Traces of emergence: an ontological unification of perception, artefact, and process

by

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Let us suppose that the idea of art can be expanded to embrace the whole range of man-made things, including all tools and writing in addition to the useless, beautiful, and poetic things of the world.

- George A. Kubler

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- *Form as an abstraction of mechanism* (2016), L. Urquhart & A. Wodehouse, Design Research Society Conference, 2016
- *The emotive qualities of pattern: insights for design* (2017), L. Urquhart & A. Wodehouse, International Conference for Engineering Design, 2017

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Glossary of Terms

- '**Designer-agent**'
  Term used broadly to describe the intentional actions of a designer or teams of designers in the development of products
- '**Ductus**'
  Concept from material culture studies that equates to the trace left by the processes of making or manufacturing that led to the creation or emergence of an object
- '**Computer-aided manufacturing**' **(CAM)**
  Software systems utilised to control manufacturing systems and often works in tandem with other process control systems like CNC
- '**Computer-numerical-control**' **(CNC)**
  System of automated geometric control of machines and tools utilising computers and software
- '**Emergence**'
  The coming-to-be of an object's properties that expand or add to initial properties
- '**Gestalt**'
  Psychological school of thought that argues for perceptual holism in which organisms perceive entire patterns or configurations, not merely individual components
- '**Human-centred design**' **(HCD)**
  Design philosophy, which highlights the importance of human experience in the overall understanding and framing of the design project
- '**Hylomorphism**'
  Theory of form developed by Aristotle in which form is composed of [primary] matter (hyle) and the [substantial] form of that matter allowing for the emergence of discrete and intelligible categories of things
- '**Interobjectivity**'

Concept from object-oriented ontology used to describe the emergent properties of interactions between objects

- ‘**Machining**’
  Manufacturing process that uses controlled cutting tools to subtract material to an intended form
- ‘**Materiality**’
  Term from material culture studies that describes the material basis on an object
- ‘**Modernism**’
  Period of art history broadly roughly from 1890-1950, in design, Modernism is characterised by the use of abstraction, simple geometry and an interest in functionality and utility
- ‘**Object-oriented ontology**’ **(OOO)**
  Philosophical theory that posits that objects exist and interact outside of human perception. The ontology is flat and hence does not give primacy to a human perspective
- ‘**Ontology**’
  The philosophical study of the nature of ‘being’ i.e. being in the world or coming to be
- ‘**Ontology of emergence**’
  The nature or route of an emergence event – how it comes to be in the world
- ‘**Pattern**’
  A set of tessellating shapes emerging from the application different symmetry operations
- ‘**Semantics**’
  The study of meaning or reference, applicable to a range of fields including philosophy or linguistics
- ‘**Texture**’
  The topology of a surface, its shape characteristics, roughness and smoothness
- ‘**User-experience’ (UX)**
  Subjective assessment of how a user interacts with and experiences a product, system or service. It may include a person's perceptions of utility, ease of use, and efficiency.

Introduction

Things men have made with wakened hands, and put soft life into
are awake through years with transferred touch, and go on glowing
for long years.
And for this reason, some old things are lovely
warm still with the life of forgotten men who made them.

- D H Lawrence

i. Meanings and patterns in objects

Objects are part of a complex matrix that contain emergent experiences and meanings. Ernesto Rogers once claimed that if a spoon was examined carefully enough, one could establish how the maker would design a city. While this observation from the great Italian architect may be an over-generalisation, it draws upon an important point – the objects that humans create are reflections of ourselves, our beliefs, our feelings, motivations, and drives. In short, our whole material and emotional culture. The study of design revolves around the dynamics between form, the processes of making and the diverse experiences of object interaction and use – ontologies of artefact emergence that articulate with the complex patterning structures and practices that produce all of material culture.

There are two dominant narratives we must consider when examining design as a practice of making. One, as a narrative of form evolution derived principally from a *hylomorphic* designer-agent ontology[1] and the other, as a narrative of making and manufacturing understood through ontologies of matter manipulation. The relationship between the two narratives, this work will argue, presents deep and poorly

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[1] 'Ontology' is traditionally understood as the study of the 'nature of being'. Within this thesis, the term is used more technically to describe how things 'come to be' in the world – following Heideggerian developments (see Harman, 2002). This tracks closely with other discussions of ontology, for example in Thacker's (2010) explorations of ontologies of 'life' and 'creation' or in design thinking concerning making ontologies, manufacturing approaches and computational approaches such as object-oriented programming, all of which will be explored.

understood problems with respect to the current taxonomies and ontologies describing advanced manufacturing, limiting the conceptual evolution of design thinking and processes of making and manufacturing. Moreover, this work will argue that pattern and patterning motions is a key meta-concept for understanding design practice that has until this point, received a limited amount of attention. While there are emerging paradigms of research including Industry 4.0 and 'new materialism', these have not comprehensively addressed the core disconnect between understanding process and understanding perception. The new materialism mostly explores the making processes of 'craft' - which have an important relation to and are indeed antecedents of advanced industrial processes – that do not include the conceptual innovations of advanced process control, CAM for instance. Industry 4.0, while offering interesting insights and innovations in terms of process control does not tend to examine the assumptions that go into forming its conceptual landscape – process 'optimization' or defect minimization are for instance seen as by definition, good.

If the history of industrial design as a practice is examined, or the history of what we might call expression through artefact creation, it is possible to see this complex relationship between perception and process more clearly; where it succeeds and where it fails. The multiplicity of design aesthetics and styles that humans have created over the centuries is testament to the fact that we inhabit lives orientated by a material culture and the intrinsic meaning derived from object interaction. The psychological connection that is felt towards loved pieces of jewellery or clothing is both a reflection of a cultural relationship and a material relationship driven by interaction, emotion, and use. Design has deep symbolic value that is driven by these semantic associations. How the processes of making and manufacturing interact with the symbolic values of objects is the core question of this work. Considering the use of pattern within design – the ordered configuration of elements– can help to unpack this question and will underpin the studies of visual and tactile interactions presented within this work. Pattern indeed is presented as a core meta-concept within design, operating at multiple levels including at the level of aesthetic symbolism and at the level of process control, and the principal medium by which these questions will be explored

Questions about how pieces of design, 'things', 'objects', 'products' or 'artefacts', convey meaning must partly be driven by an understanding of visual form and how form is conceptualised and understood. While the nature of form has been debated since antiquity, the modern studies of aesthetics in design are concerned with kinds of experience that are elicited by form. Much recent research in design for example is focused on the emotional bonds that are created between products and users and the meaning that is then drawn from these emotive bonds. What is clear, and will be argued throughout this work, is that what can be called form expression across time is a process that is visible across multiple disciplines and is deeply bounded by technology and dominant cultural ideas. Why is it possible for example to distinguish a building from the 18th century from a building made in the 1950s? This is partly a question of aesthetics and form experience, but it is also a question of making and materials and the socio-cultural interaction between the two.

ii. What design is and what designers are

It is important to frame this research; who it is for, what it is addressing and how it should be approached. The research is centred around design and how design articulates with the physical processes of making and manufacturing. On this basis, we must ask what is meant by design and what is a designer?

Speaking broadly, design can be defined as a plan or a formulation. More specifically, in refers to the embodiment of an object and the defining of associated elements such as functions, materials, or assembly. What has come to be called 'industrial design' roughly developed through the industrialisation of traditional craft practices in the 19th century[2]. Since then, the practice of 'designing', has become professionalised with entire design-education conceptual and theoretical paradigms being debated The theorist of design, Bruno Munari, stated that the role of the designer was to mediate between society and the art, introducing new modes of experience to human life. While the culture of design has changed a great deal since Munari's time, the overall goal of design remains as this mediator. Essentially design can take the abstract, theoretical or

[2] That being said there are many types of practices dating back to the ancient world which can fit a similar conceptual description (though the application may be anachronistic at times, see MacGregor 2011)

purely aesthetic and operationalise it within the context of 'function' or 'societal utility'. This is the definition of design that this work will focus on. Though there will be frequent discussion of craft based practices, the key focus will revolve around this key articulation between the aesthetic and the societal - the abstract interfacing with the functional.

But what are designers themselves? Perhaps this is not so straightforward a question and may require another thesis in its own right. Nevertheless, it is important for the foundations of the discourse to understand this. In simple terms, a designer is someone who implements 'design thinking' in order to solve problems where design thinking constitutes the systematic analysis of the problem through a range of structured methods. These methods may include the well-known practices or sketching or prototyping but also specific techniques such as 'human-centred design', 'design interaction' or 'empathic modelling' or technical methodologies such as those developed by Pugh (1990), Ulrich and Eppinger (1994) or the design consultancy IDEO.

In terms of the act of creation though, these activities are usually described as being directed by an individual actor or a team composed of actors – the 'designer' or a 'design team'. While this is not without its pragmatic utility as a description, it does encode an explicit hierarchy in which human action is paramount and the recursive problems of human life are constantly iterated upon (Flusser 1999/2015). The question for us is how can the position of the designer be ontologically recast? Perhaps design is not so much about the designer but the dynamic process that the designer or design teams find themselves enfolded within. This will be a key assumption moving forward; that the active paradigms of design thinking position the human actor – whether individually or operating in a group – as the apex of the creation hierarchy. To summarise:

- *Design/designing will be considered the act of embodiment of an object-product and the defining of associated elements such as functions, materials, or assembly utilising structured methods*
- *A designer will be considered as an individual or group who implements 'design thinking' in order to solve problems where design thinking constitutes the systematic analysis of the problem through a range of structured methods. Designers are actors enfolded within the processes of product creation and embodiment*

iii. Experiences of design

Design research started in order to establish a set of scientific principles that could describe design practices as sets of coherent methodologies. While this has had varying success, the more recent evolutions in design research seek to establish how objects interact with our psychological and physiological facilities. This research will be continuing this tradition of study and expanding beyond it by incorporating concepts from material culture studies including object materiality and making. The experiences that users have with objects is deeply complex and is one that must both reflect on the perspective of aesthetics and form but also on the processes of making. Much of the work that will be discussed within the literature review to come has assessed how meaning and value is attributed to objects of different shapes and of different materials. These beliefs about designed artefacts are not driven by rational evaluation but are embedded deeply within a psycho-social matrix of emotions and culture. The question for design researchers is to establish how our practices of design can be improved to reflect our best selves and to improve aspects of human life and human experience. The critical movements in design for emotion, Kansei engineering and design for interaction are illustrative of a philosophical shift in design culture that champions the subjective experience of users. Broadly, these sets of approaches and methods are varieties of 'Experience Design' (UX) or 'Human-Centred Design' (HCD). These methods treat people not as passive utilisers of products and other artefacts but as active participants in the material and functional interaction that the objects facilitate. Design for emotion will form one of the critical narratives within this work and will be explored as parts of the wider context of user-experience.

iv. Notions of making, materiality, and manufacturing

All human-made objects in the world have some kind of material basis and have been created through some process of making – this is the fundamental ontology of emergence that underpins design. The hylomorphic models of making deriving from antiquity have exerted a huge influence in ways of thinking about and investigating design and other human practices and technologies (Ingold, 2008). As will be explored in depth within this work, perspectives that view the designer as a master manipulator of matter fail to recognise the material as an actor in the process too. Recent trends in design research and material culture studies have sought to redress this perspective through a series of conceptual shifts of which this research will contribute. In what has been labelled the 'material turn' or the 'new materialism' (Woodward, 2007), scholarship has evolved to consider design from the point of view of makers, materials, and manufacturing. Properties of form are important, but they are not all that drive a semantic evaluation or an emotional experience. The trace of a process of making and the materiality of an object also plays a role. An old stone building decorated with an ornate pattern for instance may still reveal the marks left by the people who built and shaped it giving it more emotional weight and meaning than a modern building made from synthetic materials and automated production methods. Much of the work presented within this thesis will explore this problem and how today's production methods can be reframed to explore the qualities of object materiality through the lens of pattern and texture and an object-oriented approach to understanding the procedures and 'interobjectivities' of technical making.

v. Scope of the work

With use of a mixed method approach, combining qualities of positivism and interpretivism to structure the work, the overall scope explores several complex areas. Firstly, the work will have implications for form theory and aims to expand knowledge in experimental aesthetics by considering pattern (as a core design practice) in more detail. In relation to this, the work will examine the possibility of creating bespoke emotional experiences through design work. This phase of the work can be considered the abstract phase that will not stray too far into the material world. The phases to follow will consider the nature of making in the context of contemporary manufacturing technology more closely and the ontologies underpinning these. To examine these principles, we will engage with the processes of making themselves, bringing the two-dimensional abstract world into a material physicality with the creation of pattern-based textures. By focusing on modern advanced processes, we can extend the conceptual basis of *making* in material culture scholarship to contemporary practices relevant for today's designers and engineers. Additionally, several publications were developed in association with the practical and theoretical aspects of the work presented within this thesis and these are listed within the Contents pages above.

vi. Aims and objectives

The core aim of this work is articulated as follows:

To develop a novel ontology of form emergence integrating notions of materiality and making with protocols for advanced modern manufacturing practices to expand the conceptual and operative schemas in which modern manufacturing is deployed within the context of product development and the built environment.

With respect to this core aim, several critical objectives can be advanced in order to frame the requirements of the work more carefully:

1) *Establish a practical and empirical basis on which to assess emotional design that can challenge traditional ontologies of form emergence and feed into the development of a new ontology*
2) *Develop bespoke emotive designs as a means of further exploration into artefact materiality and making processes*
3) *Establish a suitable advanced process to explore in greater detail*
4) *Explore this process to suitable depth establishing a property of the process to investigate further within the context of form, aesthetics, and interaction preferences (UX and HCD methods)*
5) *Consolidate information in the development of a new ontology for integrating HCD and UX qualities with advanced manufacturing protocol*

vii. Overview of thesis structure

The structure dictates that the thesis is broad in scope with the narrative of the work designed to be discursive in nature to connect multiple themes and topics. Firstly, the core literature will be examined, providing a foundation for further thinking around form theory and experience, materiality and making and manufacturing practices. This sees form examined as an abstraction culminating in the analysis of line and the introduction of pattern as a medium by which to advance the study of form experience within the context of manufacturing and making. This abstraction is reversed when pattern is explored as the key meta-concept within manufacturing bringing the discussion back to the analysis of physical objects as fabricated by the advanced processes of industrial manufacturing. Accordingly, bringing the research full circle from an analysis of physical form to abstracting form then to bringing physical form back presented new theoretical avenues to explore. The logic and triangulation of this culminates in the development of a new theoretical model of manufacturing offering new space in which perceptual experiences are combined with the physical processes of making within a unified ontological architecture. Table 1 provides a breakdown of the key structure and outputs.

Table 1 – Breakdown of thesis structure with key outputs

Chapter	Key outputs	
1	**LITERATURE REVIEW (Chapter 1)**	Form theory Design and emotion Design and semantics Object materiality Processes of making
2	**METHODOLOGICAL APPROACH**	Review of appropriate research approaches Outlining of selected approach
3	**1^{ST} STUDY OF FORM AND EMOTION**	Exploration of useful psychological and semantic models to examine form. Establishment of line expression as means of analysing form and perception
4	**2^{ND} STUDY OF FORM AND EMOTION: USE OF PATTERN AS AN AESTHETIC TOOL**	Line exploration advanced into tangible and symbolic forms through an exploration of pattern; complete abstraction transformed into objects with semantic meaning
5	**DEVELOPMENT OF BESPOKE PATTERN DESIGNS +** **MANUFACTURING REVIEW AND SIMULATION**	Amalgamation of line and pattern analysis to create bespoke form that are tied to perceptual experiences Distillation of CNC machining as key area of focus for the exploration of manufacturing

		ontologies and the application of design emotion within the context of making processes
6	**3RD STUDY OF FORM, HUMAN FACTORS AND MAKING PROCESSES: INTERACTING WITH PATTERN-BASED TEXTURES**	Key contributions to knowledge and building of new theory within the space of form perception and form emergence through manufacturing
7	**NEW THEOERETICAL GROUND: NOVEL ONTOLOGICAL ARCHITECTURE UNIFYING HUMAN FACTORS AND PROCESS PARAMETERS (Chapter 7)**	Unification of themes explored within the thesis in the creation of new ontological architecture by which advanced manufacturing processes can be viewed
8	**CONCLUSIONS**	Summary of knowledge contributions

viii. Limitations of the thesis

While the overarching goals of this work are quite large in scope, it is important to note at this juncture how the work is limited. The work is both conceptually and practically limited in three key ways:

1. **Limited by its Western orientation**

While there has been some effort to explicitly explore a variety of viewpoints, this work remains Western-centric. The studies presented in the work included numerous participants from non-Western backgrounds but the discussions, interpretations and conclusions cannot be simple detached from the Western positioning of the researcher and the wider culture and society in which the research took place.

2. **Limited by the scope and scale of the experimental work**

The experimental work contained within the thesis has several implicit limitations. Firstly, the sample of participants was a convenience sample i.e. built up mostly of design and engineering students willing to participate in the research. Thus, this sample was not subject to a rigorous statistical analysis, making the conclusions less concrete.

3. **Limited conceptually by trying to bridge a gap between an ontology (specifically, an ontology of form-emergence) and phenomenology (specifically, perception and emotion)**

Perhaps the most important limitation are the work's conceptual problems. Put simply, this is the attempt to bridge an ontology of form-emergence with aspects of perceptual experience or phenomenology i.e. the world of phenomena. This presents a problem of philosophical approach as these fields have traditionally been thought of as incommensurate, notwithstanding several attempts to create coherent links by thinkers such as Heidegger (see Harman, 2002). With respect to this, the ontological positioning and the discussion of the phenomenological aspects of the work should be viewed with some caution, though any shortcomings or speculative conclusions in this regard are explicitly stated through the narrative of the work.

1. Critical review of literature

When mass production severed the connection between maker and user, design started to take on meanings other than those given it by the decorative arts. Design became an assertion of modernity

- Deyan Sudjic

1.1 Introduction

This work will explore how notions of materiality, design semantics and user experience can be framed within a novel ontology of modern manufacturing – bridging a conceptual gap that has long been outstanding. A prevalent belief of creation exists within design practice. This belief posits that form is fabricated by processes of matter manipulation contingent upon the intentionality of a designer-agent. Though ostensibly reasonable, this is a belief that is present within many creative design sectors and is challengeable on several levels. With a careful examination of history and current research trends, it can be demonstrated that design and the realisation of form has a complex basis in material culture and agency makes up only one piece of what can be referred to as an 'ontology of emergence'. This critical review will examine several of the principles that underlie design, form, and user experience and seek to challenge the prevalent narrative of designer-agent contingency. Following a general overview of how form is defined and conceptualised within the practice of design, we will consider how technological change and the ideas of Modernity transformed human relations with the material world. This will lead to the phase of discussion that will explore human-centred design (HCD), design interaction, design and semantics and design for emotion and how properties of artefacts can influence the overall experience of users. After examining these new movements in design thinking, notions of 'making' and 'materiality' will be considered in more detail. The ways the processes of making and the material make-up of objects interact with an experience of use is a hugely complex area, one that scholarship within material culture studies can help to answer.

When form is realised, made physical or fabricated through manufacturing technology and protocol; this new object physicality opens new doors of object experiential content such as tactile materiality and visual weight and depth. It is these factors of created artefacts of products[3] that build what is now referred to as an emotional experience for a user[4]. But how does the trace or imprint of fabrication affect this experiential dimension? It is well demonstrated that production materials can affect how products are evaluated emotionally and semantically to the point where certain materials are used to construct aesthetic moods. What is described as a 'rustic' aesthetic, for instance, is driven by the subjectively perceived material qualities of wood and stone interiors that articulate with cultural standards. In this same vein, the imprint of fabrication can lead to an aesthetic – stonework can be chiselled to a rough or smooth finish, but the imprint of the process remains as evidence of the fabrication method. This imprint, or the evidence of a *contingent* process from which the form is created is present in all manufactured artefacts. Depending on the nature and complexity of the artefact, it can be strongly evident or be more difficult to detect. Part of what this work will explore is how detection and awareness of this imprint alters our emotional engagement with form. How the connection between the artefact and the process of creation has been lost and how it can be recaptured.

The set of practices known as Kansei engineering orientates the act of designing around the psychological perception of potential users (Nagamachi, 1995). Seen as part of the shift towards semantics within design practice, Kansei engineering is illustrative of how the landscape of design is now increasingly concerned with the abstract experiences of users and less with functionality. The materiality of objects additionally being deeply connected to an overarching product experience (Karana, Pedgley & Rognoli, 2015). Kansei engineering and other design philosophies that mark this shift will be explored in greater detail throughout this chapter and will form one of the core considerations of this work along with emotional design, design semantics, materiality, making

[3] For the purposes of this thesis the words 'objects', 'artefacts', 'things' and 'products' can be seen as equivalent. When a meaningful distinction is needed, it will be described.
[4] A 'user' refers to a human actor that interacts with an artefact on some level - visually, physically, or emotionally.

processes and manufacturing ontologies. To begin, the concept of form and its multifarious meanings will be explored.

1.2 The nature of form

In the context of creative expression, *form* has a multitude of meanings. As an initial stage in this review, the concept of form will be explored, and a set of working definitions offered. What is important in this discussion is how form relates to the process of design, production, and fabrication, and will provide a foundation for the developments of the predominant arguments within the work. This initial exploration will examine two fundamental questions; what is form? and how does it relate to the act of creation? These questions are complex and must draw upon several strands of scholarship to answer.

1.2.1 Form: multiple meanings and definitions

Generally, form can relate to an underlying logic or rules-based system which defines or contributes to an overall structure. This is seen very directly in descriptions of language. What is described as the 'form of the language' is a description of its structural elements: its grammar, its words, letters, and syntax. All these elements provide content, and the configuration of the content constitutes its form. For this reason, we might say 'academic writing' is of a different Form to 'fiction writing' – the configuration of its content is detectably different on a semantic level and leads to separate categories of description and meaning.

Like written and linguistic form, musical form can also be considered in this way. The form of a musical composition refers to its overall plan or what Richard Middleton (1990) has called the 'shape' or 'structure' of the work. Like linguistic form, there is the same basic underpinnings – standardised rules that define it in one way or another or what Chomsky (1957) has called a 'universal grammar'. For example, the form of a Beethoven concerto differs from the form of a modern techno composition in a variety of identifiable ways. While the broad category of 'music' still applies, the sounds, tempos, instrumentation all change from which emerge new categories and genres of music that were unimaginable previously.

Essentially, form is the abstract notion of the arrangement or configuration of content. In the visual sense, form denotes an arrangement of detectable geometric elements (see Hann, 2012). This is the most important genre of form and a crucial consideration for the discussions of this work. Definitions of visual form are diverse. Some definitions pertain to a measurable shape or geometry – something with length, breadth and height, others consider form as collections of shapes or arrangements of geometric elements. Hann (2012) for example explicitly defines form as consisting of four key elements; *shape, line, point* and *structure*. From both perspectives, form is seen as a kind of ordering of visually detectable elements – these elements, which visually are the building blocks of discrete shapes, will be looked at in more detail later as we consider the cognitive processing of form.

Visual form is the central exploration of the aesthetic arts. Be it painting, sculpture, film, architecture or industrial design, the visual domain is the axis on which the formal elements rotate. To take the example of painting, formalistic interpretations of art say that understanding and appreciation of the work comes from its visual elements purely, its form and composition (Zangwill, 2001). To go one step further – the visual elements of the work define its category or genre. The geometry within the work denotes an overall form, this form denotes content and a meaning. In this traditional view, Form is the most important component for understanding a work of art. More recent developments have sought to break down this view by subverting Classical principles of aesthetics and materiality that had held dominant for centuries in Western culture. This roughly began in the late nineteenth century with the development of the Impressionistic styles in central Europe (Tinterow & Loyrette, 1995). Impressionism radically challenged the classical notions of form and questioned what it meant to *perceive* something. Instructed by earlier artists such as JMW Turner, the Impressionists broke down conventional realist and academic depictions of subjects by applying paint more freely and directly onto a canvas, sacrificing detail for an 'impression'. By subverting the academic standards of the time, the Impressionists were forerunners to the Modernist movements of the late nineteenth and twentieth centuries that introduced the concept of abstract representation into mainstream art, sculpture, and design.

While the form properties of the works changed radically, the transition was facilitated by a quantifiable change in the use of medium. Instead of being applied slow and methodically to build up detail, Impressionism used loose brushwork with bold and striking colourings. Similarly, in the world of sculpture, the way form was gradually fabricated transitioned hugely away from a Classical and realist style. Subject matter often remained the same, but the meaning of the works shifted because of their contingent medium and the application of that medium. Consider the work of Modernist sculptor Constantin Brâncuși, *Danaïde* (completed 1918) compared with a Neo-Classical work depicting Clytie (Figure 1). The content of the works remains similar as there is a patterning process at work, but an entirely different experience of the works is generated from their distinct aesthetics, materiality, and historical context. One grasps at a formal ideal of beauty that dominated the Classical Western culture, the other seeks a beauty through the Modernist concepts of abstraction, subjectivity, and impressionism. In the object-oriented ontological view, the 'interobjectivity' of these two pieces is distinct (see Morton, 2013). Harman (2002; 2018) has for example argued strongly that aesthetics including experiences of all kinds should be understood through a 'flat ontology' of object interaction where being is constituted not through human will or intentionality but through a nexus of relational 'objects' that include the artist the material and the world at large.

Figure 1 – Modern sculpture compared with Classical sculpture[5]

[5] Sources: Free image via: [Brancusi work] and nostri imago via Wikimedia Commons: [Neoclassical work]

In a similar line of reasoning, it has been argued that products are also formations of visual elements that interface with an idea of functional expectation. As Folkman (2018) has contended, the form of industrially produced products presents insight into how the humans epistemically conceptualise the world – bounding knowledge into functional devices. New strands of scholarship in material culture have sought to understand the human relationship with objects and why designed artefacts with varying degrees of use value are purchased and collected (Woodward, 2007). Naturally, the relationship with objects has transformed over time as a function of complex cultural, technological, and social changes. All these factors in part influence the output of the aesthetic arts including the visual elements of designed objects that are constrained by a dependent functionality. A building created in Tudor times has a distinct embodiment that places it within a historical, cultural, and technological context. Its difference, the feeling of distinctness that is experienced by 21st century people within these historical pieces of architecture tells us how powerful the aesthetic and material experience of design is.

1.2.2 Gestalt: form and perception

As psychological sciences developed during the turn of the 20th century, many became more interested in how perception guided aesthetic experience. The Gestalt theorists were some of the first to analyse perception in detail. The central concern of the Gestalt theorists lay in how objects, forms and structures are cognitively grouped and/or abstracted by humans as they are viewed, their central mantra being; the whole is *other* than the sum of its parts (Ellis, 1938). They proposed several principles that influence perception of visual aesthetics, the so-called 'principles of grouping' which include proximity, symmetry, similarity and closure amongst others (Wertheimer, 1923). These principles are part of a wider theory of how we cognitively process visual elements and how (to include Gestalt's recent research trends) shapes can lead to meaning creation (Pinna, 2010).

The famous optical illusion produced by the Gestalt school, shown in Figure 2, illustrates their theories of the holistic perception and processing of forms. These images are optical illusions; with respect to the image, a triangle is visualised in the centre with partial circle objects extruding out from it. In reality, there is no triangle, the illusion is a product of how the entire image is cognitively processed. Instead of being understood as several discrete elements, it is understood as a whole and acquires meaning. The same effect can be considered for the image to the right. Review work by Pinna (2010) explored a wide variety of different optical illusions constructed and explained by the principles of Gestalt. Pinna extended the Gestalt principles to incorporate a meaning-making process. As Pinna suggests, the Gestalt principles of grouping forms cannot fully explain the nature of these meanings but there appears to the observer a 'sense of happening' within the structure of the observed forms: the meaning spontaneously grows from the context.

