rounds	3
Dimensions of hammer	
Dimensions of Piece	On screen 13.5cm x 2.4cm
Thoughts while hammering	Hammering is easier to control when Z Intensity is lower.
Environment	Sitting room. 09/12/08 at 6.20pm
Note	Had to move chair as back of chair was restricting hammering arm.

	Digital – Raising with tablet and nylon hammer
Physical differences	Pen housed inside hammer head. Strike board to create mark or to distort material.
sensitivity	Z Intensity 25, Focal shift 0, Draw size 64, Geometry sub division 1
Stance	Sitting at table, moved chair sideways so it does not obstruct hammering arm.
Grip	Light, muscles in arm doing the work.
Annealed	N/A
Physical Activity	Forcefully tapping but not from a high distance from the board.
Beat metal onto	Virtual space Hammer onto board
Sound	Loud plastic tapping sound as board is quite thin and so is the pastic used to make it.
Film	yes
Time	2.40mins
Rounds	3
Dimensions of Hammer	30cmx 10cm
Dimensions of piece	On screen 13.5cm x 2.8cm deep after 3 rounds.
Thoughts while hammering	Arm beginning to ache as pressure is slight hammer does not have far to come up between each strike. Also hammer head is so light it is not doing the work like a normal steel hammer would.
Environment	Sitting room. 09/12/08 at 7pm
Note	

	Digital – Light planish with tablet and nylon hammer
Physical differences	Hammer head with pen inside.
sensitivity	Z Intensity 12, focal shift 0, Draw size 64, Standard brush Alpha 6
Stance	Sitting on chair in front of computer.
Grip	Light grip at bottom of hammer handle.
Annealed	N/A
Physical Activity	Beat surface of board with hammer face to strike and manipulate material on screen, forearm muscle beginning to ache.
Beat metal onto	Virtual space Hammer on board
Sound	Loud tapping on plastic sound
Film	yes
Time	1.40mins
Rounds	1
Dimensions of Hammer	30cm x 10cm
Dimensions of piece	11.6cm x 2.5cm deep
Thoughts while hammering	
Environment	Sitting room 09/12/08 at 7.10pm
Note	Light Z Intensity gets overall even finish with hammer. Big striking circle on board. Unlike traditional planishing where the hammer strikes one location

	Digital - Peening with hammer with tilt sensor
Physical differences	Manoeuvring hammer around in air. Not beating onto anything although the hammer head has a button.
sensitivity	Z Intensity 25, focal size 0, Draw size 64. Changing subdivision every round 1, 2, 3.
Stance	Sitting in front of laptop. Hammer works in space in front of laptop.
Grip	Very light, no striking needed.
Annealed	N/A
Physical Activity	Manoeuvre around in space strike by pressing button on handle.
Beat metal onto	Virtual space No beating physically, just pushing button.
Sound	Tapping of button
Film	yes
Time	4.00mins
Rounds	3
Dimensions of Hammer	30cm x 8cm
Dimensions of piece	13cm x 4.8cm
Thoughts while hammering	Quite hard to control, cursor slow as it seems to be tilt sensor
Environment	Sitting room at home. 14/12/08 at 3.38pm
Note	An issue with size of strike in ZBrush® can be controlled with draw size, object seems small if draw size is 64, but when beating with a 30 size point it seems a bigger object.

	Digital – Raising with hammer with tilt sensor
Physical differences	Holding hammer vertical not like normal action of hammering.
sensitivity	Round 1; Z Intensity 25, focal size 0, draw size 64. Round 2/ 3; Z Intensity 16, focal size 0, draw size 30. Continually dividing to subdivision 4
Stance	Sitting at table with laptop in front of me
Grip	Very light, not striking anything.
Annealed	N/A
Physical Activity	Holding hammer and striking using button, moving hammer to strike points.
Beat metal onto	Virtual space Hammer not beat on anything
Sound	Clicking of button in hammer handle.
Film	yes
Time	3mins
Rounds	3
Dimensions of Hammer	30cm x 8cm
Dimensions of piece	On screen 12cm x 4cm
Thoughts while hammering	Because I am not hitting on a stake I am undoing the work of blocking
Environment	Sitting room, 14/12/08 at 4.30pm Dark outside, light on.
Note	When I continued raising from peening it was uneven and could not be rectified, uneven mesh intensified

	Digital – Light planish with hammer with tilt sensor
Physical differences	Beating hammer in the air with use of a button in the handle, face of hammer does not make physical contact with any surface.
sensitivity	Z Intensity 8, focal size 0, Draw size 64.
Stance	Sitting at table, laptop in front, hammer held vertically in front of screen.
Grip	Very light as not physically striking anything.
Annealed	N/A
Physical Activity	Holding hammer and moving wrist to move pointer and hammer's location. Strains wrist as cursor is slow and awkward.
Beat metal onto	Virtual space Hammer not beat onto anything.
Sound	Clicking button
Film	yes
Time	1min
Rounds	1
Dimensions of Hammer	30cm x 8cm
Dimensions of piece	On screen 13cm x 3cm
Thoughts while hammering	
Environment	Sitting room 14/12/08 at 5pm
Note	