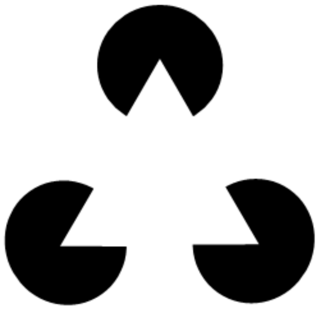

Figure 2 – Gestalt illusion: a triangle emerges from the cognitive experience of the arranged geometry[6]

Norman's (2004) model of form experience (which will be discussed in more detail in Chapter 3) differs from the Gestalt theories of perception; arguing for example that the superficial appearance of the product, the 'visceral' level of engagement, is but one in a trinity of distinct experiences. In earlier work, Durgee (1988) agrees with Norman's (2004) model by suggesting design is experienced atomistically, meaning that form experience is linear where each design or compositional element, the presence of a door or button for instance, is processed one at a time, contrasting the holism of Gestalt theory. Bloch (1995), however, argued that both interpretations may be true on some level.

Rudolf Arnheim's work, *Art and Visual Perception* (1954) described how the experience of viewing geometry, be it highly structured and composed or more abstract is fundamentally a process of reasoning or a form of visual judgement, a judgement which is indispensable from the act of seeing itself. Arnheim explored a substantial number

[6] Source: Mrmw via Wikimdeia Commons: [Gestalt illusion]

of visual perception phenomena that influence how forms are interpreted semantically and emotively. What is described as a 'perceptual force' (p.6) is one of the principal concepts that gives visual perception its dynamic qualities. This force is derived from the visual context of geometry in a similar logic to the Gestalt theorists. For instance, a set of shapes may appear to have a sense of direction and movement as if being acted on by forces (echoing the later work of Ingold, 2008 that will be discussed later). Speaking on the nature of shape and form directly, Arnheim noted that form is interpreted holistically – a person will identify the doggishness of a shape before they are able to discuss the differences between separate dogs (the Platonic ideal). This observation distils how meaning is indelibly linked to form perception. The concept of shape, Arnheim (1954, p.37) states as the 'boundaries of masses' and form as a kind of orientation and configuration of shapes whereby certain connotations can emerge from dynamic interactions. The overlapping of visual elements can lead to a sense of unity for example. A summary of form definitions is provided below in Table 2.

Table 2 – Summary of form definitions with key theorists from the Western philosophical traditions

Theoretical form definition	Description	Key theorists
Platonism	Form is a shadow of an ideal form existing in a non-temporal and non-spatial realm of 'ideas'	Plato, Walter Benjamin
Hylomorphism	Form is defined by matter and the shape of that matter	Aristotle, Aquinas
Atomism	No overarching form, only constituent parts	Democritus
Renaissance idealism	Form defined by principles of proportion, perspective and measurement	Vitruvius, Alberti, Da Vinci
The 'Sublime'	Form defined by a standard of aesthetic beauty and awe	Longinus, Kant, Hagel, Hogarth
Gestalt holism	The context and arrangements of elements are experienced holistically creating a Form impression	Koffka, Wertheimer, Arhneim

Morphogenesis	Form as a result of spontaneous or generative growth (biological organisms)	D'Arcy Thompson, Turing
Interobjectivity	Object-oriented ontology in which form is a property of 'object' interaction	Heidegger, Morton, Harman

1.2.3 Form and the conceptual ideal

Visual form or the 'aesthetic' is an intrinsic property of physical objects as perceived by human beings. Centuries of philosophy and aesthetic theory have aimed to unravel the experience of the aesthetic and explain the powerful emotional impact it has on humans and other animals. Classical conceptions in the West have been concerned with how to define the *essence* that constitutes an experienced category of aesthetic form. For example, it can be asked, what element or set of elements will constitute a horse or a chair? It is not effective to answer that they both have four legs; the fact of four legs does not give insight into the essence of either category. Pre-Socratic philosophers, troubled by observed change within nature, thought that physical things must contain some property they defined as *substance* that allowed the thing to retain its essential properties - its essence (Curd, 2020). Democritus for example proposed that the world was built from indivisible elements that he named 'atoms'. Following the Pre-Socratics, Plato influentially proposed that forms experienced in the physical world were imitations or 'shadows' of an *ideal* form that existed only in a metaphysical and epistemically unknowable state. In this view, the world of forms represents the most accurate reality, experienced reality is a world of shadows that contains only imitations of actual essences (see Ainsworth, 2016). This conception of form is a kind of solution to the philosophical question known today as the Problem of Universals, or how do we determine properties of things? The later Aristotelian view known as *hylomorphism* expanded upon and changed the Platonic conception by stating that essences are comprised of both matter (hyle) and form (morphē). For instance, the essence of a brick house comes from the brick matter that composes it – its form coming directly from the agency and intentionality of the creator and the creator's manipulation of the matter.

Plato and Aristotle were born into a Greek culture that had had an orthodox aesthetic and structural tradition in art and architecture for hundreds of years. This period, now referred to as the Classical Hellenic period adopted an aesthetic of naturalistic idealism. In the art of this period (dating from around 750BC) the form of humans or animals is represented as realistic but with idealised proportion and symmetry (Berlin & Pollitt, 1986). Similarly, in the architecture of the time, the structural design is one of visual simplicity, proportion, and harmony (Taylor, 2003). This Classical architecture has come to exert a profound influence on architectural thought and subsequent practices in industrial design. As the styles were widely adopted by the ancient Romans, there is the use of Classical designs all over central Europe and parts of the Middle East during early and late antiquity and the middle-ages. The reverence in which later European peoples saw the ancient Greco-Roman civilisations would see an extensive revivalism in (neo)Classical architecture and design where ornament was the dominant aesthetic element of the overall design. This was seen paradigmatically during firstly the European Renaissance in which the sensual and mystical aesthetics of the middle-ages were reformulated through a lens of rationalism. The widespread use of perspective, measurement, symmetry, and proportion entering the art and design of this time is testament to this cultural shift (Carman, 2014). This culture, along with fundamental developments in the political fabric of European society, culminated in what is now referred to as the Enlightenment period, one in which the dominant aesthetic idea was that of ‘the sublime’ in which beauty was defined as a mixture of an abstract sense of perfection with immensity and awe (Kant, 1764/1961). For instance, the painters of this period focus on epic landscapes, often including Classical buildings within the composition.

The Classical revivalism that foregrounded much of 18th and 19th century design in the West was soon to be supplanted however by a new ideal where beauty was not indicated by ornament but by utility, a machine beauty. With links as far back as the late seventeen hundreds (according to Pevsner, 1936/2011), the movement now called Modernism radically reconceptualised design and how form should be used by the designer. As will be explored later in more depth, the preeminent examples of Modernist design attempted to dispel a notion of ornamental beauty and focused on creating *functional* objects of architecture and industrial design. The aesthetic of

Modernist design, the reframing of form as the tool of the functionalist engineer now dominates our contemporary world.

Figure 3 – Modernist high-rise flats in Glasgow, Scotland[7]

The image above of high-rise apartment buildings in Glasgow are typical examples of Modernist architecture (Figure 3). The buildings are functional and ergonomic, meeting the core needs of the inhabitants but sacrificing aspects of ornamentation and materiality. The question this development in design raises is how forms like this affect people at an emotional and psychological level. Experientially, the designs that Western peoples grew accustomed to over the past six or seven centuries was one that was saturated with different sorts of ornamentation, symbolism, and a deep material sense (Ingold, 2013). Forty (1986) in a wide study has detailed how before the modern movement, personal and household objects were produced with ornate detailing often aimed at specific markets. Different kinds of ornamentation were used for male and female markets for example, a trend in consumer products that has continued to this day. As will be explored in later chapters, there is a wealth of complexity relating to social, cultural, technological, and psychophysical conditions that explain the aesthetic story of industrial and architectural design. Modernism matured in a world hollowed out by war at the turn of the 20th century and is in some ways seen as a radical rejection of the old world from which its founders were so scarred (Pevsner, 1936/2011). It is this rejection though that has caused a disconnect to emerge between the creations and the

[7] Source: Will Craig via Wikimedia Commons: [Glasgow high-rise flats]

creators. Early critics of some aspects of modernity noted that the mass production of objects may change art and design profoundly. The poet Paul Valéry in 1928 observed:

'Our fine arts were developed, their types and uses were established, in times very different from the present, by men whose power of action upon things was insignificant in comparison with ours. But the amazing growth of our techniques, the adaptability and precision they have attained, the ideas and habits they are creating, make it a certainty that profound changes are impending in the ancient craft of the Beautiful.' (Paul Valéry, 1928; reprinted in Benjamin, 1935, p. 1)

Valéry realised that advances in industrial technology and society could spell a huge amount of change for definitions of the beautiful. Walter Benjamin (1935), following the logic of Valéry, argued that the process of reproduction, while not a uniquely modern phenomenon, degrades the authenticity of a work, removing its historical and temporal connection to its process of creation. The reproduction of a painting on a postcard for example, is distinctly removed from the actual work due to this lost connection and lack of what Benjamin refers to as the work's '*aura'*. As an extension of the Platonic view, Benjamin sees a reproduction as a shadow, an imitation of an essence that exists physically elsewhere.

The question this discussion raises is, how has modernity affected both the conceptions and experience of form? This work is focused upon design which is a practice of creating artefacts that interface with some perceived functional value (Parsons, 2015). On this basis, it must be examined if these functional objects have an 'essence' (following Plato) or an 'aura' (following Benjamin). Discussion around design theory and philosophy offers a variety of answers. As design can be considered as a uniquely complex activity that interfaces with so many properties of human experience, an answer must be granular and complex. Following the work of Benjamin, John Berger (1990) in a praised series of lectures argued that the perception of the work of art or design relies of the social context which produces it and the context in which it is presented. Notions of 'normality', convention and cultural orthodoxy are seen as barriers to other modes of experience or understanding. In a similar line of reasoning, McLuhan & Fiore (2011) observed that the way that a message is presented can change that nature of how that message is understood and processed by an individual or a society at large. With the rise of the Guttenberg printing press for example, the codex became the standard by which information was presented, all but erasing the oral tradition that preceded it. Something similar, this work will contend, has happened with the design and creation of functional objects. There now exists a substantial ontological disconnect between the primordial creation of materially engaged artefacts and the post-industrial, technologically facilitated production of objects.

One such group that introduced a sceptical model of form perception and realisation were the Gestalt theorists of the early 20th century who proposed that form is not rationally delineated, it is holistically experienced. Additionally, the anthropologist Tim Ingold (2009) has explored this disconnect in depth. Ingold refers to the pervasiveness of a rational, linear, and technological view of creation that relies on the Classical views of Aristotelian hylomorphism. In his study of lines, it is noted how technologically enhanced navigation methods have degraded more organic and creative types of exploration that existed before the Western scientific models of cartography (Ingold, 2008). Voyages that were made into a space have been reframed as point-to-point linear journeys through a space. A similar reframing has occurred in design. Where once the presence of the methods of creation was apparent everywhere, the materiality of craft was part of the everyday experience of using and interacting with objects; advances in technological fabrication have removed this imprint of fabrication (Karana, Pedgley & Rognoli, 2015). While some movements and approaches try to challenge the rational linear model such as morphogenesis, orthogenesis or biomimicry, philosophies that see form as a process of growth or progress through growth (e.g., Thompson, 1917), the models inherited primarily from Enlightenment based Modernism prevail.

1.3 Technological relationships of modernity

1.3.1 Design and modernity

One of the preeminent figures of Victorian industrial design, William Morris, sought to re-establish the culture of high craftsmanship which he felt had been eroded by the technologies of mass production (Pevsner, 1936/2011). Morris and other figures such as the artist and critic John Ruskin hated aspects of modernity that they felt diminished the ornamental beauty of pure craftmanship. While this must be taken in context with some of their political views, Morris (1882) noted before the rise of Modernism how the link to material culture of creation could be lost through mass production and industrialisation. While some such as Morris and others associated with the Arts and Crafts and Aesthetic movements protested against the growing industrial and capitalistic society, others were interested in exploring the new. Pevsner (1936/2011) has noted, for example, the enthusiastic application of wrought iron in architecture from the end of the 18th century onwards in Europe. The preeminent examples of this being the Coalbrookedale bridge in England completed in 1779 and the Eiffel tower in Paris, built from 1887.

This new mode of material expression was influential and foresaw the developments of the Modernists over a century later. While the roots of the Modern movement are very complex, it is clear that the advancing technological capability and a growing sense of Enlightenment rationalism and aesthetic abstraction contributed to its gradual evolution (Payne, 2012). Pevsner indeed recounts that many artists, architects, and designers notably Peter Beherns, Charles Rennie Mackintosh, Josef Hoffmann and Tony Garnier embraced a new structural approach to design and material use in the first years of the new century. The Bauhaus school in Germany (1919-1933) produced some of the most radical work around the same time. The cultural implications of the wider Modernist will be examined later but at this point it is important to consider the Bauhaus and its influence on shaping thinking around design and aesthetics. As argued by Flusser (1999/2015), Modernism was effectively an extension of a European Enlightenment project that saw an inevitable moral progress through technology and new expressions of form. The Bauhaus tutors and students practised a kind of design that saw beauty embedded in function – create something perfectly functional, then it will be intrinsically beautiful, so went the logic. This is captured in the much-quoted edict ‘form follows function’. The banishment of ornament, it was proclaimed, would liberate objects and built spaces allowing them to become realms of abstraction, function and rationalism. This core philosophy that was prevalent within the Bauhaus had very complex roots. The school’s founder Walter Gropius for example had a deeply conservative attitude to craft, wanting to preserve the material knowledge of craftspeople and apply it in novel ways within the new progressive educational framework of the school (Sudjic, 2014). The culture of preservation and collaboration between disciplines was equally met with a culture of expression and experimentation as the school shifted both in terms of curricula and politics. Two of the schools leading figures, Marcel Bruer and Mies van der Rohn (who became the schools director in 1930 until its closure) both made pioneering use of new technologically derived materials to design furniture. Bruer's cantilever chair Model B32 shown below (Figure 4) was the first application of tubular steel within the context of industrial design and remains one of the most important icons of Modernist design.

Figure 4 – Marcel Breuer's tubular steel chair (1928)[8]

It could be argued that many of the early concerns that Morris and others expressed did not present themselves within the deeply modern approaches of the Bauhaus. The culture of design and production that the Bauhaus helped to develop has however had a lasting influence. While the philosophy around Modernist design was strongly liberal with an aim of creating high-quality products that working people could afford, it is unquestionable that factors such as corporate interest and consumer culture have eroded this goal, more interested in Modernism as an aesthetic rather than a use-value orientated design philosophy. Following on from the initial Modernist developments, its principles became widely applied across all aspects of design and the built environment; a home should be a 'machine for living', Le Corbusier stated in 1923.

What is vital to consider here is how people began to connect differently with fabricated objects. The mass production of goods and spaces for living, facilitated by the Modernist principles of simplicity, standardisation and ease-of-use began to erode the

[8] Source: Holger.Ellgaard via Wikimedia Commons: [Breuer chair]

historical basis of object interaction and form emergence, which was largely bespoke, organic and materially connected (Ingold, 2008). This again alludes to what Walter Benjamin (1935) referred to as '*aura*' – a mass produced object has been removed from the temporal and spatial connection to its creation. At another level, the moral basis of mass-production is called into question as capitalist-driven consumer culture is leading in part to the destruction of the natural environment. Papanek (1971/2019) for instance held that industrial designers had a moral duty to create socially and environmentally responsible products and tools. Indeed, Papanek thought that the main value in design work lay in the realisation of function and not in aesthetics or stylisation (Rolston, 2002). These dynamics that lay at the heart of these developments in design can only be addressed through a consideration of the practices of making themselves i.e., how aesthetics and functionality are embodied in created artefacts.

1.3.2 Contingencies of making

Making is a complex activity. But how do these link to the process of making and the material from which an artefact is embodied? It has been argued that currently human engagement with the materiality of designed objects is devalued due to what Tim Ingold (2009) has called the pervasive presence of hylomorphism. The philosophers Deleuze and Guattari (2013) have previously argued that the critical relationship for humans inhabiting the world is between that of *materials* and *forces*. Thus, explicitly rejecting the assumption of a designer-agent exercising their will over raw matter. Dewey (1936, p.137) has also stated that form is an 'operation of forces that carry the experience of an [object] to its own integral fulfilment'. These sections will explore some of these topics in more detail by looking at research into making processes and conceptions of manufacturing then detailing how emerging work in design research has set a precedent for reframing approaches to more advanced forms of manufacturing. These conclusions lead to the next phase of our discussion which will focus on modes of making, constriction and the materialisation of form. Given the topic explored in this section, it is evident through numerous lines of scholarship that embodied artefacts are linked to deep cultural, semantic and emotional values. This new interest in the disembodied elements of products has sparked new focus on aesthetics and interaction potential with varying levels of success. Mobile phones are a notable example of a product type that went through a hugely diverse period of creative design expression in the early 2000s – both aesthetically and in terms of interaction – only to be systematically flattened by standardisation in the 2010s (Figure 5). The production of these objects provides them their aesthetic characteristics and mechanical characteristics. What has been labelled the 'new-materialism' in Material Culture studies (Coole & Frost, 2010) takes interest in how the processes of making are contingent and bound up in psycho-social, cultural, and symbolic values and not just functional expediency. Firstly, the complex relationship between art and technology will be briefly considered.

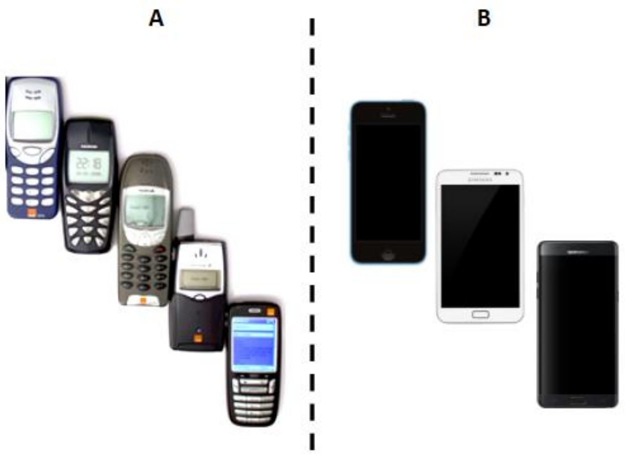

Figure 5 – A range of mobile phone handsets. A) Models designed before 2010 B) Models designed after 2010[9]

1.3.3 Design, expression and production technology

Technology and creative expression have a close relationship. As has been explored in previous sections, the West has been punctuated by philosophical changes that have affected art and design outputs, notable examples being Impressionism and Modernism. Historically, this narrative is also present where technological shift instantiates new modes of expression, functionality and, as has been argued, experience. Looking at the genesis of tools, the use of which in some form or another has been documented by archaeologists many thousands of years before the evolution of modern humans. Importantly for this discussion, the first examples of technology made from highly formable materials such as metal is seen at approximately 3300 BCE in the period following the Neolithic Revolution known as the Bronze Age (Fokkens &

[9] Source: public domain images from Wikimedia Commons, see index: Mobile phones

Harding 2013). Some researchers have proposed that the gradual reliance on simple technology and tool production significantly shaped the cognitive development of humans over thousands of years (Gibson & Ingold, 1994). The discussion previously detailing the theoretical ideas behind product interaction and affordances have their root within the historical development of the human senses of tactility and dexterity. More specifically – this is the ability of the human hand to experience variations in form and indeed manipulate that form in a dynamic way, applying what has been referred to as 'value judgements' to an object (Geist 2013).

Present even within ancient objects, pre-dating art-historical narratives, is a sense not just of a functional goal but an aesthetic – something subtly symbolic that embodies the culture that made these objects. MacGregor (2011) has noted numerous examples from history that reveal ancient peoples across the world to have complex making traditions and rich aesthetic cultures. In the Western world, the relationship between design expression and its technological contingencies become particularly pronounced during the early modern period with rapid industrialisation and new advances in forming technology. Innovators in England such as Abraham Darby I (1678-1717) experimented with iron ultimately realising a unique method for producing cast-iron. This led to the ubiquitous presence of iron cooking pots and a great fortune for Darby who had created a highly functional and affordable product (Weissenbacher, 2009).

Of course, advances in creative design work were not always orientated around function and use-value. The Victorian era saw what is now known as the Aesthetics Movement, a member of which was one of the most prominent designers dealing in mass-produced consumer products, Christopher Dresser (1834–1904) (Pevsner, 1936/2011). Dresser worked in a distinctly modern style and represented the inception of Modernist aesthetics in mass-market products. Notably, Dresser is described as someone who approached design scientifically by taking advanced processes seriously and worked with the leading manufacturing innovators of the time (Halén 1994).

The Bauhaus school already mentioned is another prominent example of new approaches empowering creative output (see section 1.3.1). What is interesting to consider is how technology interfaces with the practices of making and manufacturing and also societal values; what has also been referred to as the zeitgeist or the 'spirit of the age' (see Hagel, 1807/1976 for philosophical foundations). In a more modern example, Flusser (1999/2015) has discussed the development of interactive electronic technologies such as radios as a combination of Eastern (in this case, Japanese) and Western design approaches, philosophies and cultures:

'The Japanese pocket radio does not force Western applied science into an Oriental form, rather it is a synthesis within which both overlap.... The form of things Oriental comes about thanks to very specific and concrete experiences, causing the distinction between the human being and the world to blur' (Flusser, 1999/2015, p.71)

Flusser essentially argues that there is a theological element to design work. Western design driven by a Judeo-Christian culture that embodies objects with spirits and souls. By contrast, Japanese design culture comes from a Buddist philosophy of enlightenment where there is a disintegration of the conceptual self. These differences, it is contended, have a fundamental influence on the act of design and the overall ontology of making.

1.3.4 Materiality, experience, and interaction

Architectural theorist Juhani Pallasma, in his work *The Eyes of the Skin* (2005/2012), strongly argued that tactility and connection to the materiality of the built environment has been supplanted by a so-called 'ocular bias'. This ocular bias is represented in Western thinking as a hierarchy of senses with vision placed at the top, assumed to be the best or primary sense. Writings from the ancient world contain numerous metaphors that associate vision with knowing – *seeing* is viewed as the ontological basis of reality (see Rorty's 1979/2009 detailed study of this in 'Philosophy and the Mirror of Nature'). Some such as Nietzsche (1873) tried to subvert this bias by asserting that some philosophers had a kind of blind hatred of the other senses. One notable thinker on the topic, Maurice Merleau-Ponty (1945/2013) focused strongly on the phenomenology of visual perception. Merleau-Ponty concluded that, rather than experiencing a sum of a variety of senses, vision, sight and so on, all the senses simultaneously interpenetrate each other and interact, all defining each other in various ways. As explored earlier, this perspective of senses interacting is one that is now being examined by design theorists through Kansei research and studies in design emotion and semantics. Pallasma (2005/2012) goes on to explore how Modernist architecture and the spaces generated through Modernist design principles have led to a kind of sensory deprivation, lacking material connection. Drawing from multiple sources, Pallasma explores how the connection humans have with material objects is forged within a story of temporal interaction. For example, a stone building or a wooden chair will alter over time – signs of wear will become visible, and the nature of tactile interaction may change significantly. Other materials such as synthetic plastics, glass and concrete are less susceptible to this material change, making them culturally significant symbols of rational progress and modernity (Sudjic, 2011; Levine, 2018). Contemporary architecture and much contemporary design, Pallasma asserts, is purely interested in transcending time. Interestingly, the famed German industrial designer Dieter Rams has stated he aims to create 'timeless' objects and products that can last forever (Sudjic, 2008) - a point that reiterates Pallasma's arguments regarding Modernism. Haptic sensations and experiences are also important to consider. The organic and materially engaged city or artefact is one of 'interiority and nearness', by contrast, modern design favours 'distance and exteriority' (ibid p.33).

Many emerging research efforts have taken to exploring materiality and making and their link to contemporary developments in design. Wiberg (2013) for example has formulated a 'methodology for materiality' which seeks to act as a guide to a material-centred interaction design approach. Other researchers have also looked at the intersection between material knowledge and human-product interaction especially within the framework of human-computer interaction (Gross, Bardzell & Bardzell, 2014; Lim et al., 2007). In terms of interaction with artefacts, many research efforts have examined the relationships between tactile perception and material surface textures. Often these studies are grounded in the assumption that visual examination leads to an expectation effect for tactile interaction (Klatzky, Lederman & Matula, 1993; Schifferstein, Heylighen & Wouters, 2013). In a study by Yanagisawa and Takatsuji (2015) examining perceptions of smoothness vs roughness and stickiness vs slipperiness, they found a significant number of material samples of visual information changing tactile perception. Another earlier study from Karana, Hekkert and Kandachar (2009) directly examined the semantic meanings derived from materials and the manufacturing processes affecting the attribution of said meaning. Looking at a total of 125 products differing in material makeup and a range of processes including polishing, joining and shaping through molding the study found that particular processes can have a significant influence on the overall effect of a product. For example, sensorial properties such as glossiness and tactile roughness were strong indicators of product meaning. Metal materials and plastic materials showed a diversity in the sense they could be associated with all of the semantic values that were being examined that included 'toy-like' and 'professional'. This study has been followed by others that have found similar results demonstrating a clear link between materiality and an immaterial sensory experience (Ramachandran & Brang, 2008; Chen et al., 2009; Karana et al., 2010).

In a different line of enquiry, some researchers have explored how material properties combined with symbolic form can create a complex emotional experience during product interaction. In a notable set of studies by Niedderer (2012), a set of designs for fruit bowls were developed made using a novel laser welding method with fine strips of silver. Due to the thinness of the silver material, it took on elastic properties which are not usually applied in a functional context. Following work by Weerdestrijn et al. (2005), the study aimed to measure how the movement of the bowls that occurred during use and interaction could then be associated with a complex experience of emotion. Niedderer goes on to develop a 'soma-semiotic' framework combining theoretical work in emotion interpretation from Wallbott (1998). This framework was then used in order to record user interpretation of the movement during interaction. The bowl was said during one movement-interaction to represent 'elated joy' and during another to represent 'unsteadiness, drunkenness and helplessness' (p.66) – a notable shift in interpretation.

Other work of this nature has been creatively explored by the artist Ane Christensen who has made a series of 'Kinetic' objects (mostly bowls) that symbolise feelings such as nervousness and connectedness through form. These findings have significant implications for understanding design semantics, interaction, and emotion. If the properties of material have a clear impact on experience in a variety of complex ways, how does the process of making influence form and a subsequent experience of artefact use and interaction?

1.3.5 Making

What does it mean to make something? What is the material basis of making? Ingold (2009) has spoken of a *textility* of making whereby form emerges within 'fields of force and flows of material' (p.91). Presenting a radical rejection of hylomorphism and following the logic of Deleuze and Guattari (2013), Ingold argues that sensuous and tactile knowledge of materials and material properties and knowledge of the making processes themselves has given way to a purely geometrical conception of form. Thus, the textility, or the knowledge of the fabric of materials and making processes, has been significantly devalued. Furthermore, as Anusas and Ingold (2013) have argued these fields of forces have been encased and made opaque through the conventional modern practices of design and manufacturing, severing the links between form and its enmeshment in energetic and material transformations (see Anusas and Ingold (2015) for a further exploration of these ideas). Considering works of architecture, the great medieval cathedrals were not designed along very rigid plans, the process was organic subject to change and material flow, what Christopher Alexander (1964) termed 'unselfconscious design'. Some scholars have even argued that it is best to think of these large projects from the past as more like patchwork quilts with no solid outcome in the mind of the architects (see Harvey, 1974, p.33). In a related discussion, Herwitz (2008) has talked of different types of *mediums* that are associated with the process of making. The first medium is physical, that of material, wood, ceramic, oil paint and so on. The second is metaphysical and is related to the manifestation of the material – music uses timing and tonality for instance. The third medium in Herwitz words is 'something like the viscous substance through which flows a message, a medium is a particular field of representation and expression, social action and individual meditation' (p.113-114). Schon (1983) has theorised a kind of backtalk or transmission of craft practices and methods across generations of practitioners which relates to this notion. In a recent study Gross, Brazdell & Bradzell (2014) have argued that the ontologies of making, and materiality have significant implications for information consumption and human-computer interaction. While this, material-centric approach to making was slowly driven out by European Renaissance science (Ingold, 2013) and Modernist values (Parsons, 2015), some researchers have been exploring alternative approaches to making and form-giving, shifting the contingent boundaries of conventional manufacturing.

Other researchers have explored alternative types of computational and generative making for the purposes of interaction design. Harrison, Earl and Eckert (2015) used an exploratory generative making approach to enhance kinematic interaction for design. Following some of the shape rules developed by Stiny (1980), the study developed a set of bespoke rules for achieving kinematic functioning. In another study Gursoy and Ozkar (2015) explore materiality, interaction and function using a novel technique known as 'dukta'. Dukta involves the building up of rules of interaction that correspond to cut patterns. The cut pattern may afford a bending, stretching, folding, twisting or compressing interaction but must be appropriate for the materials being manipulated.

Gursoy and Ozkar's (2015) work explores an intersection between making and interaction but also has clear implications for design semantics and even aesthetics. Similar work has also been carried out by Parkes and Ishii (2009), Jensen et al. (2017) and Turner, Goodwine and Sen (2016) who reviewed the application of origami within mechanical engineering. A potentially more radical and technical approach has been proposed by Oxman (2012). Building on a huge amount of previous work from materials science and computer science, an approach to design that is entirely informed by inherent properties of a material is proposed dubbed 'material computation';

'Material Computation... is a computational [strategy] supporting the integration of form, material and structure by incorporating physical form-finding strategies with digital analysis and fabrication. In this approach, material precedes shape, and it is the structuring of material properties as a function of structural and environmental performance that generates design form.' (Oxman 2012, p. 256)

In many ways, this work is trying to fuse both form and function where a geometric-based conception of design is shunned for a material-based conception. One of Oxman's prototypes developed with these tools is a chaise longue: 'Beast'. The prototype is created with induced elastic properties by a process of advanced multi-material 3D printing where the form becomes adaptable, relieving pressure where required for the user (Oxman et al., 2012). Principally, the research efforts discussed demonstrate how closely linked making, materiality and interaction experience all are.

While these studies did not directly explore aesthetics and perception, other studies have considered making and form perception in intriguing ways. In a notable study, the concept of 'temporal form' is explored in which interaction design is given a 'kinship with temporal arts like music, dance and film' (Vallgarda, 2015, p.1). Following Gibson and Ingold's (1993) analysis that human life is governed by rhythms and motions within nature – day and night or the tides – a number of prototypes were created that embodied abstract interactions with an explicit temporal basis. The prototypes, as described by the authors, consisted of very simple motors and helical shape-memory alloys interacting with a cotton textile surface arranged in a simple box. The temporality of the forms was controlled by speed parameters and rotation degrees of the motors as participants were invited to interact with the boxes. In a finding similar to Desmet (2008) mentioned earlier, many people attributed 'personalities and lives' to the interaction boxes by interpreting the shapes and movements as cultural concepts (Vallgårda, 2013, p.9). Other participants in the study were reported to stare at the moving shapes describing its unpredictability as engaging and exciting.

This so-called 'temporal form' is deeply theoretical and is yet to be explored fully in terms of its implications for design practice at large. It can however be viewed as an attempt to examine the exploratory potential of making and confining it less to a system of functional interactions and more to something unpredictable and emergent. The next immediate question is what implications these studies have for designers and manufacturers in the contemporary world? As has been examined, there are myriad factors - technological, social, cultural – that influence the material basis of design and subsequently, how it is experienced. In the next section, modern manufacturing and its intimate links to design, form expression and materiality will be explored.

1.4 Modern manufacturing, materiality, and expression

Modern manufacturing methods have a huge history of development. Most of the history of making things has been embedded within a narrative of craft (Ingold, 2013) but the coming of Modernity spearheaded in part by the Industrial Revolution of the 18th century birthed a range of new manufacturing practices (Deane, 1965/2000). This section will try to bring together what has been previously discussed by examining how modern methods of production and the culture of that production influence final outcomes in terms of material artefacts. Importantly, we will first consider the concept of 'ductus' which will be important for developing the work in later sections.

1.4.1 Ductus and the ontology of manufacturing

As has been argued, modern consumer culture has disconnected human users from the material basis of products with most people having little or no conception of what materials a product is made from let alone how it is made (Adamson, 2018). Ultimately, everything *made* has a material basis and a contingent manufacturing process. Sometimes the evidence of its production is evident – the work of a stonemason for example or a ceramic artist may be plainly obvious. This is where we can explore the concept of *ductus* which will form an important element of the overall argument of this work. Scholars of material culture have spoken of a 'ductus' that guides someone through a built object or environment (Bø, 2017). Originally a classical concept from writing and rhetoric, *ductus* refers to the speed, direction and sequencing of the drawn lines or the spoken words whereby everyone has an individual and unique ductus (Kumler & Lakely, 2012) – by imperfect analogy, ductus is similar to the handwriting of an individual. Thus, with reference to material objects, ductus can be linked to the complex array of semantic and emotional connections that are made with them due to this process of 'individuation' where form emerges (following Simondon 2005). Crossley (2010) for example has applied the concept of ductus to analyse medieval architecture, providing a greater (albeit speculative) picture of the shape. Whilst ductus is not an extensively developed concept, it lends itself well to this context for further development as it encompasses a holism that other ontologies or taxonomies fail to recognise. The principle of ductus is illustrated in the diagram below. Ultimately ductus seeks to combine the potentialities within matter through a creative ontology that is implicitly combinatorial and generous; the forming of multiple elements from multiple sources.

All of manufacturing is based on the process of forming material – forcing, cutting, or molding it into a specific shape – and ductus has an implicit architecture that is compatible with that basic logic. Ingold (2008, 2013) has argued forcefully against the hylomorphic model of making described earlier which establishes the designer as a kind of master manipulator of matter. Instead making or manufacturing is understood as a kind of exploratory task, a kind of 'wayfaring' into a material space. Furthermore, object-oriented ontology posits an 'interobjectivity' in which artefacts emerge through object-object interactions (Morton, 2013; Harman, 2002; 2018).

To summarise, the concept of ductus can be described as follows:

- **Ductus is defined as a key component in an ontology of form emergence. This itself has two sub-level characteristics:**
    - *Material interobjectivity – the interactions between materials and the new objects or forms that emerge as a result of these interactions*
    - *Telos or narrative – the trace left by the processes of making and material interactions implicitly part of an emergent form*

1.4.2 Taxonomies of manufacturing

How much of this so-called 'wayfaring' or 'interobjectivity' is relevant for modern manufacturing machines, or for understanding new ontologies? Undoubtedly, one of the most important factors for modern manufacturing processes is computer technology and computational thinking more generally. Lubar and Kingery (1994) have discussed at length the core principles of manufacturing and how it operates within society at large. They note that manufacturing technology can be viewed from multiple perspectives, an industry-focused perspective or a task-focused perspective for example.

A more direct way to consider the theoretical basic of manufacturing is to study how material is manipulated – this can be done by parsing the processes with distinct taxonomic catergories. Broadly speaking the categories of manipulation through forming can be broken into several important families. Todd and others (1994) define ten distinct families. The first set of families are defined as shaping processes - mass reducing, mass conserving, consolidation and joining. The second set are non-shaping – hardening, softening, surface preparations and surface coatings. Subtractive forming or manufacturing such as machining or stone carving is mass reducing whereas casting and molding is mass conserving. More complexly, additive manufacturing involves the manipulation of material layers that are fused together meaning that it is technically classed within the family of joining processes. Some of these types of making have been present in human life for time immemorial and each have a diverse material basis. Table 3 below, adapted from Todd et al. (1994), presents a taxonomy of modern manufacturing processes and describes the material basis on which they operate ('State of material' column). This is in essence an ontological model of modern manufacturing methods. Additionally, the table describes the types of fundamental energies that are used in each process such as mechanical or thermal. Within these families of processes, the geometric forming potential is hugely diverse, and this taxonomy goes some way to reflect on the material constraints of modern manufacturing.

Table 3 – Families of manufacturing processes, adapted from Todd, Allen and Alting (1994), can be viewed as ontologies of emergence

Process family	State of material	Process energy
	Shaping	
1. Mass-reducing	Solid	Mechanical
2. Mass-reducing	Solid	Thermal
3. Mass-reducing	Solid	Chemical
4. Mass-conserving	Solid/granular	Mechanical
5. Consolidation	Liquid/plastic	Mechanical
6. Joining	Solid (except adjacent surfaces)	Mechanical
	Non-shaping	
7. Hardening	Solid	Chemical/thermal
8. Softening	Solid	Chemical/thermal
9. Surface treatment	Preparation	Mechanical/chemical/thermal
10. Surface treatment	Coating	Mechanical/chemical/thermal

Todd, Allen and Alting (1994) have advanced this taxonomy extensively. The mass-reduction process taxonomy will be the most important for this work and will be explored in greater depth in chapter 5. Given the development of these kinds of taxonomies and the mass adoption of computing technology to aid manufacturing, other authors have developed various ontologies for manufacturing to define their discreet concepts for easy application into computing technologies (Usman et al., 2013). Similarly, Zhang, Luo and Zhang (2014) have developed a framework for identifying a critical 'unit manufacturing process'. This unit is defined as a 'fundamental operation unit' and is the result of an input of material, energy and information and leads to a product output, waste, and emissions.

1.4.3 Shaping material

Considering the material basis of these processes, Lubar and Kingery (1994) and other scholars of material culture such as Hollenback and Schiffer (2010) explicitly point out that not only do our manufacturing systems shape our objects, but through a system of feedback, they also begin to shape human life and human culture as well. This is what Lubar and Kingery (1994) has referred to as 'culture reflecting machines' (p.206). Essentially, manufacturing depends on the *shaping* of material. Not in a linear way but within a complex system of feedback interweaving technological systems, material, cultural evolution, information, and experienced obstacles (using Flusser's 1999/2015 conception) that lead to decisive action ending in an artefact. Ultimately, this work has been arguing that the things people create are extensions both of themselves and their interaction with the material world. Within a framework of advanced technical processes, the link to the material basis of things may become less clear. Plastics for instance were once revered as a cultural icon of creative design potential, a kind of material of pure formability, but have since become culturally derided as metaphors for artificiality and modern 'throw-away culture' (McDermott, 2016). In some sense, the formable potential of plastics was its downfall as a culturally revered manufacturing material. From a manufacturing perspective, material workability is the critical property; in what ways can this or that material be shaped? While the long view of the history of manufacturing practices may present a picture in which important innovations helped to reconfigure what could be made, recent trends are much more focused on aspects of speed, efficiency and integration with digital computer systems to achieve precise control and automation (Yang & Wu, 2006). This focus on a kind of linear improvement in efficiency has meant there is less concern with the materials different processes can work and indeed the making processes that the machines engage in. Tim Ingold, whose work has been important for framing the initial arguments of this work, has stressed on numerous occasions that the material knowledge embedded in craft practice is lost in modern processes of systematised machine making. This new theoretical grounding is captured in the work of Oxman (2012) and Niedderer (2012) discussed earlier which grounds the resultant product forms in the very nature of making or the processes of production with complete embrace of the imperfections and advantages. This new framework is illustrated in Figure 6 where the process contributes to a form creation which then characterises any interaction qualities. It should be noted that more emphasis has been made on the non-linearity of the process since its initial drafting with an exchange between the interaction qualities and the emergent form being introduced; the process and resultant interaction properties alter the state of emergence and aesthetic interpretation. It is clear from the literature on making that the relationship between the three primary elements is more interwoven and dependent on, in Ingold's (2009) terminology, flows between materials and feedback and exchange of information and energy between them. This method is opposed to a hylomorphic model of creation and presupposes that the resultant effect from product interaction (emotional or physical engagement) is derived from a process of making or manufacturing and not necessarily from the intentions of the designers (Ho & Siu, 2012).

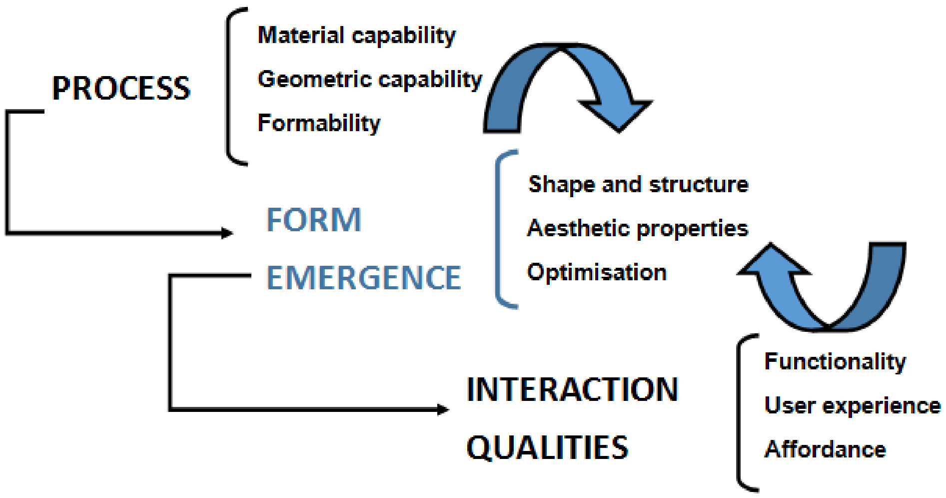

Figure 6 – Model of process leading to interaction qualities with non-linear exchanges informing form emergence

1.5 Modern processes of control

It is important to explore at this stage the development and importance of process control. As manufacturing has developed it has utilised the developments in computing technology and automation to develop systems by which manufacturing processes can be controlled more precisely. Its modern incarnation usually involves process simulation and is intimately related with CAD software which will often interface directly with these 'computer-aided manufacturing' (CAM) systems. This section will consider some background on CAM and importantly address the relationship between the cultural grounding of CAM (industrial capitalist production) and designers (individuated expression). This relationship can help us ground the discussion more fully and help to move forward with addressing the aims of the work.

While the cultural conditions in which CAM grew up are complex, a major influence was that of so-called 'scientific management' as advanced by Fred Taylor at the beginning of the 20th century. As Mitcham (2005) describes, 'Taylorism' advanced a production philosophy highly aligned with the needs of an emerging industrial capitalist society: rationalistic positivism, efficiency, elimination of waste, standardisation and a dislike of traditional practices that may inhibit maximisation of production. The logic behind this developed over the next century birthing many similar practices including Lean Six Sigma and vitally, CAM. CAM allowed for unpreceded control over processes by tethering it to computational systems and automation essentially eliminating human error or defections in part production. As the computational energy required for CAM systems has reduced, it has become a near-universal feature of modern mass production. The aim of CAM is the organisation and control of design data. As Boothroyd (2005) describes CAM attempts to integrate many elements of a production cycle where data is transferred from one operation to another within a share database structure; 'integration is particularly desirable because the geometric data generated during the design process is one of the basic inputs used by process planning when determining appropriate manufacturing sequences and work plans' (p. 356). Once the data has been functionally organised, it can be used by downstream programmes including numerical control systems. A general overview of process planning developed by Eversheim and Esch (1983) give good insight into the overarching philosophy of process control. Though the model is dated, many of the elements remain paramount within the process planning of modern production. Though there is nothing intrinsically 'wrong' with this manufacturing ontology, and much of its structure is even desirable, it presents limitations and is in essence functionalist. Boothroyd (2005) plainly states that the process planning of numerical control contains the following tasks:

1) *Determination of operation sequence required to successfully machine the workpiece. This includes feature examination and sequencing selection*
2) *Choice of cutting tools and order of use*
3) *Determination of cutting speeds and feed rates which is a function of the material properties*
4) *Definition of tool path coordinates, which may include both computational and manual inputs and potentially complex geometrical operations*
5) *Setup of programming functions including tool changes, start and stop times*

This mechanistic perspective does not consider how the process itself may add some properties of value to what the maker wants; the manufacturing goal exists before the process is considered wholly. What is interesting is how this culture of management within industrial manufacturing has led to what some theorists have called a 'flatness' in contemporary production (Pallasma, 2005/2012). This flatness is arguably manifest in the ways in which the digital systems of form building (CAD) and process control (CAM) fail to embody or recreate the intuitive skill embodied in traditional, craft-based making methods. In a summary by Rosenbrock (1989) he argues that a 'cause and effect' culture of Western science has led to our modern systems of manufacturing to neglect the 'purpose' implicit within the systems of traditional making. Human purposes become detached or irrelevant, there are only Taylorist manufacturing goals, engineered around production efficiency for the benefit of capital.

1.6 Human-centred design, semantics, and emotion

The next immediate question is whether the material intelligence of craft-based and artisanal making can be brought into contemporary manufacturing technology? To do this, the true impact of design of designed artefacts must be assessed. Recent scholarship has proposed a compelling view that the products humans interact with are not just functional tools but layered with emotional significance and semantic meaning. The complex dynamic between product function and product aesthetic, between the maker and the made, the object and the user can all be considered as fundamental to the end experience of product use. Flusser (1999/2015) points out that the dynamics of function and use-value come from perceived obstacles. These obstacles are surmounted by design and artefact-based solutions that then present new obstacles. The observed problems of function-driven design influenced new approaches to production in the West. One notable movement, which will be explored more in chapter 3 in more depth is Mid-century Modernism, beginning around the 1940s. This offshoot of the initial Modernist movement reframed industrial design as a consumer orientated project using Classical principles of beauty, form, and materiality (Crowther, 1984). As consumer pleasure became the focus for designed objects, this has since fostered an interest in what has come to be called human-centred design (HCD) and user-centred methods more broadly (Vredenburg et al., 2002). The central issues with many of these ideas though is measurability – how easy is it to link a process of making to an end user experience?

1.6.1 Interaction and design

Human-centred design became a systematic approach in industrial design around the 1970s with the rise of *Kansei Engineering* (Lévy, 2013). Kansei Engineering, developed initially in Japan, attempted to carefully consider the psychological and physiological needs of users by doing methodical testing of various aspects of product use. Kansei engineering tried to grasp the question of linking process to end user in some ways but chose an eminently human-centred approach and not one that explored the intricacies of making and material interactions. In line with this identified 'gap', the next stages of this investigation will explore this question further. Defined by what is known as 'Kansei information' which is split into three levels or dimension: low-level information – shape, form, colour and texture, mid-level – concept and artefact names, high-level – subjective semantic descriptors, sociological values, and emotional dimensions (Bouchard & Kim, 2014). Tools such as semantic differentials, for instance, are used to derive points of value during the experience of product use. More directly, users may be observed utilising medical equipment monitoring brain activity or eye tracking to measure aesthetic interest (Thoring et al., 2019). Broadly, the tests can be defined as cognitive-based, physiology-based and psychology-based encompassing a range of quantitative and qualitative data.

In the United States, Muriel Cooper pioneered work in human-computer interaction and HCD at MIT's Visual Language Workshop by developing methods for software engineers to produce more intelligible graphical interfaces for users (see Richmond's, 1994 article). Her methods have been influential on subsequent graphical interface design. Others, such as Johnson et al. (1989) spoke of design 'usability' relating to experiences of consistency, compatibility, feedback, error prevention and recovery. Patrick Jordan (2000) in addition to this related product usability to Maslow's (1943) 'hierarchy of needs' stating that *pleasure* in product interaction is the principle need for users. British designer Bill Moggeridge applied HCD principles within the physical embodiment of personal computers. In the 1990s, Moggeridge designed some of the first laptop computers and adopted radical methods to create products with a carefully designed *interaction* experience for users. The theory of interaction, as described by Moggeridge (2007) consists of five critical dimensions:

1) *Words*; Representing semantics or meaning of the user's interaction
2) *Visual representations*: Refers to elements that are not within a product, mainly graphics, typography and other icons come into this category
3) *Physical object or space*; The tangible means of connection and control for the user i.e., mechanical controls or interfaces
4) *Time*: How much time the user spends during a given interaction
5) *Behaviour*; Users' reaction to a particular interaction implicit in the design

The dimensions can be interpreted as layers of an experience, each layer representing a different function in the product experience. Moggeridge's work overlapped with other designers and engineers of the computing revolution notably Bill Verplank and Dougas Englebart. Verplank worked closely with Moggeridge on the emerging concepts in interaction design and Englebart developed one the first widely used computer mouse tools. Notably, the computer mouse has become an icon of design and an archetype of tools mediating interaction between humans and computer systems. Of course, there are good examples of interaction design throughout the story of modern industrial design. In many ways, Moggridge's work is an articulation of some older approaches that were present within early Modernist design and even earlier, with the advent of the computer interface acting as a catalyst. Fundamentally, the experience of the user has been valued and placed at a near focus for the development of this product thus opening new modes of experiential engagement with the object. As Kevin Silver notes:

'…designed behaviour dictates the flow between action and reaction, which is the basis of an interaction. A user takes an action through an affordance, which in turn causes a reaction in the presentation layer' (Silver, 2007, online resource).

The term *'affordance'* will be introduced later but the principle point here is the nature of feedback – mechanical and aesthetic. Mechanical feedback has been a central concept for interaction design and laterally, experience design. It is broadly defined, in the context of product use, as a tactile sensation that will either apply a force or vibration to a user as a direct response to a particular action the user takes with the product's components or interface (Burdea & Brooks, 1996). Equally, aesthetic feedback – colours, shapes and symbols have an important role as taken together, both of these sensations can act as a guide for how the product is used (Rogers et al. 2011). The form of an object conveys a meaning to us – a button suggests 'pressability' or the handle of a mug suggests 'holdability' (You & Chen, 2007). It has become particularly important for the dynamic interfaces of smartphones and other handheld electronic devices with the incipience of a concept known as haptic feedback. Haptic feedback is a kind of kinesthetics-based communication that simulates sensations of touch. Rogers and others describe the concept of 'vibrotactile feedback' which is being used to enhance touch sensations for people using electronic products. A notable example that is pointed to is a device dubbed the MusicJacket that used this principle to help prospective musicians learn the violin (van der Linden, Schoonderwaldt, Bird, & Johnson, 2011). Other work has used haptic feedback to improve keyboard typing experiences, considering user behaviours and not simply functional aspects of the design (Wu & Smith, 2015). This highly complex mode of interaction with objects has become widespread and now constitutes a large part of experience design for graphical user interfaces.

To bring the discussion back to the relationship between object function and object aesthetic, there is a curious physicality that has emerged – or *re-emerged*. While the digital world offers fantastical aesthetic explorations and experiences, a distance emerges between the aesthetic and functional commands. The emergence of interaction design and features such as haptic feedback return a sense of organic control to users by mediating between functional commands and aesthetic feedback. Even design archetypes from redundant technologies are introduced to aid the user's journey through product use. The phone function is given the aesthetic of a dial-up telephone, the map function, the symbol of a compass (no compasses are required for orienteering with Google). These examples of skeuomorphism in design are used frequently in interaction design and place the user within a more organic space, full of symbols from the past (Backhaus et al., 2018). Many have criticised the use of skeuomorphs (see article from Carr 2013, in Fast Company) but they relate strongly to how object interaction can become richly layered. If the disconnect between the maker, the process and the user is going to be addressed, the symbolic nature of form is a seam that must be tapped. HCD and interaction design addresses some of these concerns by mediating the user across boundaries of form, function and aesthetic but more can be explored. The next sections will consider how object interaction can be understood through examining human perception and cognitive processing of the visual.

1.6.2 Affordances and design

Affordances have become an important concept for HCD thinking. The concept has its roots in the pragmatist philosophical schools that developed in the United States in the 1950s. Its principal developer was vision psychologist J.J Gibson who articulated it fully in his 1979 work *An Ecological Approach to Visual Perception* after decades of development. Gibson suggested that the environment will 'furnish' an animal with particular functional options called affordances, climbing up tree branches to gain height for example. The matrix of affordances that may be presented to an animal exist whether or not it is recognised or acted upon. The key points are intentionality and human or animal needs – an affordance can only be acted upon if there is a relation between the intentional use of an affordance opportunity and a need that must be satisfied. A human interacting with a computer may 'see' numerous affordances but might only act on a few with others becoming relevant for use much later. In this respect, an affordance is relational and deeply associated with aspects of culture and socialisation (Gibson, 1979).

What is most relevant for this discussion is the more decent developments in the affordance theories which have deviated somewhat from Gibson's original conception. Design theorist and cognition researcher Don Norman has laid the groundwork for much of the discussion surrounding affordances and design. Focusing on human-computer interaction, Norman (1988) reframed affordances as 'action possibilities' that may be present in a physical or digital environment and split the idea into two broad categories: 'real' affordances and 'perceived' affordances. Real affordances are physical characteristics that allow operation as opposed to perceived affordances which are visual clues regarding how a device or object is used. However, Norman notes an important distinction between an affordance and a learned cultural convention – deviating from Gibson's original social-intentional understanding. A cultural convention, in Norman's words, is an acting constraint that 'prohibits some activities and encourages others' (Norman 1999) meaning that some affordance options are ruled out based on some standard of taste.

Gaver (1991) took the concept even further by proposing four 'situations' of affordance, perceptible affordance, false affordance, correct rejection and hidden affordances. This framework is illustrated below in Figure 7 – a fully perceptible and true affordance is one where an affordance exists and there is information available to establish this.

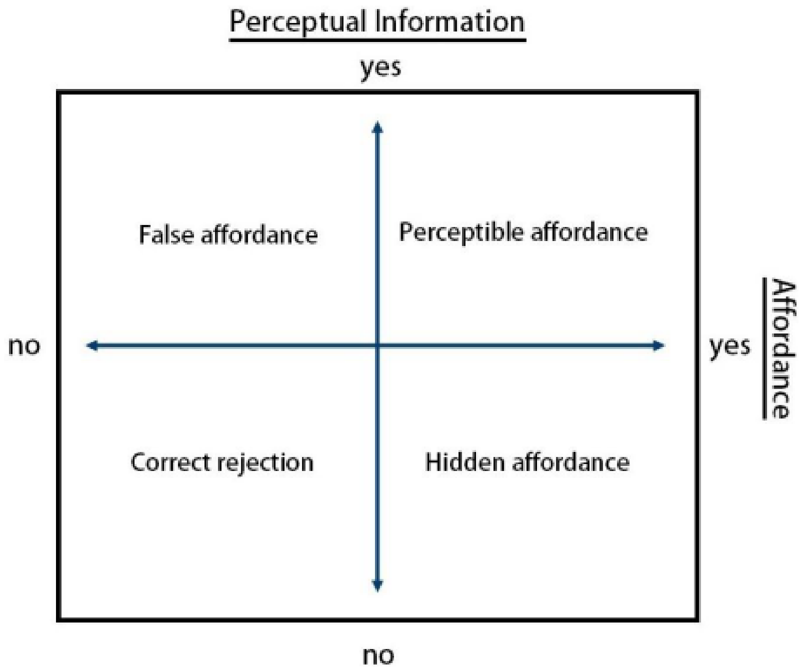

Figure 7 – Gaver's (1991) model of affordances

The concept has continued to be explored extensively in a design context due to the prominence the graphical interface now has in modern industrial civilisation. Hartson (2003) for instance, focusing on human-computer interaction, has pointed out that the language used to describe affordances is possibly inadequate and needs to be more granular. Regardless, the graphical interface and its relationship with concepts in interaction design will continue to be an important consideration for designers. Norman (1999) points out for example that there are both logical and physical constraints associated with affordances, understanding of which will be valuable. Chapters 3 and 4 will explore how affordances link to the symbolic qualities of form and material but at this stage the topic of design semantics must be introduced which overlaps with aspects of affordance theory and has large implications for Kansei engineering and human-centred design.

1.6.3 Design and semantics

Semantics is the study of meaning. Design semantics is the study of what objects *mean* to users that interact with them. What is now referred to as the 'semantic turn' describes the reframing of design understanding away from notions of use-value to notions of subjectively experienced meaning (Demirbilek & Sener, 2003). The concept was introduced by Krippendorff and Butter (1984) and is in notable opposition to

Modernist notions of design understanding. Klaus Krippendorff, who specialises in studying communication, has stated that the semantic turn can be seen as an equivalent to the linguistic turn in philosophy where philosophical problems were recast as problems of language use and the subjective nature of language (Deetz, 2003). Krippendorff's (2006) work '*The Semantic Turn: a new foundation for design'* explicitly details the precedent for a human-centred understanding of product interaction and use. Citing historical thought as far back as the ancient world, Krippendorff (2006) argues that the world as experienced is one of incomplete subjective perception and, following Gibson (1979) and Norman (1998), states affordances are the central mediators between the visually experienced and interaction choices.