	Digital – Heavy planish with hammer with tilt sensor
Physical differences	Beating on air. Pushing button in handle
sensitivity	Z Intensity 16, Focal size 0, draw size 64, subdivision 1
Stance	Sitting at table with laptop in front.
Grip	Very light as not striking physical surface.
Annealed	N/A
Physical Activity	Moving hammer in physical space to locate pointer on screen pressing button on hammer to strike material on screen.
Beat metal onto	Virtual space Hammer not beaten on any surface
Sound	Clicking button in handle.
Film	yes
Time	1min
Rounds	1
Dimensions of Hammer	30cm x 8cm
Dimensions of piece	On screen 12cm x 3cm
Thoughts while hammering	Pressure too much but can change in programme with Z Intensity.
Environment	Sitting room, 14/12/08 at 4.50pm
Note	

The following notes were taken alongside the design project that explored the differences between traditionally designing and raising a silver disc and digitally hammering a disc of in ZBrush® to try and replicate the same form.

Traditional	Digital
Designed tactile organic shape that is symmetrical.	Started with a disc of ZBrush® mesh with the simplest geometry.
Fine silver disc 200mm x 200mm x 1mm thick.	The disc has no assigned size
Working in the workshop in the department of Goldsmithing, Silversmithing, Metalwork and Jewellery at the Royal College of Art.	Working at home in front of computer on desk in my bedroom.
Always thinking about stance when hammering and the silver's position on the stake to keep the hammering consistent and even all the way round.	Using the handheld stake with lentils and polystyrene balls.
Annealing after each round have to watch colour to dark red, so it is not overheated as it can cause cracking. It became harder to raise as metal is hammered towards edge.	I did not have to strike down hard as I was not getting a lot of height. Don't have to strike hard
Aware of putting hammer marks on silver. I had to soften the edges of the raising hammer as it was catching on metal and putting grooves in. These will with have to be hammered out.	I can hammer on any point without affecting surrounding mesh points. I also don't have to hammer symmetrically, but have to be aware of keeping mesh even and not hitting individual points more than others.
Disc of fine silver cost approx £200	The digital material has no value in the digital realm. I can keep making objects to practice my hammering.
I am using standard raising stake but will have to find the right shaped stakes to fit	As I hammer the mesh points the facets enlarge. It is hard to keep these even as

<p>vessel in the planishing stage.</p>	<p>there is no stake to conform to. I can change the size and amount of facets by dividing the geometry of the mesh.</p> <p>The simpler the mesh the more likely the cursor jumps to surrounding points, dividing the mesh resolves this.</p>
<p>Stake moved in vice as I was hammering down onto surface which meant I had to constantly adjust and tighten the vice.</p> <p>Unfortunately at one point I did not notice and piece hit vice leaving a few marks.</p>	<p>As I am hammering piece down into Z axis after a while I am working on the inside of piece which makes it more difficult to see, but it is possible to hide the outer surface and see straight into the object by turning off double sided view under display properties in ZBrush®.</p>
<p>As the pressure for hammering needs to be consistent I was beginning to tire and arm becoming strained.</p>	<p>As the accelerometer in hammer head is always on when striking the mesh the cursor moves too. This makes it harder to achieve accurate striking and not hit the surrounding points. As a result striking is slow and considered to control aim and accuracy.</p>
<p>It was frustrating if I missed the stake when planishing as I had to replanish the form around again.</p>	<p>Although shade of mesh alters, it is difficult to see how much mesh is beaten in Z axis when view is looking straight down.</p> <p>Another solution is to move object by rotating in the surrounding space to be able to change the view. Perhaps could have device in hand stake that moves object.</p>
<p>I was aware towards the edges that cracking might occur.</p>	<p>Although there is no pressure the hammer strike is affected by the speed of tilt making strike deeper.</p>
	<p>It is possible to create default objects using the tool palette in ZBrush®, but I would</p>

	<p>not get the hammer effect.</p> <p>I am able to change the default colour of the mesh from red wax to silver make the mesh more realistic.</p> <p>Sometimes strikes do not register as button is not tight enough and allows room for movement sometimes not making contact.</p>
<p>Time taken to raise and planish finished piece</p> <p>14 hours over 3 days</p>	<p>Time taken to create digital object ready for output.</p> <p>5.48pm- 6.38pm</p> <p>1 hour and 10minutes</p>

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