This articulation of design, as mentioned earlier, is sceptical of the function based or use-value view of design that dominated the 20th century. Michl (1995), cited by Krippendorff (2006), argues that much of Modernist design discourse and expression uses the concept of function as a carte blanch to justify any given design decision. Instead, as the prominence of the interface grew, *interaction,* became central to design comprising three central elements: 1) interaction – the action and response sequences of a product 2) dynamics – the time implications of human use and 3) autonomy – the containment of a process or mechanism (Krippendorff, 2006). Indeed, the emergence of human-centredness in design deviates from what is referred to as the 'technology-centred design' by including 'stake-holder participation' (p. 32), an idea originally conceptualised by Rittel (1984). Krippendorff advances semantic theories in design further by arguing that distinct meanings emerge for different people during product interaction and use, decisively suggesting that subjective meaning matters more than intended function:

'...the engineers' functions are meaningful to engineers, but these functions are not the only truth and not necessarily shared by nonengineers' (Krippendorff, 2006, p.50)

What is vital here is the suggested plurality of design – different subjective interpretations about the same fundamental interaction. Indeed, it is subsequently argued that someone's relative sense experience is not only complex and grounded in a huge number of conceptual details, but also indistinguishable from its cause and never (experientially) in doubt. This sense experience leads to the processing of *meaning,* the definition of which is hugely complex. Some, such as Saussure (1916/2013) defined meaning through the interpretation of signs and what he called 'signifields' and 'signifiers'. The former being the raw perceptual experience, the latter being a culturally derived conceptual understanding of the raw information. Latter work by language philosophers detail how context is the central driver of meaning creation (see Austin, 1962, Searle, 1969 and Habermas, 1981 for detailed studies). Krippendorff (2006) argues that meaning derives from perception and largely follows the logic of Saussure and Gibson's (1979) affordance theory:

1) *Meaning is a structured space, a network of expected senses, a set of possibilities that enables handling things*
2) *Meanings are always somebody's construction*
3) *Meanings emerge in the use of language*
4) *Meanings are not fixed and have conceptual openness*
5) *Meanings are invoked by sense experience*

This understanding of meaning is presented in a dynamic model incorporating sense, actions, and the external world (Figure 8).

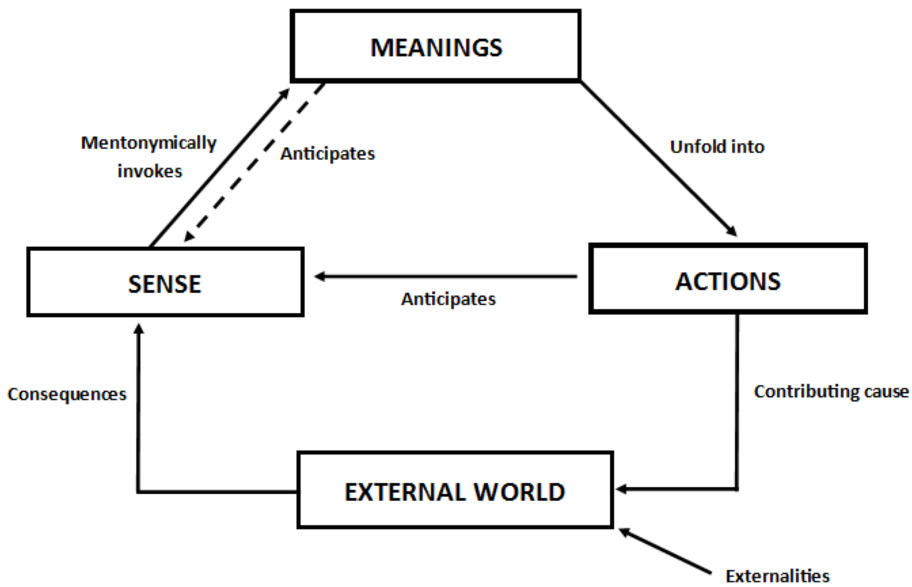

Figure 8 – Krippendorff's (2006) model of meaning emergence

Two other important concepts have also been introduced by the work of Krippendorff (2006) that will have implication for the work to follow; second-order understandings and semantics layers. Second-order understandings are when the two subjective understandings that exist when artefacts are designed – that of the design and that of the user. This is opposed to a first order understanding which is essentially defined as a God's eye view where creation is viewed as pure intention of the creator with no external influence. A second-order understanding is key to HCD thinking as it assumes that a user can understand an artefact through perception and use – users are seen, in Krippendorff's words, as 'knowledgeable agents'.

Artefacts, it is also argued, may have what are referred to as 'semantic layers' (Krippendorff, 2006). This is most explicitly seen in products that use complex mechanical or electrical systems as parts of their overall function. The interface of a cash machine for example must be configured for a large potential user base to understand and use effectively. However, the cash machine is also used in different ways by other actors that interact with it: the people who replace the cash or the technicians who maintain its technological workings. All of these systems are designed in different ways with various degrees of layered meaning to allow for different specialists to understand them. Wikstrom (1996) even argues that some products must have incomprehensible aspects of use for certain groups citing medicine bottles with respect to young children.

Krippendorff's seminal study in design semantics has been extremely influential on subsequent researchers particularly in HCD and design emotion research (see Crilly et al. 2004). The semantic content of an object resonates on both the cultural level and the level of cognition. The theoretical approaches that have produced dynamic user interfaces and some of the most celebrated pieces of interaction design rely heavily on semantic knowledge. Another concept has been equally as significant in both design theory and practice - *emotion*. Human emotion is extremely complex, but its universality has led to its consideration within the context of HCD thinking with numerous research efforts considering our emotional relationships with artefacts.

1.6.4 Design emotion

Design emotion has been actively researched for approximately two decades with the first conference dedicated to the topic taking place in 1999. An emotion (which will be explored in much more detail in chapter 3) can be defined as subjective feeling or sensation experienced by a human or other animal, but absolute definitions are difficult

(Wierzbicka, 1992). Early work in perception that overlaps with the ideas of Gibson and Krippendorff discussed in the last section, produced results that showed people would explicitly relate different types of aesthetic forms or motifs with different emotive categories e.g., 'love' or 'anger' (Poffenbeger & Barrows, 1924). Historically, there is a long history of considering aesthetics within the context of feeling. This will be addressed fully in chapters 3 and 4 but this story and the wider story of HCD methods has driven design for emotion research and explicit practice.

In the previous section, the work of Norman and Jordan was mentioned within context of HCD and interaction design research. Jordan (2000) expanded his discussion around user needs to deliver methods that could be used to design 'pleasurable products' focusing on emotional experience. Norman (2004), building on the work of Jordan, set out a compelling argument around the complex cultural connections humans make with artefacts. Arguing that the functional qualities of products are of less fundamental importance to users, Norman states that emotional engagement is paramount splitting the experience into three main types; 1) *Visceral design*: the superficial appearance of an artefact 2) *Behavioural design*: the pleasure that the user derives from using the product and 3) *Reflective design*: the personal memories that a particular product might induce. In a recent paper, Ho and Siu (2012) used the three types of engagement introduced by Norman to develop a dynamic model of design emotion that considers the interactivity between the three types, user reflection upon artefact uses and the initial intentions of the designers. This overlaps significantly with the work of Krippendorff and Butter (1984) and Krippendorff (2006) by removing the function of the product as the principle need for users and replacing it with psychological needs. Additionally, it has also been argued that a reframing of the self may be taking place during human-product interaction. Belk (1988) called this phenomenon a kind of 'self-extension' the way a skilled painter might see her tools as an extension of herself.

So how do products affect human emotions and how can emotions inspire creative design work? Much research has focused on these questions in recent years (Desmet & Hekkert, 2014). Working to advance and explore a range of theories, the work of design researchers Pieter Desmet and Paul Hekkert has been of crucial importance. Desmet (2003) and Hekkert and Desmet (2002; 2007) developed and introduced a 'basic model of product emotions' and other theories around emotion measurement. This model consists of four key parts: a product and a related concern leading to an appraisal, the appraisal then leading to an emotive experience (Figure 9).

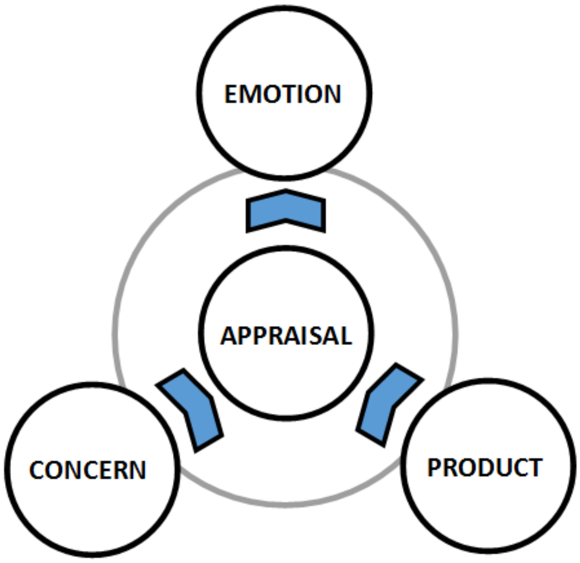

Figure 9 – Hekkert and Desmet's (2007) basic model of product emotions, diagram has been adapted

Desmet (2003) details this model describing how the product dimension is the object focus of the subsequent emotion. One must be afraid of something or in love with someone. The concern dimension relates to how products fulfil emotional needs not just functional ones – buying a particular type of jacket or shoes may relate to both a functional need and a concern to integrate with a peer group. The appraisal is the precondition of the emotional experience – a kind of assessment of a product interaction or an aesthetic. The resultant emotive experience can take many forms based on many factors such as culture and social background. Indeed, Desmet (2003) goes on to develop a taxonomy of potential concern, appraisals and emotional experiences that can be derived from product interactions. Three kinds of concerns – *goals, attitudes, and standards*, five kinds of appraisals – *novelty, motive compliance, intrinsic pleasantness, legitimacy and challenge and promise*, and five kinds of emotional outputs – *surprise emotions, instrumental emotions, aesthetic emotions, social emotions, and interest emotions* are advanced as part of the overall model.

Desmet has also produced a range of work focusing on other aspects of design emotion. Desmet, Porcelijn and van Dijk (2005) for example produced work focusing on creating products that elicit a so-called 'wow' response. By studying mobile phone aesthetics, it was concluded that a 'wow' response could be produced through an emotional product experience that combined fascination, desire, and surprise. Other work includes the exploration of product 'personality' where two studies examined how changes in product interaction characteristics can change the personal feelings towards a product (Desmet, Nicolas & Schoormans, 2008). The topic of product personality is an interesting one that has been explored by a range of researchers; Janlert and Stolterman (1997) or Govers and Schoormans (2004) for instance both explore the diverse ways in which humans tend to give personality traits to non-living artefacts. Mugge, Schoormans and Schifferstein (2009) also found that strong emotional bonds with products can grow through forms of personalisation as an artefact can become an extension of the self.

Desmet's work with fellow design theorist Paul Hekkert is also of note and has produced much theoretical discussion around design emotion. Desmet and Hekkert's (2003) basic model of product emotions was mentioned earlier but later work has advanced this model further to create a more holistic model of product experience (Desmet & Hekkert, 2007). The model builds on work from Hekkert (2006) in identifying three distinct components of product experience: aesthetic pleasure, attribution of meaning (following semantic theory) and an emotional response. At the aesthetic level, Hekkert argues that products can be seen as beautiful or may feel or sound pleasant. There may also be, as Overbeeke and Wensveen (2003) have explored, a kind of beauty of use where there is an innate pleasantness in a discrete product interaction. Explored in section 1.6.4, design semantics is the critical component for the attribution and experience of meaning. Following work by Crilly and others (2004), the experience of meaning is defined as a semantic interpretation or a symbolic association. The corresponding emotional response is linked to the other factors and is considered as a coherent and functional system determined by an appraisal event. Later work by Desmet (2012) has advanced theory in human-product interactions by describing 25 positive emotional experiences that can be drawn from said interactions. This work studied a range of emotion models and typologies and concludes that emotions such as love, joy and sympathy can be coherently linked to particular product interactions. Additionally, in more recent efforts, many researchers have been working towards a more holistic 'design for well-being' approach which consolidates the initial studies in design emotion with emerging research in lifestyle choices and quality of life metrics (Desmet & Pohlmeyer, 2013; Casais-Brinkman, Mugge & Desmet, 2016).

Hekkert's work has focused more explicitly on the emotional impact of aesthetics and form. While some of this work will also be explored later, it is important to consider some of the research efforts in this area at this point. Hekkert (2006) argued decisively that emotionally pleasurable design can be broken down into sets of four aesthetic principles. Principle 1, 'maximum effort, minimum means' states that sense perception, vision, hearing, smell are constantly trying to operate on an efficient basis, extracting the most amount of information with minimum effort. Principle 2, 'unity in variety' refers to the tendency to group potentially unrelated things – the bookshelf containing books may feel like an object but is actually made of many diverse objects. Principle 3, 'most advanced, yet acceptable' (MAYA) was introduced by famed American designer Raymond Loewy and refers to how aesthetic preferences tend to fall within traditional archetypes. If designers want to create both innovative and appealing products, the MAYA principle should be applied. Principle 4, 'optimal match' relates to the intrinsic pleasantness of related design elements – if one element is much more pleasing than others, this introduces a kind of dissonance in the experience.

These principles have since been expanded and revised in subsequent research efforts (e.g., Xenakis & Arnellos, 2014) but critically, there is a strong set of principles that try to combine sense experience and product aesthetics. Coming back to semantics, some researchers have explored the complex relationships between semantic categories and emotional responses to products. In an analysis of the theoretical issues surrounding product semantics and emotion, Demirbilek and Sener (2003) argued that the complex relationships between emotions, users and products is rooted in a complex nexus of generations, social groups and cultures and ultimately remains elusive.

In any case, the importance placed on the emotional attachment consumers have with products, mostly build from positive memories, is becoming an increasing area of interest (Schifferstein & Zwartkruis-Pelgrim, 2008). Khalida and Helander (2005) for instance state that designers should make satisfying the emotional needs of customers the most important driver in design work as consumer choices are at base, irrational and cannot be guided by a functionalist view entirely. The upshot of these research efforts is that human-product interaction is extremely complex and must be viewed with semantic, emotional, cultural and preference values in mind. Work by Agost and Vergara (2010) developed a model titled 'Subjective Impressions in Human-Product Interactions' (SIHPI) to map how a designer interfaces with these different values. In a detailed study, the model was applied to measure the emotive and semantic links to personal values and preferences for different tiled flooring designs (Agost & Vergara, 2014). The study found that aesthetics and symbolic meaning were strong determinants of product emotion assessment and that some personal values played a significant role – a result echoed by Fenko and Schifferstein (2012) in a different study.

1.6.5 A new materiality?

This discussion centres around developing a reformulation of making and manufacturing that highlights both the material basis of things and how this interacts with the very processes of making. It has been discussed earlier how the language of products – their symbolic associations, the emotions they elicit – is derived from a complex interplay between materiality, form, interaction, and culture. It has also been argued that knowledge of the material basis of the products of daily life – telephones, cars, laptop computers – is almost entirely absent as the imprint of manufacturing has been systematically removed. As has been suggested by Yang and Wu (2006), the modern culture of manufacturing is one of advancing efficiency and precision and not exploring the interactions between designer, materials, and machines. Design theorist Bruno Munari (1966/2008) stated that a designer should act as a 'mediator' between art and society. Perhaps this should be extended to include the manufacturing engineer who may still be tied to the Modernist philosophies of rational efficiency, seeing less value in the textural or the ornamental.

Some of the most interesting work of Western design has been explicitly engaged with the materiality of the produced objects and how this interacts with a multifaceted product experience encompassing complex visual and tactile sensations. Marcel Bruer's work that was mentioned earlier was notable for its exploration with novel material components. Designers of the mid-century movement Charles and Ray Eames similarly experimented with previously unexplored modes of production creating innovative pieces of furniture from bent plywood (see Koenig, 2005 for an overview). More recently, the acclaimed Apple head of design, Jonathan Ive has spoken of a deep interest in materials and processes as the root of successful and meaningful form creation:

‘Form and the material and process – they are beautifully intertwined – completely connected. Unless we understand a certain material — metal or resin and plastic — understanding the processes that turn it from ore, for example – we can never develop and define form that’s appropriate.’ (Quoted from ‘Jonathan Ive on Apple’s Design Process and Product Philosophy’, New York Times, 2014, online resource)

Apple’s recent line of MacBook computers are heavily reliant on advanced machining processes. It is clear from Ive’s point of view that much can be drawn from a focus on materiality and not a form-centric view of design. These examples of iconic design work are all bounded by the processes of making – their forms are contingent upon it and reveal them. Nineteenth century art critic and theorist John Ruskin (1857/2012) spoke of ‘leading lines’, or lines of formation that were present within the natural world. The undulations and irregularity of mountains, for instance, reveals the processes of formation – the flow and movement of energy and material. There is an analogy here with manufacturing. Earlier, the concept of ductus was discussed which describes a map through a rhetorical composition (Ingold, 2008; Carruthers, 1998). It is possible to extend this concept to a manufactured product whereby certain markers can provide a ‘map’ into and through the processes of making. These marks of making are generally seen as kinds of imperfections where the presence of material texture for example is obsessively removed. In advanced machining practices aided by computer-numeric control (CNC) and computer-aided manufacture (CAM) systems, the general culture is orientated towards the removal of the traces of the machining process by a systematic flattening of material texture. This culture is arguably the result of and reinforces the modern dichotomy between science and art. As Snow (1961) notes, since the European Enlightenment (approximately three centuries ago), the two cultures have become increasingly distinct and specialised with one grounded in conceptions of the ‘rational’ and the ‘linear’ with the other more ‘primitive’, ‘organic’ or ‘sentimental’. In design these manifest in an unwavering search for more efficient and more precise methods of producing products – where textural features are flattened by a belief in a symbolic rationalism. Work by Mikael Wiberg (2013) has considered how materiality could be considered more closely within design and design methodologies. A model is proposed that accounts for non-linearity within the design process by viewing it as a dynamic exchange between *materials, details, texture and wholeness* (Figure 10).

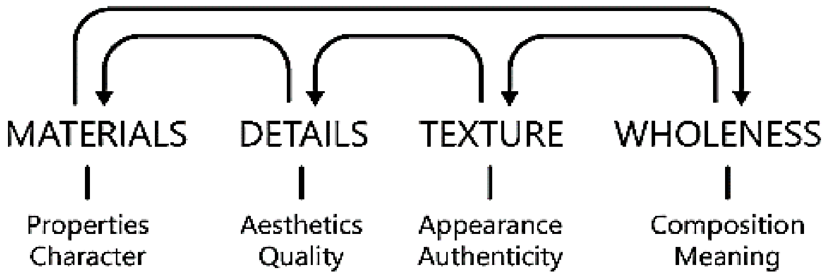

Figure 10 – Dynamics between materials and wholeness, adapted from Wiberg (2013)

In Wiberg's framing, the materials dimension should be the process of understanding a work material, its 'character' and the limitation of that material. As Wiberg states 'material character is about how a certain material can be used, what it expresses, and its inherent structure and logic' (p.630). This relates to ideas of detailing or 'attention to detail' and material texture which can be interpreted both visually and through tactile interaction, sometimes to different results (Robles & Wiberg, 2010; 2011). The resulting 'wholeness' is described as a kind of composition formed from the other elements taken together. This then results in a sense of meaning and completeness or as Jung and Stolterman (2012) have said, 'a subjective interpretation about qualities and values of a material artefact' (p.649). From the studies in design semantics, interaction and emotion discussed earlier, it is not difficult to see how the contingencies of making and materials (what has been referred to overall as the contingencies of form), have a deep influence on end user experience.

1.6.6 Links between research topics

The previous sections have highlighted some of the research paths that have defined much of the last decade of design and material culture research. Thus, the most relevant question now is how a novel research path is defined that may open doors to fresh knowledge contributions. Critically, there are interesting links between making ontologies and the end experience of use and interaction (see Figure 11). These also articulate with scholarships exploring psychological perception namely emotion and semantic theory. What was identified as a missing component from this picture is the status of so-called ‘advanced’ processes. While there is a wealth of research exploring process parameters and aspect of machine operations, there is little consideration of how the extant concepts of emotional experience and sematic meaning interact with these processes at either the point of artefact creation or the end product. As there is a clear relationship between these phenomena, the research path aims to explore this further through a variety of research methods and introduce both empirically grounded and theoretical conclusions for further discussion and study.

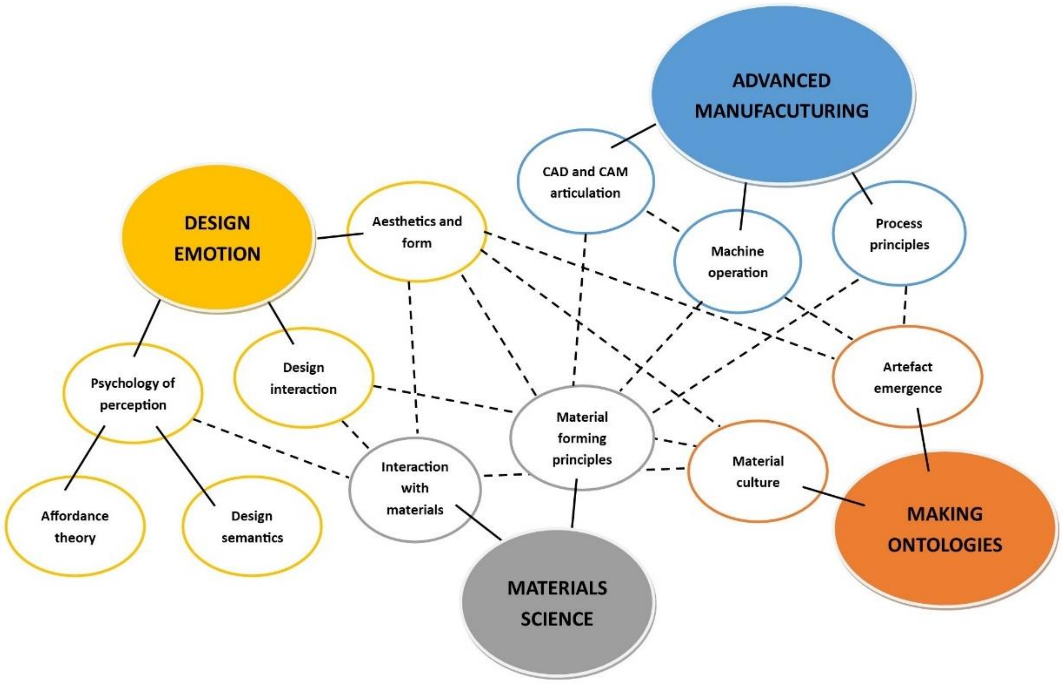

Figure 11: Relationships between literature topics

1.7 Summary

Many areas of scholarship have been discussed across this critical review tracing a story between emerging research philosophies in design such as design semantics, design emotion and ontologies of making. A general discussion of form identified entrenched narratives of design, notably the hylomorphic model which sees artefact emergence as a linear result of designer-agent intentionality. Through an examination of scholarship concerning making, materiality and manufacturing taxonomies and ontologies it was further demonstrated that these narratives also penetrate the cultures of contemporary fabrication. Challenges to these narratives, notably the concept of ductus, were introduced and present critical questions regarding manufacturing fundamentals and modalities. Recent development in design research and culture were identified that explore integrating emotional and semantic experiences into design work. As a counter to linear hylomorphism, integrating these non-linear concepts with the linear principles of modern manufacturing presents the possibility for new understandings of object experience, novel definitions of materiality and new ontologies of emergence. The critical take away points from this review are listed as follows:

- *Form is a highly complex and diverse concept, within the context of design, form is meaningfully defined as a geometric embodiment that interacts with aesthetic judgements*
- *Ontologies of emergence, making, materiality and subsequently advanced processes have been strongly influenced by the Classical concept of hylomorphism. Fused with Enlightenment rationalism which influenced the development of Modernism, modern manufacturing is often defined in strict terms of linearity*
- *Experiential facets of designed objects have been increasingly explored as a possible challenge to the linear models of design*
- *A significant gap exists between the cultures of modern manufacturing practices and the cultures of designers interested in the experiential facets of form*

The critical questions are what type of investigation could allow for an exploration between the two worlds of theoretical design and modern production? And how can the discourses around making, and materiality be introduced into modern manufacturing protocols or ontologies of emergence? A research methodology for attempting to answer these questions is presented next.

2. Research methodology

Science is nothing but perception

- Plato

This research uses a triangulated methodology drawn from elements of positivist, interpretivist, and realist approaches. The following sections review sets of research methods and justify this approach for the project overall. Thematically, the work deals with several discrete topics that can be analysed scientifically. Principally, human perception and experience of form and aesthetic elements and physical production parameters derived from manufacturing technology. Considering that topics of this nature are very different and the scientific approaches to studying are highly divergent, constructing a coherent methodology can be problematic. Accordingly, this project must consider both qualitative and quantitative factors, both the highly subjective and the demonstrably objective. Hence, this chapter will set forth the research method for the project. Firstly, it will review the various research approaches and philosophical positions that can be applied to guide research more generally. Following this, the critical themes of the work are laid out against the various approaches reviewed and the most suitable direction of methodology is triangulated.

2.1 Philosophical positions

In developing this research, we must firstly consider a range of critical philosophical positions and assumptions. The overall aim is to enhance understanding of the emotional experience of form and translate this into sets of manufacturing rules or protocol. These central aims must initially be split into broad themes from which we can delve more deeply into what philosophical positions and questions we must consider. If we demarcate the statement of the aim into two parts, we can more easily consider the discrete themes of the work. First, *understanding of the experience of form from a semantic and emotional perspective* and second; *translate this into sets of manufacturing rules or protocol.* The first statement can be further divided into three clear themes, namely, emotion, experience, and form. The immediate questions that are raised are what is meant by these terms and how do they relate to one another in meaningful ways that can be studied? Philosophically, each of these topics has a rich and complex history of thought behind them and the positions expressed within this work must, in some ways, be considered within a historical narrative and context. For example, it is ill-advised to analyse contemporary architecture without considering the influence of the Neoclassical tradition that preceded it.

2.2 Adopted research approach

As the work will be carried out over a long period of time and over many phases, a mixed-method approach will be used incorporating aspects of positivism, realism and interpretivism (see Creswell, 2014). The central goal of this work is to unify abstract knowledge gained through the experience of product use and interaction with manufacturing protocol. The immediate problem is that the broad field of theoretical design research, material culture studies and aesthetic theory can be highly subjective, and, by contrast, manufacturing protocol and engineering principles demands objectivity and have objectively measurable results. Thus, this research demands a complex philosophical position which draws from both the subjective and the objective approaches.

2.2.1 Ontological position

The ontological position of this research will be described as *weak-subjectivism*. The starting phases of the work are driven by the subjective experience of participants and the subjective interpretations of the researcher. Reality is multi-layered and external to the human mind but can be subjectively interpreted by it. Following the *grounded theory* of Glaser and Strauss (1967/2017), this subjectivity can be tempered by looking for codes and patterns in data to establish theory. Similarly, it will be tempered by the extraction of solid objective data from the manufacturing phases of the work. This means that an objective phenomenon is being analysed in an interpretivist paradigm – the quantitative fused with the qualitative and a causal link between them is assumed.

2.2.2 Epistemological position

Epistemically, this research considers aspects of positivism, realism and interpretivism. The most prominent and relevant position is *realism,* but the researcher will also adopt a position of *weak-positivism* and *weak-interpretivism*. Breaking this down, we assume that the world and knowledge attained empirically through its analysis is intrinsically questionable and may be a function of the researcher's values. However, it will also be assumed that some form of objective knowledge is possible through quantitative methods. This research will not hold to a strong antipositivst view which sees the acquisition of scientific knowledge as effectively impossible, but it will recognise (and use the language of) Kuhn's (1962) view of science as a succession of paradigms in which knowledge grows. This work is part of an evolving paradigm, and this will be explicitly referred to within the content of the research. Additionally, in the treatment of historical facts and analysis, the broad position of *social history* will be taken which views historical developments through a lens of social and cultural factors and the lived experience of people.

2.2.3 Methodological and axiological position

The primary methods of the work will be *qualitative* combined with numerical analytics of a quantitative nature (statistical grouping). This will allow for the meaningful analysis and interpretation of aesthetic phenomena. The latter stages of the work will use *quantitative* methods involving the objective measurements of components. Given these criteria – the overall methodological position is that of a *mixed-method triangulation* allowing the research to *deductively* explore a range of diverse phenomena from the social and experiential world in addition to the more precise engineering world. Axiologically, this research is *value laden.* It will be assumed (following the realist framing) that the values of the researcher and the participants will influence the output and interpretation of the data and that other interpretations are equally valid. This will be taken into consideration when experimental results are discussed. The overall approach is summarised in the diagram below (Figure 12).

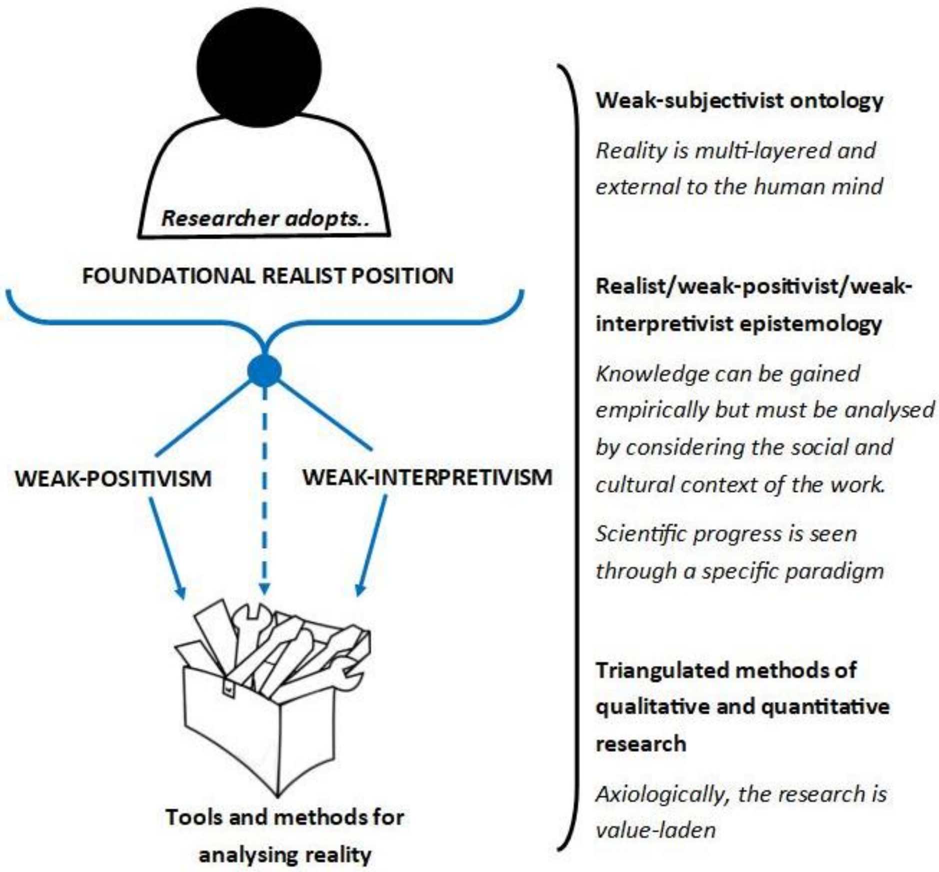

Figure 12. Summary of adopted research positions and approach

2.3 Workflow and objectives

This section will detail the overall workflow and research objectives in more detail. Each objective will be broken down into a short description and the methods used within each will be discussed. This will allow the reader a clear picture of the overall research narrative. An overview of the whole thesis structure can also be seen in Figure 13.

2.3.1 Objective 1 – Qualitative and historical analysis

Following the critical review of literature, the first objective will be a qualitative aesthetic analysis. This stage will follow closely the approach of grounded theory (Glaser and Strauss, 1967/2017) described earlier and will provide a foundation to much of the later discussions within the work. It will also include a historical analysis which will follow a social history paradigm refined through the methods of art history. The implicit subjectivity of this stage will be tempered by referring directly to empirical work in psychological science that will reinforce the arguments.

2.3.2 Objective 2 – Mixed qualitative and quantitative

Objective 2 will triangulate qualitative and quantitative data in a mixed method approach following Denzin (1970). This stage of the work will focus on experimental aesthetics where aesthetic forms, motifs and concepts are analysed with psychological methods. The primary methods will be semantic differential scales which are designed expressly to measure opinions, attitudes and values (see Osgood, 1964). Additionally, associative expression tasks will be used to validate aspects of objective 1 and provide further foundations for the activities of objective 3. 30 participants will be involved in this experimental phase.

2.3.3 Objective 3 - Qualitative

Objective 3 will be driven directly by the results from objective 2. This stage will consist of qualitative design work which seeks to integrate consumer experience[10] with the development process itself (see Page and Thomas, 2009). This approach is part of the paradigm in design thinking known as Kansei engineering; the subjective feelings of the potential users explicitly inform the design development (Lévy, 2013).

2.3.4 Objective 4 - Quantitative

Once the design phase has been completed, a secondary phase of quantitative work consisting of simulations will constitute objective 4. The simulations will provide numerical data relating to the manufacturing phase of the work and allow particular inputs to be tested in advance of actual production. This will be a vital input in the triangulation of the overall argument. The simulation information will also be used as a datum by which to analyse the manufactured parts.

2.3.5 Objective 5 - Mixed qualitative and quantitative

The fifth objective will be driven by qualitative methods that will be quantitively analysed (similar to objective 3). This stage will involve the systematic analysis of the emotional and tactile properties of the manufactured parts. Again, semantic differential

[10] The concept of an 'experience' is complex and multifaceted and will be explored in depth later within this thesis. In this case, a Deweyian conception of experience is being referred to.

techniques will be employed to gather data, this data will then be analysed quantitatively, looking for patterns of experience in human participants. 30+ participants will be used for the final experimental phase.

2.3.6 Objective 6 – Qualitative / theoretical

The sixth objective is the development of theoretical conclusions that are derived from the experimental findings. This is an amalgamation of the themes discussed in the work connecting the gap between the physical experimental work exploring advanced manufacturing processes and the subjective and theoretical discussions focused on perception and emotion throughout.

2.3.1 Objective 7 – Qualitative

Objective seven is a final qualitative analysis which will consist of a series of expert interviews. These interviews are designed to act as a form of validation in which the theoretical conclusions and practical developments of the work can be examined from an external perspective.

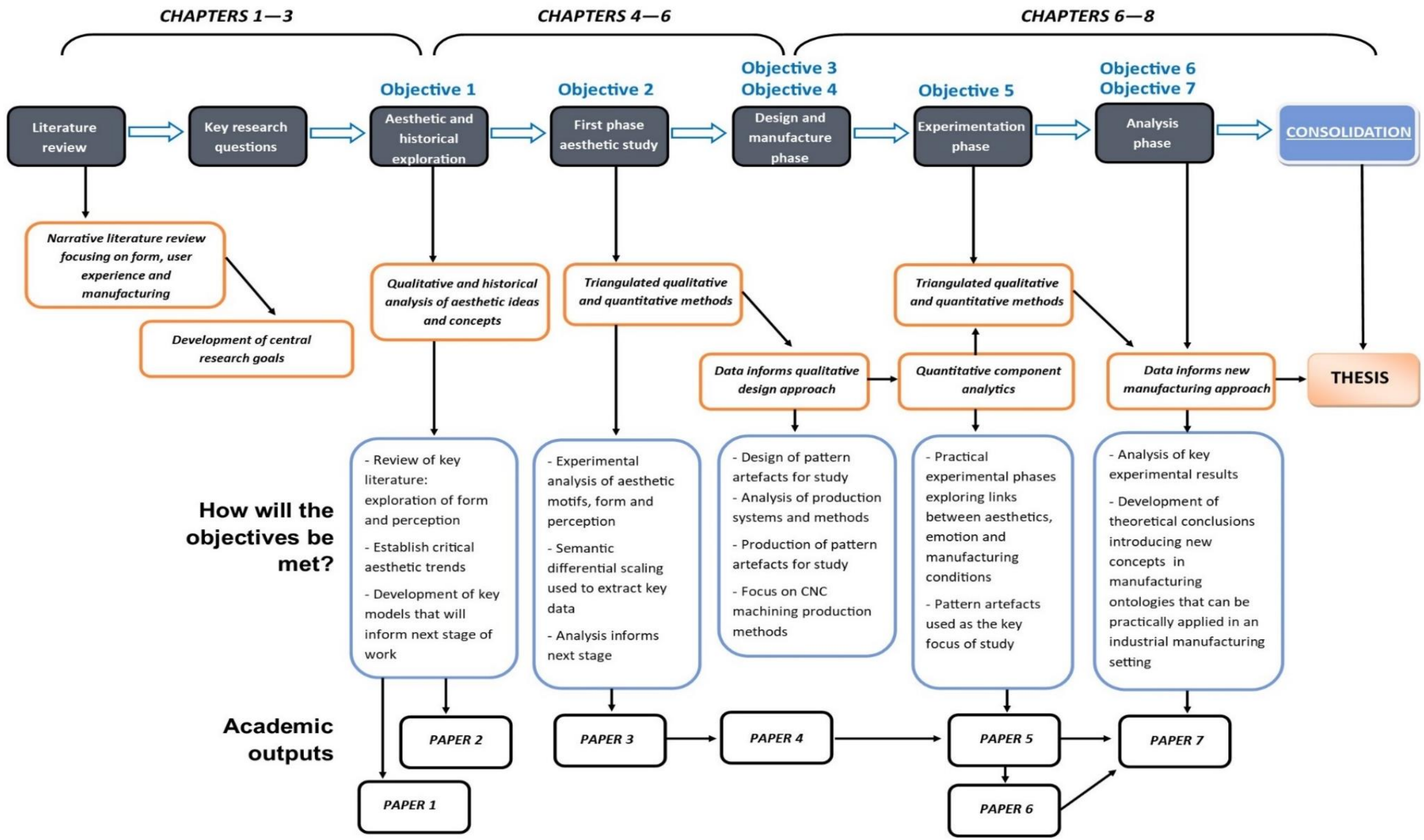

Figure 13. Overview of thesis timeline including chapter and objectives breakdown and details of activities and outputs

2.4 Summary

The research is complex and multifaceted, dealing with many different areas of study and scholarship. This intrinsic complexity demands a considered methodology grounded in well-established approaches. It was proposed that the appropriate methodology would be developed by triangulating a range of epistemological theories in order to extract the key areas of new knowledge utilising both qualitative and quantitative methods. The adopted research positions and approaches are detailed in Figure 12 and posit a foundational realist position that introduces elements of positivist and interpretivist thought. Neither strong positivism or strong interpretivism are appropriate for this work but aspects of positivist empiricism and interpretivist subjectivism will be used throughout the work. Allowing for the operation of multiple frameworks allows the research to explore many lines of interpretation and extract value where possible. Given the formulation of the overall approach and research philosophy, the research is subsequently divided into eight chapters that correspond with seven key objectives. Each objective has been described in terms of the methods that will be required at each stage. Both quantitative and qualitative methods have been triangulated at critical stages, notable at objective 2, and 5 which will be driven by the approaches of experimental aesthetics and subjective interpretation. Objectives 1, 3, 4, 6 and 7 will use either purely qualitative or purely quantitative methods.

3. The experience and perception of form

Every art communicates because it expresses. It enables us to share vividly and deeply in meanings

- John Dewey

Chapter 1 explored how interaction with designed objects is deeply complex and is dependent upon many facets of experience including cultural cues and understanding. The tool used to do this is form. This chapter continues this theme by presenting an analysis of the emotional experience of form. Several strands of scholarship are examined – the definition of experience, how human emotion is conceptualised as a discrete experience, the relationship between emotion and human perception of the visual and the historical expression of form through aesthetic styling. Influenced by Tim Ingold's work on lines, a model of form and emotion is developed that consolidates this scholarly analysis and an additional examination of Western design history mediated through its line-based building blocks. Additionally, findings from an experiment exploring form embodiment and representation are presented that establishes pattern and symmetry as central meta-concepts for the study of design, form and ornamentation.

3.1 Theoretical overview of emotion

3.1.1 Having an experience

To begin this discussion, the notion of experience must be given some attention. The American philosopher John Dewey wrote extensively on the perception of aesthetics and described the term *experience* as an event that is demarcated by a clear beginning and an end, ultimately creating a whole. Discrete activities shape the experience, what Dewey refers to as the relationship between 'doings and undergoings' (Dewey, 1934, p.44). The definitions of experience are largely ambiguous but can generally be said to relate to temporal narratives, that is phenomena bounded in some conception of time or what is referred to by Bergson (1910/2008) as *duration*. For example, a person may be 'experienced' in a particular discipline, implying a kind of acquisition of knowledge or skill. Some of the phenomenologists, such as Merleau-Ponty (1945/2013) mentioned in Chapter 1, see experience as a kind of matrix of perceptions all interacting with one another; a point that echoes Hume's (1738/1985) 'bundle theory'. By contrast, philosophers such as Kant in his *Critique of Pure Reason* (1781/2008) dismisses the notion of experience for a framework based on ideas and concepts. In Kant's view, experience cannot be counted as a meaningful path to truth or knowledge. Later work of philosophers and theorists such as Bergson, Merleau-Ponty and Whitehead (1979), experience was reconfigured as a process of 'emergence', constantly in flux and influenced by perception, senses, and memory of the past. For the purposes of this study and the examination of human interaction with aesthetic phenomena, Dewey's (1934) definition is particularly useful. The experience of having an emotional response to an aesthetic object can be viewed, in Dewey's terms, as a temporally based activity or event that shapes an overall whole experience from the cognitive perspective. What defines an experience absolutely in either philosophical, cognitive, or neuroscientific terms is still an ongoing problem and addressing this fully is beyond the scope of this work.

3.1.2 Emotional experience

A central property of many human experiences are emotions. Work on the emotional experiences of humans is extensive and many theories have been proposed throughout recent history (see Izard, 2009 for a detailed summary). Some of the earliest scientific theories were purely physiological – it was understood that emotions could relate to differing facial expressions (see Darwin 1856/2009 for example). Delving back even further, the ancient concept of the four humours – blood, black bile, yellow bile, and phlegm – considered emotion as a constituent part in producing disease by causing imbalance in the secretion of one of the four fluids. Notably, historic conceptions of emotion were physiological; an emotion could affect the body in a tangible way. In the 17th century, following the influential work of Descartes (1641/1999), the mind and by extension the experiences of the mind, were demarcated from the physical object of the brain. This idea, referred to today as mind-brain duality, led to the view that emotions were beyond the realms of empirical understanding. As the mind was considered separate from the brain, a non-physical and non-spatial substance, it could not be empirically examined meaningfully. The problem of how physical body parts create huge varieties of subjective experiences is still a major problem in philosophy and science – conceptualised by Chalmers (1995) as the 'hard problem' of consciousness. Regardless, this dualistic view began to break down towards the end of the 19th century when the emerging psychological sciences started to examine discrete experiences such as perception and emotion. Some of the earliest research into what constitutes a human emotional experience that is meaningfully scientific begins with William James, the American psychologist and philosopher of the pragmatist school. James' (1884) theory proposed that emotion was a function of an antecedent arousal state. When the body experiences physiological change, the emotional experience that follows constitutes part of the physiological changes through a system of feedback – a quickening heartbeat when one is frightened for example. This inversion of the more linear approaches to emotion understanding was radical and has proved challenging to disprove with elements of it being integrated into modern neuroscientific understanding (Dalgleish, 2004). Aspects of the theory have, however, been criticised since its development and later theories have considered other factors to be the central mode by which emotions operate. The Cannon-Bard theory for instance presented evidence that directly opposed James' theories by proposing that stimulation of the hypothalamus led to emotional experiences rather than a process of feedback (Cannon, 1927). Work by Barbalet (1999) however suggests that James' views on emotion have been consistently misunderstood and that the apparent Cannon-Bard disproving of his theory amounts more to a misinterpretation of James' thought.

While it became abundantly clear through competing theories that emotions, as discrete experiences, were difficult to analyse, researchers began to question what role emotions play and why they were present at all in human experience. Research from the middle of the 20th century considered the functional role that emotion played both in terms of human development across time and the social functions of emotion. One prominent theory posited that an emotional experience is built from physiological stimuli and contextual cues of a process of cognitive labelling that allow the experience to be understood (Schachter & Singer, 1962). This two-factor theory demonstrated how emotion cannot necessarily be understood in simple terms of physiological change – it requires an intelligible contextual foundation without which an emotional state can be misattributed (Dutton & Aron, 1974). Other theories, such as those from the

Behaviourist school of thought, proposed that human emotion is a learned behaviour that is determined by environmental changes or by systems of reinforcement or punishment; a kind of social conditioning (Staats & Eifert, 1990).

Some of the of the most significant theories of emotion have drawn on the perspective of cognition - mental processing of stimuli. Lazarus (1991) for instance, considered emotions of high importance in general human reasoning, what has come to be called appraisal theory. These models developed the earlier two-factor theories by incorporating a factor of cognitive intentionality. As Lazarus argued, the fact that an event can be interpreted and understood in a particular way will lead to an emotional response followed by an action of some description – a cognitive appraisal, followed by a physiological change characteristic of an emotion, followed by an action response. This model has proved influential where emotion serves as a functional tool that can guide the body in one way or another. Another theory from Frijda (1986), explores the possibility that emotions elicit action tendencies that, in turn, advance certain behaviour – the cognitive appraisal is more closely associated with an end action. This multi-faceted behaviourist view proposes that emotions serve certain fundamental human needs, a view also held by Solomon (1977) who argues that emotions are types of judgements and can be adapted and revised in a similar way to beliefs. In opposition to James' view, he argued that one could experience anger without displaying any physiological characteristics of anger (Glazer, 2018). The cognitive theories are generally utilitarian in approach; the abstract sensation or a feeling of emotion has a tangible function that assists in the understanding of an event, ultimately aiding survival in the context of an evolutionary struggle.

More modern work on emotional experience has posited a wide range of theories and concepts. These can be considered broadly in two categories – physical theories and phenomenological theories. For the purposes of this work, we will be considering the phenomenological approaches whereby the experience of emotion is examined. Physical theories are extensive (see Dalgiesh, 2004) and fundamental in an overall understanding of how brain functioning might cause emotion but does less to advance our understanding of the experience itself. Indeed, Lisa F. Barrett's (2006) theory of constructed emotions takes a psycho-social approach and sees the experience of emotion as a function of 'interoception' or the feeling of an internal bodily state, a person's understanding or interpretation of discrete concepts and the social context from which the individual comes. From this point of view, each discrete experience of an emotion has been constructed by a range of factors including sets of powerful cultural influences. Other work has suggested that emotions extend beyond individuals and operate as a kind of social system – a temporal structure that exists between people as they communicate (Butler, 2017). Another prominent contemporary theory explores the possibility that our understanding of emotions is only driven by a so-called direct perception; when you see someone smiling, this is the only way that the emotional experience of that person (happiness) can be known epistemically (Gallagher & Zahavi, 2012).

3.1.3 Categorising emotion

While these theories explore the process and origin of emotional experience, work has also been undertaken to describe and categorize the varieties of experience. The idea of classifying emotions dates back into ancient antiquity. Gradually, factors of discrete human experience and indeed facial expressions would be recast to relate to feelings and specific emotions. A process that Dixon (2003, p.180) refers to as the 'creation of the emotion' where, during the late 18th century, the experience of emotion was recast as a physical mechanism.

This consideration of emotions as distinct categories of experience has been followed until the present day. One of the most prominent modern theorists, American psychologist Paul Ekman, has proposed a model of basic emotions where emotions are discrete and measurable states. In a set of studies, he proposed that emotion can be split into six broad categories: anger, disgust, fear, happiness, sadness, and surprise (Ekman, 1980). The categories were produced from facial expression studies across different cultures. Later this list was expanded to include amusement, contempt, contentment, embarrassment, excitement, guilt, pride in achievement, relief, satisfaction, sensory pleasure, and shame (Ekman, 1992). Similar to the work of Ekman is the prominent model of emotion categories developed by American psychologist Robert Plutchik (1980). Known as the 'Wheel of Emotions' (Figure 14), it attempts to show the relationships between distinct classes of emotions and how emotive categorizations are not necessarily discretely definable and emotional states themselves are highly transient – a point also intimated by the later models of Russell (2003). For example, the intensity and character of feeling in the emotions we call joy are similar (according to Plutchik, 1980) to that of anger.

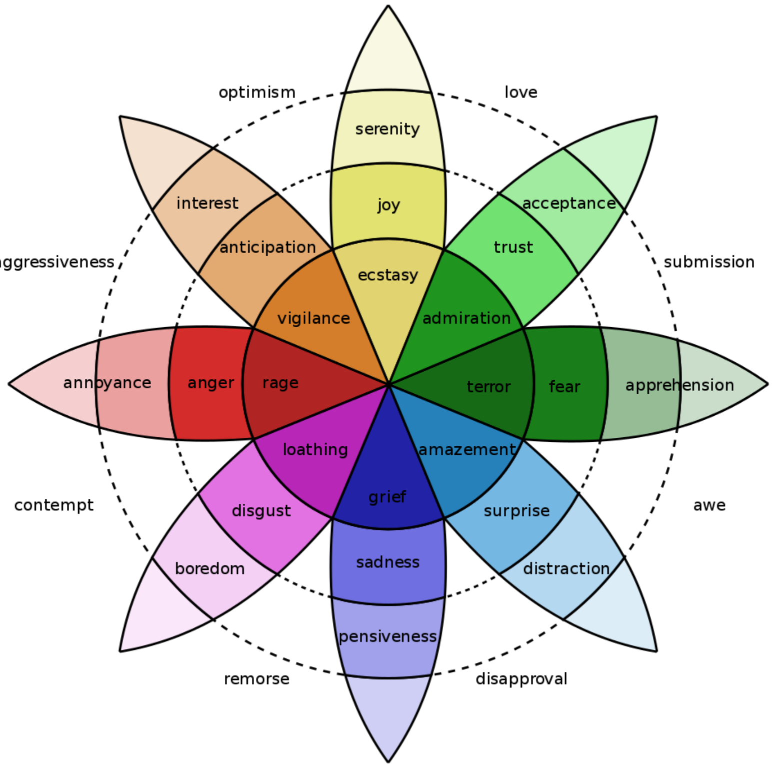

Figure 14 – 'Wheel of Emotions' model, from Plutchik's (1980)[11]

What makes the experiences distinct is the context; what has been experienced and to whom it has occurred – a point considered paramount in many of the theories described earlier. Other useful models include the work of Shaver et al. (1987) and Cowen and Keltner, (2017) who define 27 distinct categories of emotion. If we relate this back to our discussion regarding form-experience, the context of form is important. Much research has shown that isolated geometry can relate to distinct emotive classes. The task of understanding emotional responses to aesthetics has been challenging for researchers due to it not having an immediately obvious evolutionary advantage. Clearly, emotion serves a range of very complex functions, and we must consider that emotive responses to form are serving both fundamental human needs such as

[11] Source: Machine Elf 1735 via Wikimedia Commons: [Wheel of emotions]

cognitive processing and understanding of the environment and socially constructed needs and values such as taste or fashion. Categorisation is important to consider and can help provide foundation to our form and emotion model presented later.

Emotion may be the critical factor for a form-experience. Recent architectural theory has associated aesthetic ideals with critical human needs and values. Gaston Bachelard's (1958/1994) work *The Poetics of Space*, originally published in 1958, explicitly considered the emotive experience of architectural form from a phenomenological perspective in a similar way to Pallasma (2005/2012) discussed in Chapter 1. Modern research in aesthetics, drawing on Dewey's (1934) initial foundation has considered the process of aesthetic appreciation as an experience. The model proposed by Leder et al. (2004) considers the experience of art or form to be constructed by a complex system of feedback where an analysis of the form, emotional affective states, memory, prior knowledge, and social setting all play a role in a resultant aesthetic judgement and emotion. In an updated version, more prominence is given to the emotional affective state of the observer that drives the overall experience (Leder & Nadal, 2014).

3.2 Emotion and form

The form of objects and the built environment acquires meaning through our emotional engagement with it (Desmet, 2003; Krippendorff, 2006). The artist and critic William Hogarth in the 18th century produced his aesthetics treatise *The Analysis of Beauty* that argued that a representation of beauty can be found in a simple wavy line. From his diagram (Figure 15), Hogarth indicated that line number four has the true essence of a beautiful form with the others being described as bulging, clumsy, mean and poor (Hogarth, 1753). Later theoretical work by R.G. Collingwood (1938/1958) echoes Hogarth by arguing that in some sense, all art is an expression of emotion and does not discretely represent ideas or concepts. Within the context of design, this can perhaps be extended to include the principles of function and affordances which also influence aesthetic judgements. Within the work of Hogarth and Collingwood are more modern ideas relating abstract shapes and lines to specific emotive and semantic properties of psychological experiences and perceptions. Modern work from cognitive psychology analysing visual perception has presented evidence that suggests human beings have a natural inclination to prefer curved forms to angular ones, partially validating Hogarth's initially subjective insights (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016). Curves, it seems, have long been a prominent feature of artistic or creative expression; examples of curving imagery such as waves and abstract impressions of animal movement are present even in the cave painting of Palaeolithic humans dating back around twenty thousand years (Clottes, 2016).

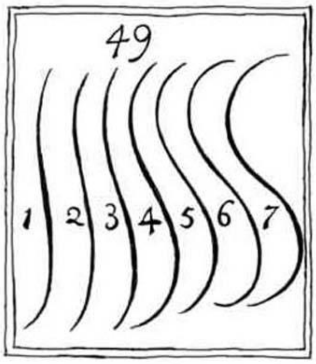

Figure 15 - Hogarth's 'The Analysis of Beauty' (1753) related line styles to emotional and semantic values[12]

The questions concerning the experience of form – shape, curves, angularity, and its overall structural foundation - have often been approached using categorisations of form qualities. Research within perception and emotion has tended to focus on form as an abstract entity, as a non-descript isolated shape or simply a line, usually characterized by implicit angularity or curvature. Work in the psychological sciences has consistently shown that humans will be inclined towards curved forms (Bertamini et al., 2016). This experimental work has usually utilized isolated form abstractions in a variety of contexts to demonstrate this inclination. Early work by psychologists Poffenberger and Barrows (1924) showed that angular stimuli were semantically associated with words such as powerful, serious, or hard. Their experimental work used 18 variations of simple line drawings, all with a wave-like sinusoidal structure, varying in frequency, where participants were asked to assign sets of adjectives to each. The curved forms were associated with words such as gentle, quiet and playful meaning there was an important experiential distinction as people looked at the different lines. Notably, small changes in the axis angle of the lines altered their semantic value – for

[12] Source: Public domain, Wikimedia Commons: Hogarth lines

example, a wavy line previously associated with the word gentle became associated with the word lazy when rotated clockwise slightly. Similar results have been recorded more recently by Collier (1996) in a set of experiments, in the well-known 'kiki/bouba effect' shown by Ramachandran and Hubbard (2001), and by Bar and Neta (2006) utilising common objects and what they term meaningless patterns – sets of arranged abstract shapes. Both studies showed participants had a higher preference for curved objects and patterns as opposed to the angular variations. Additional work relating expressly to industrial design has noted a trend in recent car interiors design, moving towards curved structures and away from angularity that was seen extensively in the 1980s and 90s (Leder & Carbon, 2005).

Research by psychologist Marco Bertamini and others has sought to understand the curvature response more comprehensively by evaluating how our perception of form, lines of abstract shapes is influenced by other factors such as perceived complexity, visual information and colour (Bertamini et al., 2016). In a set of experiments, the researchers found that curved forms were preferred in a wide variety of contexts. In one experiment, abstract curved forms were preferred over angular ones and angularity was notably associated with complexity. Another used very simple stimuli of coloured lines in various arrangements. Again, curved forms were the most preferred in the various configurations that they appeared. Critically, the context of the lines did not seem to affect the propensity for curvature preference.

Many of these studies suggest that some visual preferences are innate and occur naturally, or possibly are instilled at a very early age (Lewalski, 1988). At the biological and cognitive level, explanations vary. Some researchers have concluded that our propensity to prefer curved structures is some form of primitive threat response, reminding humans of teeth or treacherous environments (Bar & Neta, 2006). Related work by design theorist Del Coates (2003) has attempted to integrate form perception with information theory using a concept named 'concinnity', broadly defined as a sense of harmony. Coates considers two types of concinnity; objective – which speeds the process of pattern finding or intelligibility of interacting with an object for example, and subjective – defined as logical emotional cues that speed up the mental processing of an object's meaning (Coates, 2014). A sphere can be said to have the maximum amount of objective concinnity in a three-dimensional environment given its bilateral symmetry across any central axis (Coates, 2003). The concept of concinnity relates directly to mathematical theories of smoothness. In this context, the rate of curvature is known as curvature continuity. Figure 16 illustrates through line relationships the differences between the geometric categories with the definable tangent points marked. What is called G-0 continuity is positional, where two surfaces share a single and definable edge. G-1 continuity is tangent where the surfaces share an edge but there is no discernible break in the transition from one surface to the next. G-2 continuity, or curvature continuity is defined by surface planes having equivalent rates of curvature before joining – in this way the points of surface transition become theoretically undefinable as one curved surface moves into another (Foster & Halbstein, 2014). It is an important fact that any object capable of being visually perceived by humans can be abstracted into these sets of simple line relationships. Indeed, work by the computational design theorists Mothersill and Bove (2015) has directly applied this psychological work to develop a form and emotion taxonomy.

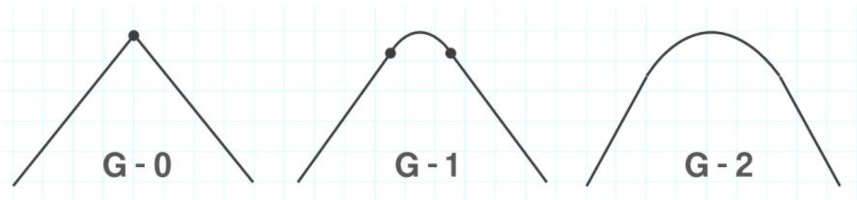

Figure 16 - Three levels of curvature continuity that form can be abstracted into

3.3 Developing a model of emotion and form

The following sections describe the development of the 'Line Model of Form and Emotion' as a means of analysing the emotive and semantic experience of form and to show how the various manifestations of form across time can be interpreted and understood from the perspective of emotional experience, specifically, discrete categories of experience such as joy or anger. Outlined in this section is the overall method for distilling and analysing form. The principle of form and structural archetypes is set out to clearly bound the analysis. The method has been closely informed by the design theorist Rowena Reed Kostellow - her principles of dominant and subdominant structural elements are applied to refine the understanding of the visual elements (Hannah, 2002). Erwin Panofsky's (1939) iconographic approach to art analysis has also closely informed the method.

The key challenge to address is how to reasonably find examples from the various epochs in the history of art or design; the nature of this task is intrinsically subjective. It is worth noting here that aesthetic development cannot be looked at in a simplistic and reductionist way, it must be viewed more holistically with the complex connection - both historical and cultural - laid bare. Thus, in developing our model, the idea of a form 'archetype' was considered. An archetype, in this context, refers to an element of form or structure that is coherent and stable enough to be identified in a multiplicity of places during a historical period. For example, what we now call Neoclassicism has many archetypal features – Doric and Corinthian order pillar design for instance. While there may be small variations due to factors like artistic expression, the form can be clearly linked with a certain style that was prominent during a certain time historically.

3.3.1 Form archetypes

With respect to the discussions concerning the nature of form and its interpretation, we can attempt to establish how an archetypal form feature can be classified. The model takes a historical approach by analysing changes across time, from the Neoclassical period to the present day, so it is important to clarify how critical changes can be measured and categorized. Four critical elements can define a form archetype; 1) a recurrent aesthetic feature, 2) a feature with an identifiable underlying structure, 3) an identifiable character to the form – built from geometric elements or, 4) the possible presence of tangible semantic properties (the forms convey a meaning). These four elements can theoretically be used to broadly categorize dominant features of historical movements in aesthetics. These form archetypes are a narrower kind of analysis. Archetypes of structure or the underlying foundation from which the forms grow from and are framed within must also be considered.

3.3.2 Structural archetypes

Structure provides a foundation to form (Hann, 2012) so we must consider structural archetypes within this discussion. Three elements that can define a structural archetype are as follows, 1) an identifiable framework by which the form is developed around, a square grid structure for example from which other, more complex features can be built, 2) conformity (or lack of) to certain rules or formalities – proportion, symmetry and rhythm or the repetition of elements and motifs for instance and, 3) scalability or the structural design – the design can be identified on the macro scale and are also applied to features at the smaller scales like ornamentation. Both types of archetypal element (form or structural) will be crucial to consider in our line analytics. By establishing these key elements our analytics can be more structured and constrained when developing the model.

3.4 Components of the model

3.4.1 Theoretical and Philosophical Underpinnings:

The methods rely primarily on theories regarding the interpretation of form from the point of view of emotion and semantics. As discussed in the previous chapters we are considering several notable research methods from the empirical sciences and theoretical and philosophical approaches such as the Gestalt psychologists discussed in chapter 1. The base assumption here is that form, as it exists to be experienced by humans, has tangible effects on them leading to interpretations of meaning (semantics) and emotional experience. There are large areas of study that clearly demonstrate that geometric characteristics such as curvature are emotively more pleasurable for human beings. This essential nature has been discussed and formalised philosophically since at least the 18th century (see Hume, 1757) and modern theorists continue in this line of reasoning attempting to disseminate the enigma of aesthetic experience. The work of Arnheim (1954) proposed that the visual senses are primary sources of reasoning, perhaps more important and primal than the comprehension of language. Arnheim argued that the visual arts were not expressions of an abstract creativity but were in fact other forms of reasoning – there is an inherent logic in the creation of form, its exploration and development an essential aspect of the nature of the human animal. Given this narrative of form analytics, it can be extended to include a dissemination of the history of ideas and cultural changes.

3.4.2 Iconographic historical approach

A historical approach must be considered for this exercise as antecedently defined historical categories were relied upon. The goal of creating a model which represents both historical changes in form expression and categories of emotive human experience such as awe and excitement through form demands us to look for the semantic meaning in form. Within art history, this approach can be considered iconographic where specific formalisms give way to social context and the overall cultural meaning of the work (D'Alleva, 2005). This approach principally follows the logic of the art historian and theorist Erwin Panofsky who argued that the form of a work cannot be isolated from its content. His work *Studies in Iconography* (Panofsky, 1939) defined three levels of analysis that will be used to assist our examinations of form and the built environment and align the literature strands we are exploring; 1) identification of formalisms within the work 2) identification of key characteristics, motifs or representations, traditionally in art history this may be a known story or myth 3) the deciphering of meaning within the work considering time, place and cultural elements. Panofsky was widely influenced by German philosopher Ernst Cassirer who argued that images, both physical artefacts and artistic works, have a deep symbolic value that act to document aspects of civilisation and culture (Barash, 2008). Formalism is also important to consider here as our analysis relies on the identification of specific compositional elements, but this will principally be used to situate the examples of analytical value within the appropriate artistic genre – this position within art-history has been defined as moderate formalism (Zangwill, 2001). The method involves both the identification of sets of formal properties, the archetypes described earlier, and an analysis of what these qualities mean culturally, semantically, and emotively.

3.4.3 Reed Kostellow principles of composition

The design theorist Rowena Reed Kostellow studied the structural make-up of visual relationships in sculpture and industrial design and proposed a model for establishing the most critical elements within a composition of solid elements (Hannah, 2002). This methodology is influenced by her compositional theory and applies it directly to establish the important elements of a designed object within the paradigm of an iconographic analysis. Reed Kostellow's compositional theory splits form and structural elements into three categories; dominant, sub-dominant and subordinate elements defined by size and visual weight (following Gestalt principles). Compositions of abstract geometry help to illustrate what is meant by the distinct elements an example of which is shown at Figure 17. These relationships between the dominant, sub-dominant and subordinate elements, are crucial for the development of our model and allowing us to trace the importance of specific form motifs through time. While nearly all movements or art, design and architecture incorporate a large range of geometric manifestations, it remains the case that certain geometric features can be identified as more compositionally important through size and visual weight – dominant – in Reed Kostellow's terminology, the cuboidal angularity of Modernism for instance.

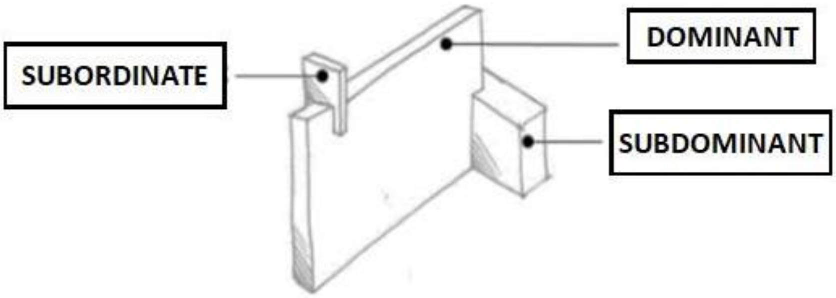

Figure 17 - Reed Kostellow form classifications showing the dominant, sub-dominant and subordinate forms in a hypothetical composition (adapted from Hannah, 2002)

3.4.4 Isolation of points and lines

This approach uses the analysis of images, where the most important form relationships are highlighted using superimposed lines following Arnheim's (1954) and Hann's (2012) respective theses; line is the basis of structure from which geometric shapes flow and shape is the foundation of form experience. Ingold's (2008) conception of lines as kinds of flows of material and energy also proved insightful. Broad black lines outline the dominant structural visual elements, thinner blue lines outline the subdominant or subordinate elements following the Kostellow Reed design compositional theories (Hannah, 2002). This method allows us to identify archetypal elements of form and structure and will ultimately form the basis of our model. Eleven prominent movements in Western art, architecture and design encompassing the last three hundred years were considered for our visual analysis, namely, Neoclassism, Gothic-revival, Art and Crafts movement, Art-Nouveau, Early-modernism, Art-Deco, Mid-twentieth century modernism, Brutalism, Functionalism, High-tech and Post-modernism. Sets of examples were amassed using an iconographic approach by examining the literature focusing on these specific historical periods and considering their key defining traits or archetypes.

Open-source image resources and personal photographic endeavours of finding and documenting appropriate examples were used as it was deemed the most efficient approach to acquiring and examining many types of forms. Key word Internet searches were used such as 'classical architecture' or 'mid-century modern design' to isolate relevant sets of images. The primary focus was the built environment, so most of the examples were either architectural or industrial design. Painting was sometimes included to examine the nature of an art movement more directly. For the set of 11 aesthetic categories that were deemed historically influential, 30-40 images were amassed that represented archetypal examples of this historical period following our guidelines for form and structural archetypes. From this initial set, 20 were chosen for the more detailed stage of analytics. The first phase of this is illustrated in Figure 18 where the key structural features of a built object – in this example a Brutalist building - are identified and marked manually (free-hand) on the image. The marking method follows our predefined form and structural archetype criteria and Kostellow-Reed's composition principles (Hannah, 2008) detailed earlier.

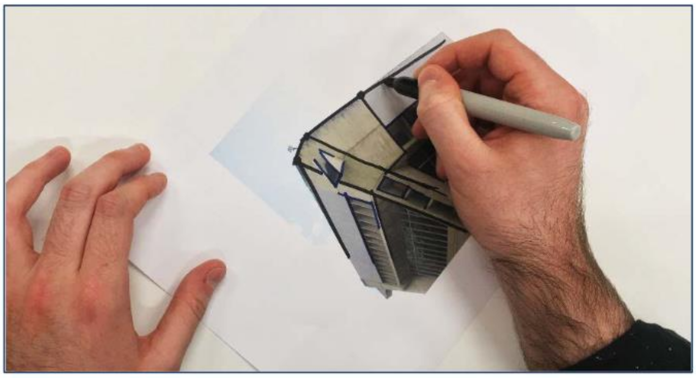

Figure 18 - Manual identification stage

Following the manual identification process, the important form relationships were processed digitally. This digitization allowed for a clearer representation of the form structures and allowed us to view the geometric elements in isolation. This isolation allows our iconographic historical analysis to be undertaken. An example shown in Figure 19 shows the process of the digitization of the manually assessed image, this image example belongs to the category of architecture known as Brutalism. As shown, the critical form features are highlighted. From this point, we can isolate the form features even further as shown on the right.

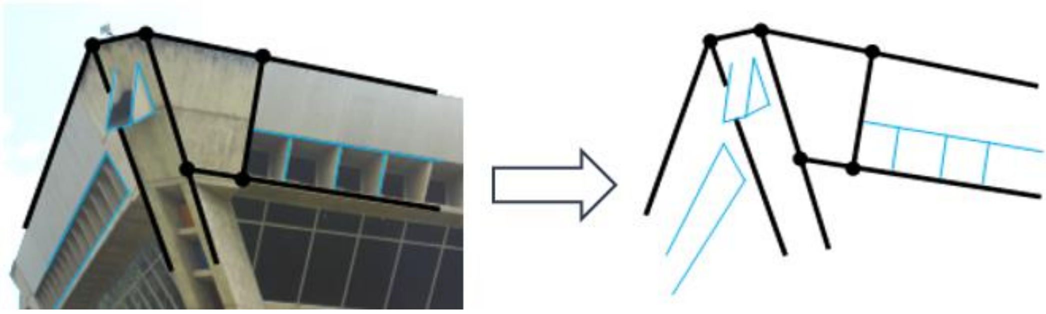

Figure 19 - Isolating points and lines where the lines are digitally superimposed atop of an image allowing the line relationships to be revealed in more detail[13]

3.4.5 Integration with emotional experience

From the analysis using line abstractions we can see how particular characteristics help to define certain art or design movements. It has already been discussed how form relates strongly to emotion and semantic meaning at the level of experience. The final stage in the methodology is to relate these raw geometric elements with emotional experience and delve deeper into the historical context of the examples we are examining. Figure 19 (left) is a typical example of Brutalist design, and it can be determined that its emotive associations are likely to be semantically negative (negative emotions such as frustration or anger) based on its high dynamic angularity, which has been demonstrated to generally have negative emotive responses (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Collier, 1996; Palumbo & Bertamini, 2016; Poffenberger & Barrows, 1924). This information allowed the building of the line model of form and emotion presented. The following sections will explore the methods in more detail by considering four examples – two with dominant curved forms and two with dominant angular forms.

3.5 Curvature

Figure 20 displays examples from the Neoclassical tradition which dominated Europe from the mid-18th century until roughly the mid-19th century (Bietoletti, 2005). The movement is a reinvention of the Classical styles typical of the ancient European civilisations such as the Greeks and Romans. When we abstract the structures into line relationships, we can identify several notable features. Firstly, the forms are highly precise and have been designed – following Vitruvian standards - to exact proportional

[13] Source: Liliana Amundaraín via Wikimedia Commons: Brutalist building

rules such as the Golden Section which some have argued is, aesthetically, an innate design preference (Doczi, 1981). Curvature has a more dominant role in the structures; angularity is used to order and frame the designs. This seems to be a design archetype as these structural features are repeated many times. During the Neoclassical period, which is now commonly referred to as the Enlightenment, Europe experienced an outpouring of industrial, scientific, and philosophical advance which would eventually culminate in much of modern Western culture (Zafirovski, 2011). This coupled with a shift in aesthetic output from the visual arts allowed the grand structures of the period to be realised. One of the central beliefs of the Enlightenment period was that man could use the power of reason to have power over the natural world (Robertson, 2015). This belief can help to explain the aesthetic that emerged during the 18th century across Europe and America. These forms are set within imposing structures and have a strong sense of visual order. There are organic forms that aesthetically relate to the natural world, but they are subordinate to the dominant, inorganic structures surrounding and framing them. There is also ornate sculpture (another archetypal feature that has been highlighted with dotted boxes) that is extremely common in design of this period. From an iconographic point of view, this work is abounding with symbolic meaning often incorporating representations of classical myths or historical events triumphed by the people of a certain place or culture. The line abstraction revealed extensive use of ordered curvature in the underlying structure; significantly, architecture and design from this period is often semantically associated with traditional ideals of beauty, order, and elegance (Bietoletti, 2005).

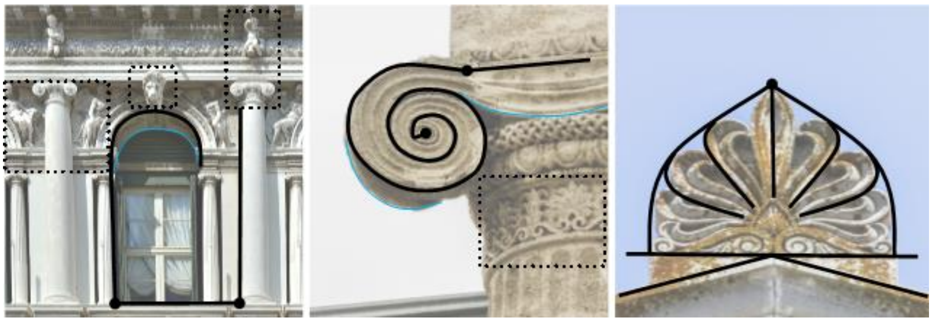

Figure 20 - Neoclassical architecture and decoration showing various Classical motifs including organic imagery and use of proportion and symmetry highlighted by superimposed lines (18th & 19th century)[14]

[14] Sources: Wolfgang Moroder, via Wikimedia Commons: Classical example 1.
Plus free to use images: Classical example 2 and Classical example 3

Art-Nouveau, which was a design movement beginning roughly at the end of the 19th century and has many structural similarities to Neoclassical art, is notably dominated by curved forms. Principally, it stood in opposition to academic art – a style that had become associated with the French academies of painting which was favoured across Europe (Duncan, 2001). Aesthetically, the Art-Nouveau style is characterized by the frequent use of organic themes and symbolism, features we would argue are archetypal of this style. In some ways, Art-Nouveau was an early use of what is now called biomimicry or biomimetics with the explicit use of forms found in nature used directly as design inspiration (Benyus, 1997). If we consider the examples shown in Figure 21, decorative pattern, interior architecture, and a household utensil - there is almost no use of straight lines and academic use of proportion appears not to be considered strongly – curvature dominates both the underlying structure and the forms themselves. The movement overall had strong emotive, semantic, and symbolic characteristics (Raizman, 2003). As a rejection of the academic nature of art at the time, the artists and designers found inspiration in the non-rational, non-linear world of nature often using explicit plant and flower motifs, asymmetrical and undulating (Howard, 1996).

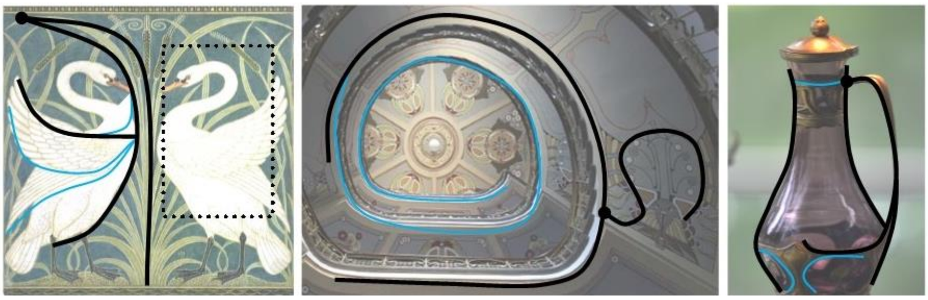

Figure 21 - Art-Nouveau art, architecture and design showing unorthodox uses of proportion and highly organically inspired decorative motifs highlighted by superimposed lines (late 19th century)[15]

3.6 Angularity

Within architecture and industrial design, the Modernist aesthetic has a notable coherence. The examples shown below in Figure 22 are paradigmatic cases of early modernist design; a house within the Weissenhof Estate designed by Le Corbusier, the

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[15] Sources: Walter Crane via Wikimedia Commons: [Art Nouveau example 1](), Hans A. Rosbach via Wikimedia Commons: [Art Nouveau example 2](). Plus free to use image from: [Art Nouveau example 3]()

Bauhaus school building in Dessau designed by Walter Gropius and early abstract art by Piet Mondrian. To use Kostellow Reed's guide (see Hannah, 2008), the dominant and subdominant structures within the designs can be identified; these designs follow careful grid structures creating dominant vertical and horizontal box forms that frame other box forms. Considering the forms iconographically, they all interplay with a sense of logic and coherence. As explored earlier, the Modernist philosophy was a radical rejection of many of the prevailing ideas that came before, an important quality being the notion of representation and ornamentation, often explained explicitly within the manifestos of the time (for an example of this, see *Ornament and Crime* by Adolf Loos, 1908). An antecedent of this can be seen in the work of the Impressionist and Post-Impressionist artists of the 19th century where exact representation according to visual perception was radically challenged (House, 2004). The Modernists were the pioneers of the (Western) use of abstraction in art, architecture and design, complexity did not have to be represented by intricate forms, it could be abstracted and viewed from multiple perspectives at once (see the work of the Cubists for examples of this). This quality of abstraction and simplicity provides Modernism with its aesthetic coherence and is its principal archetypal quality. While there are exceptions, the art of Kandinsky or Picasso for instance can be viewed as highly complex and dynamic, there is consistently a quality of abstraction and a geometric reductionism to simplicity and isolation where subject recognisability is lost (Dickerman & Affron, 2012).

Figure 22 - Modernist architecture and painting showing dominant use of angular forms highlighted by superimposed lines (early 20th century)[16]

Dominant angularity and heavy use of positional form structures are archetypal features of Modernism particularly within industrial design and architecture.

[16] Sources: Andreas Praefcke via Wikimedia Commons, free to use image from: Modernism example 2 and Piet Mondrian via Wikimedia Commons: Modernism example 3

Additionally, the buildings and products of the Modernist movement are highly proportioned and ergonomic – expressly designed for use by human beings, tailored to our needs, machine-like (Smock, 2009). Abstraction was another critical component of the movement generally – it could even be argued for instance that Modernist buildings are abstract versions of the preceding Neoclassical buildings. They lack what Arnheim (1954) described as 'dynamic obliqueness' meaning they appear very stable and structured. Through a process of line abstraction, we can see that the designers associated with the movement were interested in arrangements of right angles and cuboids. Functionalism was the central belief of Modernist design; aesthetics was viewed as secondary to the utility of the building or the product. Modernism is a direct descendant of the rationalism that was implicit within Neoclassical styles while simultaneously being a rejection of its traditionalist and academic values (Pevsner, 1936/2011). The central difference is Modernism in design took forms to high levels of abstraction, ostensibly devoid of symbolic meaning and cohering around a philosophy of brute functionalism where the social and philosophical changes in society directly translated into a shift in aesthetics (Greenhalgh, 1990). It is thus reasonable to state that design utilizing controlled angularity is a semantic representation of utility, functionality, and order.

Mid-century modernism followed on the traditions associated with the first Modernists with noticeable differences in structural output. Analysing the work of North American design provides an important insight into the aesthetic and cultural shifts taking place. Technological development in manufacturing during the 1940s (largely stimulated by the onset of war) presented new scope for form experimentation in product design as the mid-century beckoned. Figure 23 presents what is an iconic work by Charles and Ray Eames, and architecture by Alvar Aalto and Arne Jacobsen. Abstracting the forms into their underlying line relationships, both the presence of curvilinear and angular structural relationships can be seen – both equally strong as structural elements. The development of mass-producible plastics meant curved structures could more simply be applied within a product context. Additionally, we propose that these new, arguably more organic forms are a reaction against some of the functionalism of early Modernist tradition that perhaps seemed too dogmatic. During this time, the United States and many areas of Europe were experiencing a counter-culture movement. This new hippie culture manifested itself in industrial design and architecture by the presence of more sweeping curves, bulbous forms, and brighter colours. To take but a small sample of work from the Eames', Raymond Loewy, Greta Grossman, Eero Saarinen, the Finnish, Nordic and Danish design schools – the aesthetic trend is quite clear. The forms were more emotionally resonant with the inclusion of generous curves, they were less intellectual by not adhering to a doctrine of strict functionalism and were presented to a mass-market of normal consumers (Quinn, 2004).

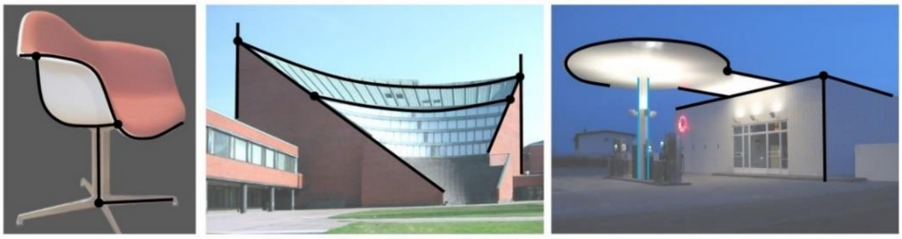


Figure 23 - Mid-century modern design and architecture showing the inclusion of generous curving features and less use of dominant angular features highlighted by superimposed lines (mid-20th century)[17]

While these designers were not explicitly part of the counter-culture movements, the broad changes in society – culturally and politically – had a tangible effect on form expression amongst professional designers. Following the logic of Deleuze and Guattari where the expression of form is always connected to the world of the political (Quinn, 2004), we can say that the designs of the mid-twentieth century did in some ways reflect the liberalisation of culture that was taking place – the renewed emotional optimism and progressivism of post-war America and Europe (Kaplan et al., 2011). A summary of the key form characteristics is presented below in Table 4.

Table 4 – Summary of historical movements in aesthetics charting characteristics, emotive and semantic connotations with abstracted form archetypes.

Neoclassicism				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1750s onwards	*Dominant curved forms framed by precise angular forms. Frequent use of symmetry, organic and symbolic forms*	*Peace, calm, awe*	*Romantic, organic, beauty, strength (Bietoletti, 2005)*	

[17] Rama via Wikimedia Commons: Mid-century example 1, J.-P. Kärnä via Wikimedia Commons: Mid-century example 2 and Christian Lylloff via Wikimedia Commons: Mid-century example 3

Gothic revival				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1750-1860	*Dominant use of curves and angularity. Frequent use of symbolic and organic forms – highly complex*	*Awe, amazement*	*Power, authority, prestige (Frankl & Crossley, 2000)*	
Arts and Crafts movement				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1880-1910	*Dominant organic and curved forms. Frequent use of floral imagery*	*Peace, calm, happiness*	*Organic, floral, decorative, romantic (Blakesley, 2006)*	
Art-Nouveau				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1890-1910	*Dominant organic and curved forms. Frequent use of floral imagery and symbolism*	*Peace, calm, happiness*	*Organic, floral, decorative, romantic (Howard, 1996)*	
Early-Modernism				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
Approx. 1900 onwards	*Dominant angular forms, highly precise. Some use of curved forms. Little use of symbolism*	*Serenity, calm, pensiveness,*	*Functional, utilitarian, simple, rational (Pevsner, 1960)*	
Art-Deco				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1920-1940	*Frequent use of angular and curved forms. Frequent use of symbolism*	*Intrigue, awe, agitation*	*Vibrant, geometric, organic (Bayer, 1999)*	
Mid-century Modernism				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*

1930-1965	*Dominant curved forms with frequent use of angular forms*	*Happiness, calm, serenity*	*Functional, beautiful, elegant, quiet, smooth (Quinn, 2004)*	
Brutalism				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1950-1975	*Dominant angular forms, little use of curved forms*	*Surprise, intrigue, frustration*	*Harsh, authoritative, functional, strange, cruel (Clement, 2012)*	
Functionalism				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotation*	*Common form archetypes*
1950 onwards	*Dominant angular forms, little use of curved forms. Some symbolic value*	*Surprise, earnestness, tension*	*Utilitarian, functional, (Bürdek, Dale, Richter, & Hausmann, 2015)*	
High-tech				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1970s onwards	*Use of both angular form domination or curved form domination*	*Joy, awe, surprise, tension*	*Technological, precise, organic, rational, structural (Abel, 2004)*	
Postmodern				
Dates	*Form characteristics*	*Emotive experience*	*Semantic connotations*	*Common form archetypes*
1980s onwards	*Use of both angular form domination or curved form domination (typically angular). Frequent use of ornamentation*	*Surprise, confusion, intrigue*	*Geometric, strange, juxtaposed, comedic (Kolb, 1992)*	

3.7 The Line Model of Form and Emotion

The methodology of line abstraction and art-historical analysis allows us to probe the meaning and the emotive layers of form through an iconographic historical approach. The model, shown in Figure 24, is presented as a flowing line. Inspired by Hann (2012) and Poffenberger and Barrows (1924), the line is presented in a form similar to a sinusoidal wave that varies in frequency and structure. There is no start or end necessarily, the line should be viewed as a continuum in the same way emotional experience is constant and changeable. The model was developed iteratively until a satisfactory range of form line-abstractions we had investigated was suitably represented. The model has distinct features that bring together several narratives from form, emotion, and semantic theories in the visual arts and, industrial design. The model considers four key aspects:

1) *Emotive and semantic qualities related to form experience*
2) *The embodiment of these qualities with aesthetic movements across recent aesthetic history (form and structural archetypes)*
3) *Form as a representation of information and related cognitive processing*
4) *The intensity of the emotive and semantic values*

Resulting from the review of the previous studies in form perception, there is a great deal of evidence that suggests a kind of dichotomy of perception – curvature versus angularity relating to positive versus negative emotional states respectively. While actual cognitive processing of form is much more complex, this fact presented a good starting point and therefore the model was split into two halves respectively displaying curved geometric continuities transitioning into angular continuities. Furthermore, the model bears some theoretical resemblance to Kubler's (1962/2008) 'shape of time' model which also sees repetitions and recurring themes throughout the history of made artefacts that link to recurrent meanings drawn from problem solving practices and diverse spiritual needs.

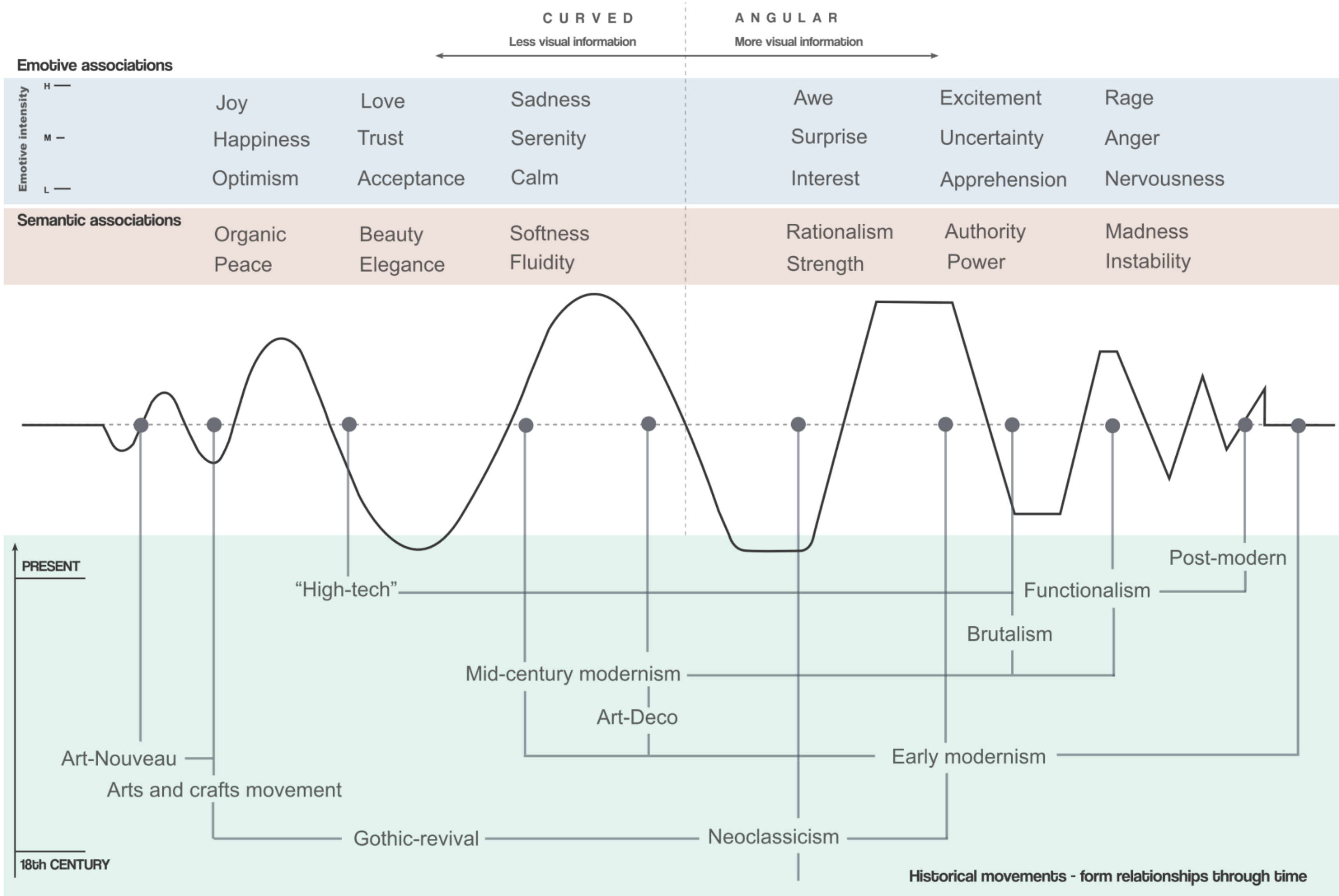


Figure 24 - The Line Model of Form and Emotion – top details the emotive and semantic connotations of the line form, the bottom considers the historical changes in form across time. The emotive categories are derived from Plutchik (1980), Shaver et al., (1987) and Cowen and Keltner (2017)

3.8 Lines of emotion and historical transitions

One of the central themes of the model is the psychological experience of emotion. We reviewed some of the critical research into emotional experience and categorization and have used it to inform our model. Importantly, we have considered the work of Plutchik (1980, 2001) who recognized the inherent complexities of human and animal emotion and the difficulties in supplying absolute definitions and categories. His models describe emotional states that have a certain fuzziness. Joy, for example, is composed of aspects of love and optimism and in turn stands between serenity and ecstasy in terms of intensity. This relates to the experiential qualities of emotion which are multifaceted, complex and challenging to define absolutely (Scherer, 2005). In this model, joy does not stand alone; it is changeable and dependent on other experiential qualities. The similarity between emotive experiences is also a point of interest. Although there is a good deal of difference between joy and anger in terms of intensity and composition, there is not such a clear difference between anger and hostility or disgust and surprise. These emotive distinctions are illustrated on the model where joy, for example, is placed above a large curve, it also is assigned a high degree of intensity. The same can be observed for rage on the angular end of the model. These emotions have more intense states of arousal and as Coates (2003; 2014) has observed, contain more visual information (edges, corners, or changes in directionality) making them more cognitively challenging to process.

The changing nature and non-linearity of emotional states when observing art, buildings, objects is the point we are trying to convey with this model. Although there is some experiential stability, the context of form can lead to dynamic emotive associations. As the line flows, emotions flow with it. When we encounter structure, we are also encountering states of change and the dynamic forms of experience and perception described by Dewey (1934) and Arnheim (1954). The holistic thought of the Gestalt also is relevant where visual experiences of form and the relationships between elements are processed as a whole and assigned meaning before being broken down. Sometimes this meaning is understood through culture or a social context, sometimes through innate preferences and psychological drives. Angular forms have some connection to aesthetic conceptualisations of nervousness and fear, but their association with rationalism may be a gradual cultural construction derived from the principles of engineering and functionalism.

Connection to the historical past and the history of ideas is a fundamental component of the model. Its visual information conveys form structures associated with clear aesthetic movements within the history of art, architecture and design. This was developed with an iconographic approach following Panofsky (1939), where compositional form aspects were examined structurally, and then, in terms of semantic meaning and emotion, establishing relationships. The historical movements examined within the model show no linear path in form evolution, no clear inevitability. We have argued that some features of form and structure can relate to societal feelings and philosophies but the diversity of thought within artistic and design practice makes this very difficult to pin down in an absolute sense. Although Modernism can lead to its mid-twentieth century variant, which was thematically and philosophically similar, the same is not seen in the transitions from Art-Nouveau to Modernism as the dominant styles because the underlying philosophies were very divergent, and our model clearly visualises this divergence. The movements are placed on the model on a time scale of roughly the beginning of the 18th century to present. When lines intersect the central axis, this indicates that the surrounding line abstractions are the archetypal structural and form features of a particular movement. The complexity of some movements, Art-Deco for example which incorporates both elements of angular form with curvilinear form dominantly, is indicated by intersection with multiple points of the model. The connections between the different aesthetic movements becomes more apparent using our model. If there is one root from which many of the modern and contemporary movements come, it is arguably the Neoclassical tradition. Due to its dominance in Western art, architecture and design, the movement has exerted a profound influence on subsequent work, both aesthetically and philosophically (Bietoletti, 2005). While early Modernism pertained towards a radical sense of abstraction, it still adopted the structural underpinning of the classical traditions. Contemporary High-Tech architecture, also known as Structural Expressionism, includes both curves and angularity in a wide variety of forms. Although, this movement has been abstracted from its initial roots in the classical traditions, the core semantic message of achieving beauty through the principles of reason, remains. Our line abstraction method has allowed us to reveal these relationships with greater clarity.

Additionally, technological advance is a critical element that has not been directly considered within the context of the model but much of the tangible aesthetic shifts we consider have been influenced by these changes. Indeed, it has been argued that the constraints of available manufacturing technology are a significant influence upon the final form of a product (Crilly, Moultrie, & Clarkson, 2009). Form development may be a function of emotional needs and socio-semantic reasoning fused with structural preferences, technological capability, and clear functional requirements. The novelty of certain aesthetic movements may come from the coherence of form and structural archetypes allowing for more stable emotional engagement.

3.8.1 Limitations of the model

The line model presents a theoretical synthesis of information, and it is important to discuss its limitations at this stage. The model is not traditionally empirical due to the lack of a direct study but seeks to discursively bring together a wide variety of literature a novel approach to distinguishing form characteristics. This model is theoretical, is in its early stages of development and must be advanced and changed with future research. Currently it can be used as a visualization tool for designers but is, with this initial iteration, an incomplete picture. A more systematic and empirical approach may validate the model through psychological studies, and this may be a point where other research efforts can add to the ideas within the work. Two critical aspects that were not considered are material properties and colour; what are the emotional differences between experiencing a sandstone building or one made from glass and steel? Or experiencing a brightly coloured object as opposed to one of more muted colours? These are interesting questions that the model does not yet explore. One additional consideration is how the model is limited to European and American culture – the artistic movements from parts of Asia, Africa and the Middle East are not included in this iteration of the model. For instance, the aesthetic of traditional Japanese interiors was a major influence on Western Modernist architects (Tanizaki, 1933). Including all these movements would be beyond the scope of the work but future iterations of the model could map these aesthetic histories. Visually comparing the differing stories of Eastern and Western art may be a useful tool for scholars.

3.8.2 Relevance to research

This exploration of line, as well as offering some of the insights described above, helps to advance some of the theoretical transitions this work wants to explore. It has been effectively demonstrated with reference to scholarship that complex emotive and semantic concepts can be conveyed through simple forms such as line. In addition, the layering and interweaving of these linear elements culminates in the textility and materiality of the built environment and designed objects. In essence the meta-argument of the line model is one where the simple two-dimensional world of discrete or atomised elements directly interacts with the holistic experience of form in the physical realms – culminating in the embodiment of abstract cultural ideas in the human made buildings and objects of the world.

Exploring this area sets a foundation for a continued exploration of semantic and emotive representations through form. It is, however, still not clear if these representations can be connected to a grounded ontology of emergence: are the representations carefully devised or are they driven by something more mysterious or primal? This is a question that can be explored directly with consideration of the process of representation.

3.8.3 Representing emotion through line: an experimental exploration

The line model could be accused of a kind of reductionism and may fail to capture many of the complexities of experience and perception. It is however possible to validate some of the ideas and explore the emergence of representational forms. An experiment was formulated to practically examine some of the premises of the model and to elucidate some other aspects of emotional experience and its potential connections to aesthetic expressions that were not captured by this initial iteration of the model.

A variety of research in the field of experimental aesthetics was reviewed over the course of this chapter, that connected forms and compositional arrangements of shapes with emotional concepts and the experience of emotion. This was used as the basis for the line model but how can this be taken further? Lines have been an important concept in the discussion so far with much direction taken from Ingold's (2008; 2015) work on the subject. Poffenberger and Barrows (1926) study used pre-drawn lines as did many of the other studies examining this phenomenon but using this approach may be semantically loaded. To explore this further, the experiment that was formulated explicitly used aesthetic expression to explore emotive concepts (*anger* for example). In a kind of inversion to the experimental work that has been done before and explored throughout this chapter, the participants would be free to express an emotion through *line creation*.

3.8.4 Protocol

The study consisted of 30 participants, 14 males, 16 females, aged between 20-35. This was a convenience sample built mostly from undergraduate design engineering students. Using Plutchik's (1980) emotive categories, a worksheet was provided to each participant with one of eight emotive terms and two points separated by blank space. The emotive terms refer to what Plutchik (1980) called 'basic' emotions – the emotions most central to human experience and the key components of more complex emotional experience. Each participant was instructed to, in their own time, represent the emotive terms in the form of a continuous line. Ingold (ibid) has made plain that forms of representation through line can be laden with significant cultural and symbolic values. This is the key property that was to be explored – using an interpretivist approach, the lines would be analysed for aesthetic trends or coherent geometric patterns. The emotive terms selected included fear, trust, anger, joy, anticipation, surprise, disgust and sadness. The terms were presented in that same order to each participant and were selected to explore a diverse range of emotive categories. Four of the terms were selected for their positive valence (following Ekman 1980; 1992) – trust, joy, surprise, and anticipation. It should be noted that 'anticipation' is semantically more unclear and was selected to explore some of the ambiguity around emotional experience. The other four were selected as examples of negative valence and are more unambiguously associated with unpleasantness. The following sections will explore the results of this experiment by going through some of the line creations presented by the participants and the identified aesthetic trends will be examined. The analysis is subjective and interpretivist, bringing in ideas from art and aesthetic theory and should not be seen as a definitive analysis.

3.9 Representations of negative emotions

Half of the words presented to the participants were ones conventionally associated with negativity or a negative valance in psychological terminology. The negative emotions were derived from work by Plutchik (1980; 2001) with close reference to other emotion theorists including Ekman (1980; 1992). Ultimately the goal was to examine how a set of participants would represent an emotion through line. Each negative emotion can be considered in turn starting with *fear*. Many of the images presented have marginal colour edits in order to make the drawn lines more visible against the page.

3.9.1 Fear

Fear, in Plutchik's (1980) model is diametrically opposite to a feeling of anger. Where anger represents a kind of energetic hatred, fear is conceptualised as a kind of submission or powerlessness and is seen as a core emotion for human experience. In terms of representation through line, a number of interesting motifs were commonly explored by the participants. Consider some of the examples in Figure 25 below.

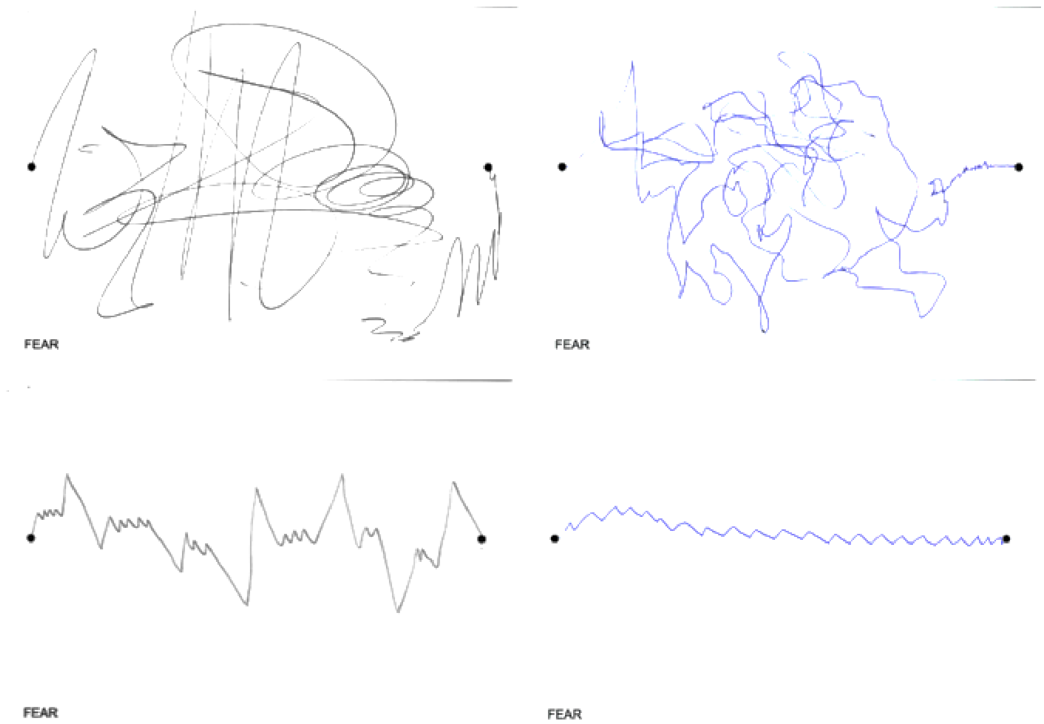


Figure 25 – Representations of fear

The key feature here is one of disunity and chaos as a patterning emerges across the various forms. This kind of highly unstructured line was seen in most of the representations and may point to the feeling of powerlessness or submission mentioned before. The feeling of fear may bring about intense emotions of panic and is as such represented in a line that has no clear path or direction but is highly energetic. Geometrically, the lines are mostly of a curved quality, but this curvature is one that is more probably representing chaotic transitions as a sense of panic rapidly changes – a feature seen in other art forms such as music or film. Fear is an emotion that was not included in the final iteration of the line model

By contrast, another motif was common amongst the participants – one of a continuous spikey line with a high frequency of structured directional change. While this may also convey some of the chaotic sensations associated with fear, it is also possible this is something more primal. Some theorists have hypothesized that emotional responses to form may have evolutionary roots and are driven by survival. In this sense, these representations may point to an instinctive fear of teeth or claws or dangerous rocks. While this is not definitively clear, the line drawings do bear a striking resemblance to some of these natural threats.

3.9.2 Anger

The emotion of anger is characterised by a combination of contempt and aggressiveness that is one step removed from *rage*. Some of the motifs seen in the linear representations were similar to that of fear, validating the positive-negative dichotomy in some ways. However, there were a number of notable distinctions. Firstly, the representations made much more consistent use of angular geometry with less use of curving motifs and structures. The lines are also highly energetic whereby the changes in movement are dramatic and intense. Secondly, the lines overall were more structured – the motifs presented were interestingly quite consistent and were often drawn within a bounded area between the two points. The representations shown at Figure 26 are similar to a minority of the lines drawn for the *fear* exercise – suggesting the same link between anger and a symbolic representation of teeth.

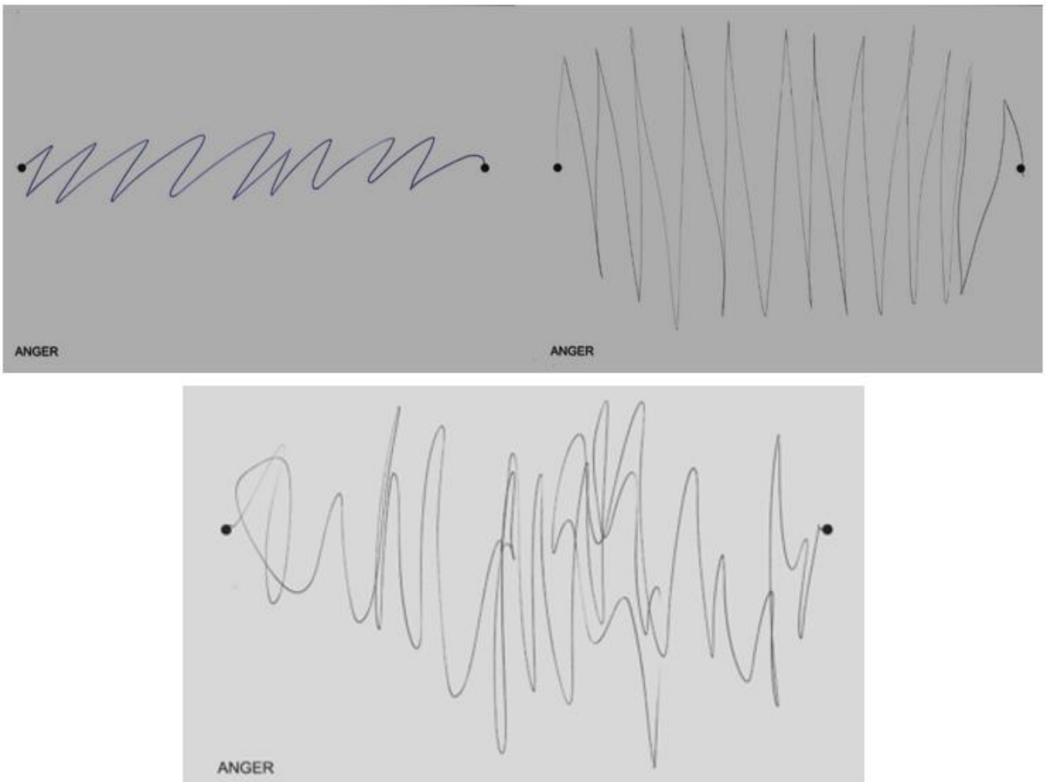


Figure 26 - Representations of anger (note, contrast altered for visibility)

When comparing these results to fear, there are some striking similarities, suggesting that people view the two emotions as experientially similar in character. Many researchers (Bertamini et al., 2016 for example) have noted that subtle changes in abstract geometry can change the overall perception of a line. Here these subtleties may also be at work with the fear lines being notably more chaotic. Although some examples from the anger exercise point away from this and can be viewed as equally chaotic as fear. The critical take away is the consistent use of angularity and the energetic nature of the line suggesting a quick application.

3.9.3 Disgust

Within Plutchik's (1980) model, the core emotion of *disgust* is placed at an opposite to *trust* as an emotion related to the complex feelings of remorse and contempt. Overall, the motifs presented for this emotion were very varied and made use of a range of geometry and visual energy. The diversity presented makes an absolute assessment of the lines difficult, however, there are a few elements that can be discussed. One such element may be a consistent sense of discontinuity; the representations were often sharply non-linear with motifs present similar to those seen in the fear and anger exercises. Considering the examples shown in Figure 27 below – while the chaotic nature of the other lines may not be present, there is certainly a similar dynamic visual energy. The emotion of disgust is related to feelings of hatred and disagreeableness – these Forms may be representing these feelings through symbolic disorderliness, antithetical to the aesthetic of Western Classicism. Additionally, it may be noted that some lines appeared to have a kind of temporality, suggesting a change in mood or character over time and travelling through different states.

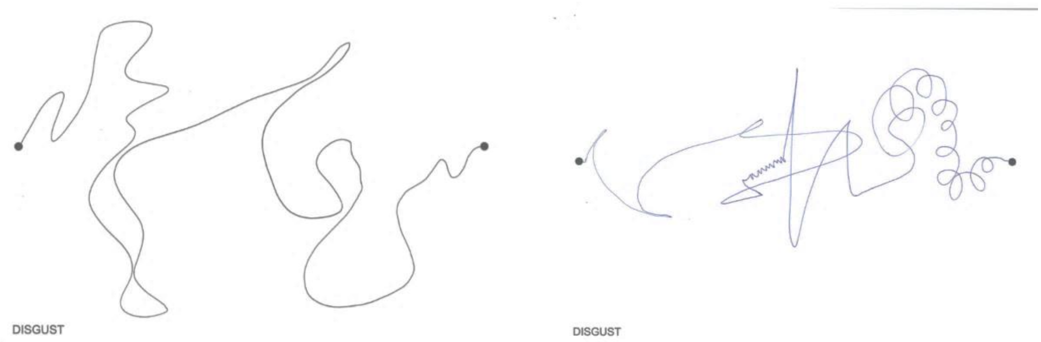


Figure 27 - Representations of disgust

3.9.4 Sadness

Sadness is the diametric opposite to *joy* with respect to Plutchik's (1980) model and is connected to the complex emotions of disapproval and remorse. The representations for this emotion were notable for their lack of visual energy and low frequency of change across the line. In addition, it appears many participants treated the worksheet space as a kind of Cartesian grid where 'above' the two points is seen as positive and 'below' the two point as negative. Pallasma (2005/2012) has pointed out that this tendency to associate 'up' with betterness is deeply ingrained within Western thought with connections to religious ideas of the transcendent. With respect to this, many of the lines in this part of the exercise were portrayed with this explicit depression in their journey across the page. Examples are shown in Figure 28.

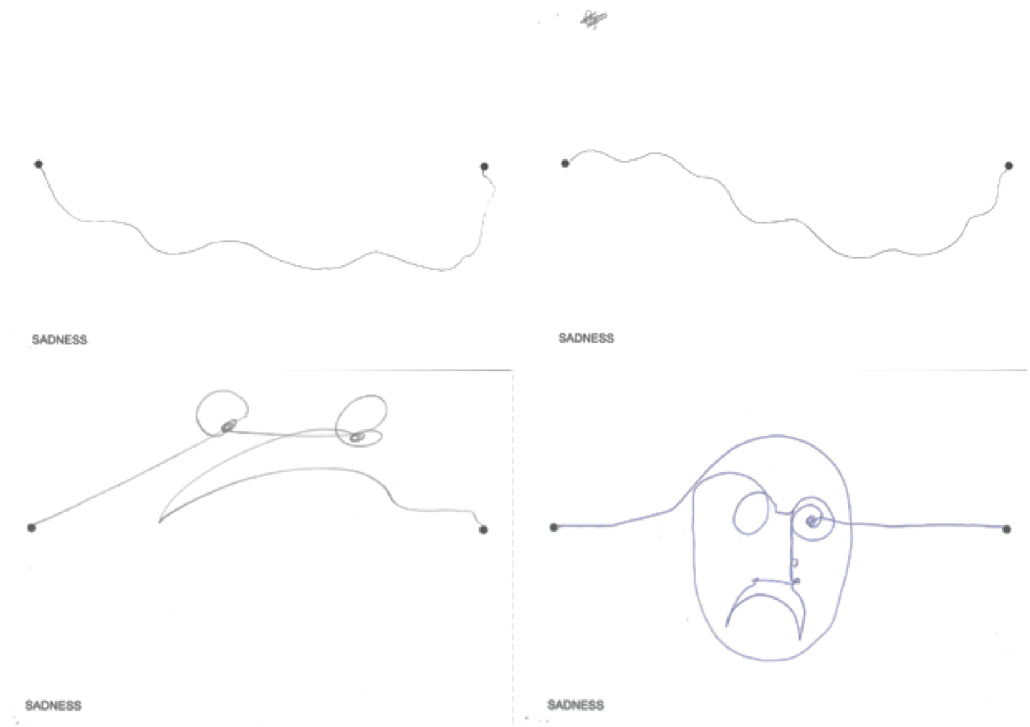


Figure 28 - Representations of sadness

The lines meander like rivers on a map but have a clear directionality, flowing downwards relative to the composition of the page. In addition to this it should be noted that there was consistent use of curvature in the representations. This is counter to some of the evidence presented earlier from other scholars who have found angularity hugely dominant for interpretations using negative valence (Bertamini et al., 2016). Curvature does seem to have its own melancholic associations – perhaps related to the character of the experience itself as something more drawn out and less energetic and dynamic than anger or fear.

Other interesting depictions of the emotion through line saw the explicit use or anthropomorphic Form. As the exercise was completely open ended, depictions of human forms were not prohibited. These representations use faces conveying experiences of pain or unhappiness. Ontologically, these are interesting as they explore how emotion is often communicated and validated through non-verbal (facial) communication between humans.

3.10 Representations of positive emotions

3.10.1 Trust

Following Plutchik's (1980) model, trust is positioned as a core emotion placed between admiration and acceptance and related to the complex feelings of love and submission. The representations for *trust* were coherent with many participants aligning around a few motifs and visual ideas. Arguably some of the key features of the trust lines were that of simplicity and symmetry. The geometric elements tended towards abstraction with minimal dynamic changes in direction and a lack of visual energy or movement. One motif that was seen frequently was that of a near straight line from one point to the other – this is shown in Figure 29 below.

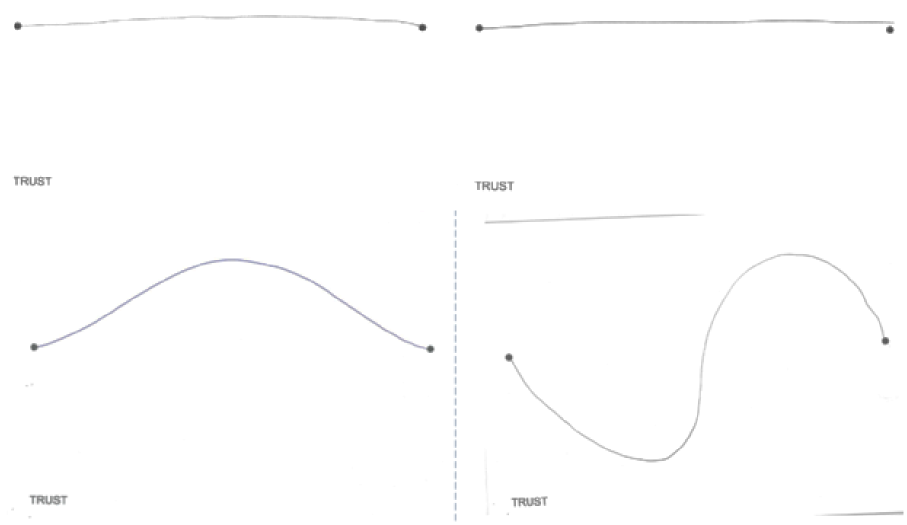


Figure 29 - Representations of trust

The two examples shown above are strikingly similar and there are perhaps two interpretations that can be made for this kind of representation. The first is that the lines relate to the idea of (and actual aesthetic of) a bridge. A bridge, in static engineering terms, is a solid structure that connects two otherwise disconnected geographical points. It is a solid and ridged structure that is structurally designed to be extremely safe. Relating trust to this kind of motif suggests that the emotion is related to concepts of flatness, solidness and unambiguousness that are paramount in the structural design of bridges. The other interpretation is that of the path or the journey.

This is discussed at length by Ingold (2008) where a kind of 'straightness' has come to be representative of rationality in Western culture. This kind of thinking may be influencing the representations where a simple and very direct line is viewed as more decisively rational – and hence trustworthy - than one that travels around the page.

Another important motif that was explored by many participants was that of symmetry and balance and particularly the use of curving motifs. Again, the page seems to have been naturally split into quadrants by the participants with lines of symmetry running from point to point and splitting the page in two across its length. Consider the examples shown in Figure 30 below. None of these examples is perfectly symmetrical, but all are exploring a balanced visual representation that is very simple. The line on the right for instance could be seen as two inverted halves of equal size and movement. The line on the left is highly symmetrical and sits in the 'positive' section of the page. Contrasting this to the depictions of anger and fear explored earlier, the differences are plain – balanced curved motifs versus more unstructured angular motifs. Considering some other examples from the participants, the theme of ordered and balanced curvature is consistent. The three examples shown below come from both the male and female participants. As shown, the aesthetic motif of a wavy line, similar to a sine wave has been repeated consistently. It is not clear exactly why many of the participants were drawn to this motif, but it is certainly congruent with aesthetic simplicity and, in many places, symmetry – perhaps an interplay between two halves.

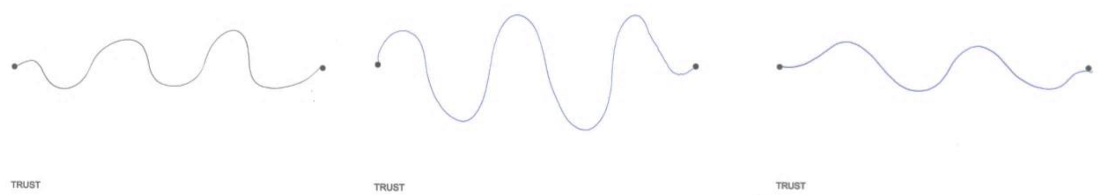


Figure 30 - Representations of trust

3.10.2 Joy

Joy is the quintessential expression of happiness or enjoyment. In Plutchik's (1980) model, joy is a core emotion and is related to the complex emotions of love and optimism. It is placed between ecstasy and serenity in terms of its subjective intensity. Representation for this emotion were again coherent, with many participants aligning around several interesting motifs. Similar to the motifs expressed for trust, wave-like forms were very often produced by the participants. One noticeable but subtle difference was the use of overlapping lines, a line that looped across its own path. An example of this is shown below in Figure 31.

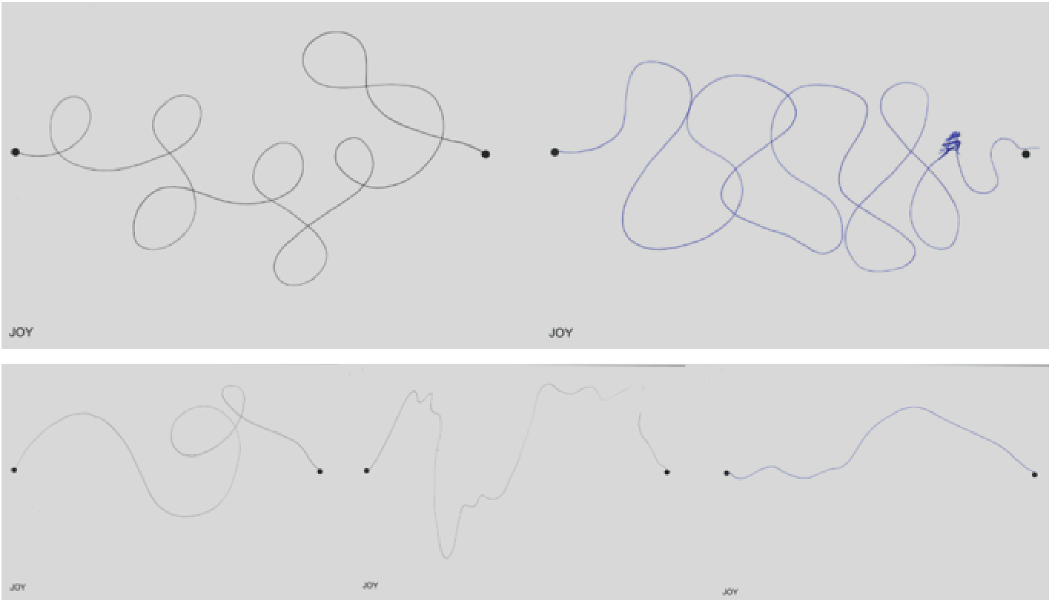


Figure 31 - Representations of joy (note, contrast altered for visibility)

The visual energy present in these lines is clear and both lines travel across a large amount of the page. Arnheim (1954) has pointed point that visual energy can be conveyed by the Gestalt principles of balance and proximity. In this case, the drawing on the top left is less balanced compositionally but makes more use of the page, the line on the top right makes more direct use of proximity and is more balanced – both however achieve a similar visual character. The movement of the lines could perhaps relate to a bouncing motion; indeed, aspects of the drawing could theoretically map the path of a bouncing ball as it travels through space. Additionally, the bouncing motion may have a physically connection with positive feelings of excitement. Notably, the lines are all of a curved aesthetic, substantiating the link between curvature and positive valence. In the line model presented earlier, these forms were often present in the design and architecture of the more ornamental styles – Neoclassical, Neogothic and Art-Nouveau – with direct links to depictions of organic forms.

Another type of depiction that was common was a kind of inversion of what was observed for the *sadness* lines. If we again consider an up-down split of the page in a conventional Cartesian graph system, the upper half would be numerically positive. Consider three examples at the bottom of Figure 31; the lines are drawn almost entirely in the upper half of the page and contain no angular motifs and are quite minimal in terms of dynamic directional change. All the lines have notably dipped as they travel across the page, but all rise and ultimately float above the central axis. This is a good indication that on the level of perception and emotional experience, positive emotions can be semantically linked to a directional 'upness' or rising.

3.10.3 Anticipation

As a core emotion in Plutchik's (1980) model, it is connected to the complex emotions of aggressiveness and optimism and sits between vigilance and interest with respect to subjective intensity. Anticipation was selected to explore an emotion outside a clear positive-negative valence dichotomy. Although it may be viewed as generally more positive, there is a noted ambiguity – one may anticipate an event in a negative way, evoking feelings of discomfort. The results for anticipation were also quite diverse and there was no clear preference for either curvature or angularity within the depictions. One interpretation that can be explored is viewing the lines as not just a journey across the page but in some regard a temporal journey - a journey in time and an emotional transition through time. Anticipation has an implicit sense of time within its definition – its meaning is derived from the feeling of expectation for some future event, contrasting with other emotions which may not have the same temporal dimension but are experienced more as a visceral present. It is possible that this aspect of the emotion was the key inspiration for the representations that the participants produced. To look at some examples (Figure 32), all of these lines can be seen as a kind of temporal journey with the left point representing a metaphorical present and the right point a metaphorical future. The line on the left explores angularity and the line on the right explores curvature but both have a similar temporal structure that can be seen as a map of the emotion. The experience of anticipation can be viewed as a kind of build-up of feelings that climax in one way or another. With respect to this, both lines have this sense of build-up and climax – the 'climax' expressed through a semblance of interesting shapes.

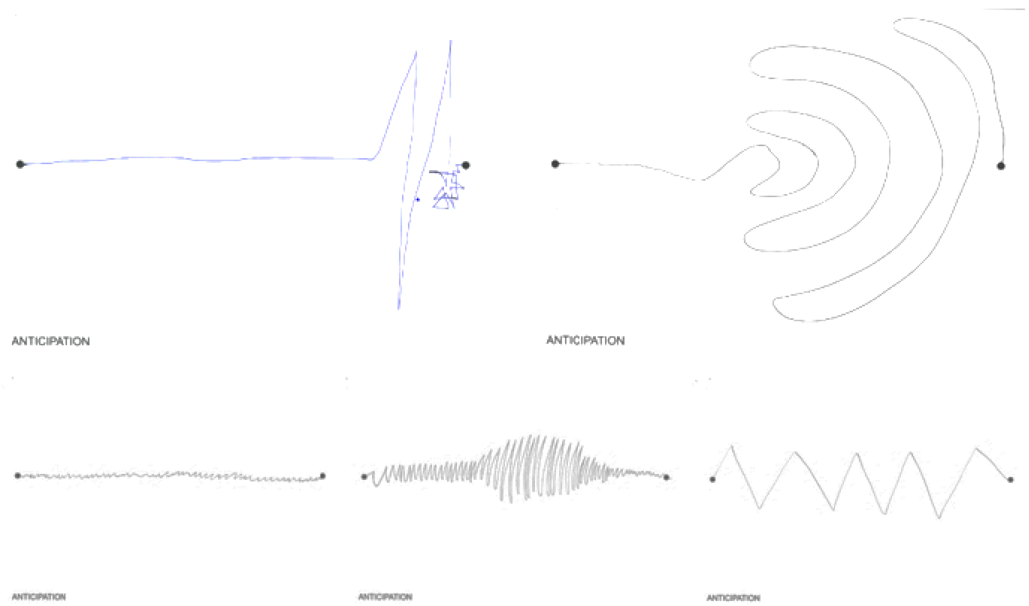


Figure 32 - Representations of anticipation

Another motif that proved popular amongst the participants was one of a bounded wave-like patterns. Anticipation, for many people, may have associations with feelings of sustained excitement or even nervousness. Considering the examples shown previously, the lines are much more controlled within a particular space and could be interpreted as an energy that is somehow contained. The feelings associated with anticipation may relate to this aesthetic representation; the physicality of excitement or nervousness manifests in many ways such as foot tapping, or other obsessively repeated movements and the repeated wave forms of the lines may represent this (repeated motions across a sustained time). Notably, in these examples, there is little to indicate a kind of climax, the patterns are sustained suggesting the feeling of anticipation may be temporally drawn out. Additionally, the lines are very angular dominant, suggesting that anticipation may be viewed by some as a categorically negative emotion. Overall, this emotion was notable for its variety of representations. Some others were more simple, utilising line journeys that rise and fall and others that explore the nervous energy motif but in other ways.

3.10.4 Surprise

When comparing the results for *surprise* and *anticipation* there are some notable crossovers. Many of the lines can be interpreted as having a temporal dimension, showing explicit changes in dynamic as they travel across the page. The main difference, however, is that these lines are kind of mirror images of some of the anticipation lines. As anticipation suggests a waiting or a sustained feeling leading to some kind of climax, the feeling of surprise come from something unexpected that may be highly engaging. Interestingly, in Plutchik's (1980) model, surprise is placed at an opposite to anticipation, sits subjectively between amazement and distraction and is related to the complex emotions of awe and disapproval. In this sense, we can see this represented in the lines. Consider the lines below in Figure 33. If they are read left to right in an orthodox fashion, all the lines begin with dynamic and energetic movement (the example on the right in particular). This dynamic visual energy that is present at the beginning of the line dissipates by the time it travels to the far point in all of these examples. It is possible these are, in some ways, representations with a temporal dimension where the initial feeling or shock or excitement is followed by a calming of mood or a resolution. The overall movement of the lines seems to bust out as an intense growth in Form and then come to rest. Aesthetically, this is represented by visual complexity moving towards a state of visual simplicity.

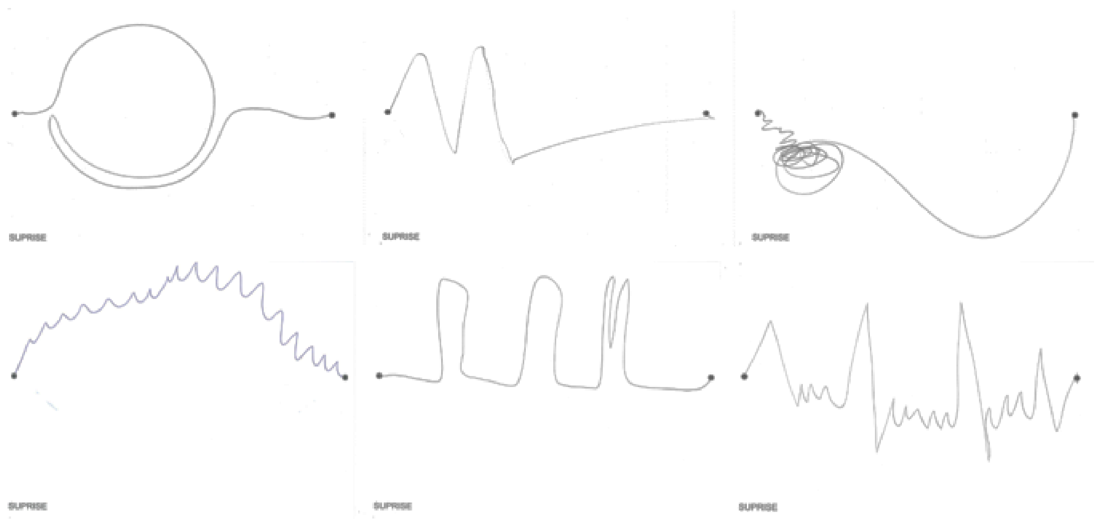


Figure 33 - Representations of surprise

Not all the lines drawn for surprise had an identifiable temporal dimension that could be interpreted. The generated motifs were quite diverse overall but were mostly visually energetic with lots of changes in the directions of the line. While their geometric qualities are distinct and there is no clear alignment to either angular or curving motifs, all the lines have a wave-like journey that travels up and down the page. The examples on either side are somewhat like those seen for anticipation but the middle example is a little more distinct. Broadly they are characterised by a journey that is up and down and dynamic. The visual energy implicit within these lines indicates that surprise is viewed by many as a visceral emotional experience. As there is no clear alignment with either curvature or angularity, it is possible that the emotion is viewed with some ambiguity – only characterised by feelings of the unexpected or a shock – not necessarily positive or negative in nature. 'Postmodern' architecture and industrial design are often described as shocking and surprising due to their mixture of incongruous and anachronistic stylistic elements. Perhaps this is reflected somewhat in these representations as one of the few coherent representations of the emotions may be a visual language of incoherence.

Taken together, these results and interpretations reveal a complex and layered story of form experience and form expression. Many of the participants within the study utilised structural repetition, patterning, and symmetry to build their motifs. Symmetry was often used in association with emotions of a positive valence and repetition of forms used to highlight a sense of balance. Additionally, these rules led to interesting displays of 'narrative' within the forms.

3.11 Summary

This chapter demonstrates the complexities of form experience and form representation. Considering numerous threads of scholarship, the argument that physical form or a physical aesthetic can be deconstructed and reframed as a series of textured interwoven lines was advanced. The holistic experience of these elements creates the materiality of the objects and embodies cultural ideas and emotions. The textility of the interweaving and interacting lines creates the rich experience of form and connects us to the processes – both material and conceptual – that birthed the artefact.

These arguments were consolidated firstly within the line model and were latterly examined in the presented experiment. The experiment was exploratory in nature and subjective in terms of results interpretation but is however useful for examining form, expression and perception in ways that have not thus far been done. Considering emergence, the experiment revealed that pattern and symmetry (albeit abstract and sometimes chaotic) is the lens in which form is represented; the lines were often structured around a symmetrical rule or used a repeating motif to convey the emotion, some even had complex dimensions of temporality. *Pattern* was identified as a prominent 'meta-concept' or overarching theme at work, operating at a macro-structural-level and also at the micro-level of styling, detailing and ornamentation which appears to be the key driver of emotive engagement with designed things. (A similar argument has also been made by Alexander and others (1964, 1977) in which abstract patterning processes are used to form design solutions). Indeed, the use of repeating motifs and symmetry was present in nearly all of the representations indicating its intrinsic importance within the conceptual schemas of form emergence and representation. With recognition of this fact, pattern as a critical tool of the designer will be examined in more detail next. From this section, the critical take away points are as follows:

- *Experience cannot be discretely defined but relates to a temporally bounded event that may influence perceptions, emotions, and feelings*
- *Emotion can be viewed phenomenologically as a complex set of experiences that are transient and changeable and influenced by perception*
- *Studies in experimental aesthetics have demonstrated the emergence of representations that appear to embody emotions and semantic values*
- *An analysis of Western design through the use of line reveals the presence of these forms of representation interwoven through the textures of the made objects – this analysis contributed principally to the development of the presented line model*
- *Pattern and symmetry were identified as the unifying meta-concepts in which the interweaving forms and structures could be more directly explored*

4. Studies in pattern

Are you really sure that a floor cannot also be a ceiling?

- M C Escher

The last chapter established that pattern, or the operation of repeating particular themes or motifs in a structured way, can be viewed as a critical tool or meta-concept for the designer or maker, especially when trying to embody abstract concepts such as emotions within form properties. This chapter will consider pattern in more detail as a means of examining both the emotive effects of aesthetics in design and the textilities of making (following Ingold, 2010) and product fabrication. Firstly, a working definition of pattern is presented, detailing different types of patterns, their historical use, how they are constructed and their relevance for the modern day. Secondly, two studies are presented that analyse the emotive and semantic content of pattern; how people perceive pattern as relating to subjective descriptions of emotional states, feelings, or concepts. From these studies a number of conclusions are proposed relating to the semantic content of form. This discussion then facilitates the development of sets of bespoke pattern designs that embody distinct emotions. Following the previous discussions on form and the experience of emotion, this section clearly demonstrates the human connection to the aesthetic and how this can be applied within design practice, it also presents a distinct model of emergence.

4.1 What is a pattern?

Design aesthetics can be viewed as varieties of meta-patterns – an ordered structuring of elements that are fabricated through complex processes of emergence. Pattern itself represents a kind of bounded system but facilitates all of the complexities and strangeness of designed artefacts through the structuring of elements. This relates to what Morton (2013) has referred to as 'interobjectivity'; an interaction between object properties that creates an emergence. N+1 objects interacting can create a 'magic birth' from what Harman (2018) describes as the 'sensual ether'. Recorded history of the aesthetic arts and ancient architecture reveals the prominence of patterns of many different varieties (Figure 34). From the meta-patterns of the overall structural designs to ornamental detailing. While there are speculative historical reasons why patterns emerged as an artistic phenomenon or as a way of structuring physical objects – the primary being the gradual development of a geometric understanding and formalism in ancient Babylonia, Egypt and Greece (Hann, 2013) – it remains largely unclear what the semantic properties of these forms were. What did they mean to the people of these times? This may be almost impossible to determine absolutely but considering the responses of modern-day people to historical patterns may provide some answer and additionally provide other useful insights for contemporary design practitioners. Patterns as a kind of meaning-driven ornamental design feature developed along with other practices within the visual arts and now have a very rich history. Critically, there is a lot of divergence as pattern motifs move and change through different cultures. The patterns of Ancient Greece, India and Egypt were highly geometric, angular, and associated with forms of ornamentation contrasting with Pictish and Celtic knot patterns from the 3rd century AD which are much more explicitly organic, dominated by undulating curves. Incredibly complex pattern design is also seen in the Arab and Islamic world incorporating a range of symbolism and ornate structural motifs which have been extremely aesthetically influential since their creation (Broug, 2013).

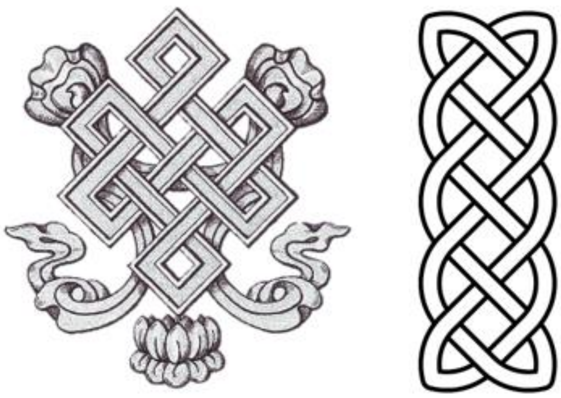


Figure 34 – Examples of Jewish (left) and Celtic (right) knot pattern motifs

Repeating aesthetic motifs – what might best describe a pattern – have been seen in expressive artistic practice for thousands of years with evidence of pattern decoration on ceramics dating back at least as far as the Neolithic period in Mesopotamia (Cruell, Mateiciucová, & Nieuwenhuyse, 2017). Christie (1929) has noted that pattern 'necessarily implies design composed of one of more elements' that have been arranged or transformed in some way. Considering that pattern creation relies on mathematical operations, the aesthetic changes in patterns across time have always been constrained by sets of rules, systemically bounded. We are dealing primarily with *tiling* patterns which consist of several fundamental elements, limited but not restricted to*; repeatability, symmetry, infinite coverage of a plane, deconstruction into simple shapes or rules, colour and symbolism*. Indeed, repeating geometry that fits together, known in mathematics as a *tessellation* is the central concept in pattern creation; what Christie (1929) has called processes of 'interlacing, branching, interlocking and counter-changing'. Hann (2012) details that patterns are built from sets of simple symmetry operations. These operations provide an emergent complexity when applied to specific geometric shapes and are illustrated below in Figure 35; *A) Translation B) Rotation C) Reflection D) Glide reflection.*

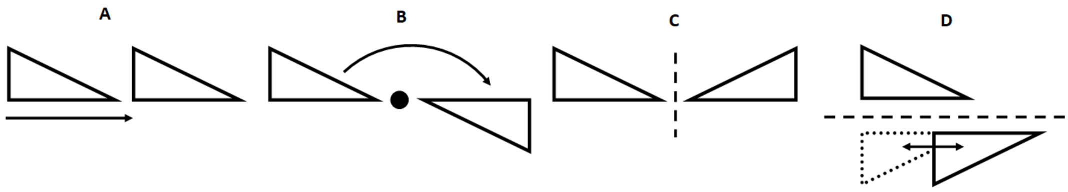


Figure 35 - The four operations of symmetry – A) Translation B) Rotation C) Reflection D) Glide reflection

Every known two-dimensional pattern is built from these simple rules of symmetry that transform arrangements of geometric shapes and allow tessellations to emerge. To take these in turn, *translation* (A) is defined by the movement of a shape across the plane that is entirely parallel. This is the simplest form of operation but is important as it constitutes the basic repetition of geometry. Rotation (B) is more complex as it assumes a central axis by which the shapes can move around. It is important to note that within pattern arrangements, individual shapes or entire groups of shapes can undergo rotational transformations. Reflection (C) can be classically recognized as a simple mirroring of the shape, a basic symmetry by which the geometry of the shape is inverted. This principle of symmetry is arguably the most powerful operation in the creation of patterns. As an extension of the classical symmetry concept, glide reflection (D) is denoted by both a reflection operation and a relative shift of this mirrored shape. As shown in example D above, the shape is both reflected across the central axis and then moved relative to its mirrored starting position. This is effectively repeated along the axis to create the glide reflection pattern.

Depending on the arrangements of the shapes, great degrees of complexity can be achieved. 17 tessellation configurations can exist to create a pattern in which a plane can be perfectly covered ad infinitum without varying any of the fundamental geometric elements. This relates to the maximal six-order rotational symmetry based on one of the five Bravias lattice frameworks (Hann, 2012). These lattice frameworks were developed within crystallography and describe the dimensional positioning of atoms in a given space. The 17 pattern types and how to derive them is illustrated in Figure 36. As shown, tiling patterns are defined by properties of geometric rotation and symmetric operations and deviation from these rules means a failure in perfect pattern creation – an infinite plane will not be covered successfully. It should be noted, however, that imperfect pattern designs have also been developed throughout history. Given that pattern forms can achieve high complexity, they can always be assessed within the bounds of this framework. Furthermore, there is some speculation that the use of complex symmetry operations in the context of pattern or decoration is a kind of prehistoric group-theory that became highly developed by ancient Egyptian civilization (Washburn & Crowe, 1988). Pattern could thus be considered an expressive and aesthetic manifestation of mathematics – the underlying structure illustrative of discrete mathematical principles.

From simple rules comes all the variety of pattern seen in the world today. Identification, categorisation, and analysis of patterns has been undertaken by a large body of researchers over the past two centuries. Owen Jones' exhaustive study *The Grammar of Ornament* (1856/2008) is one of the first serious collections of the decorative elements of the multifarious world cultures. Jones not only details the contemporary design of his time but also historically significant pattern work from the Ancient Romans, the Celtic peoples and the Islamic and Byzantine peoples amongst others. While Jones' work is clearly dated and its analysis of the aesthetic cultures of non-Europeans is laden with the common prejudices of his time, it remains a valuable resource for aesthetic analysis and as a record of the semantic associations that were made with the various forms of decoration and ornamentation. He presents a series of 17 'propositions' from which his theory of aesthetics is advanced. Proposition 4 for instance reads as follows; 'True beauty results from that repose which the mind feels when the eye, the intellect, and the affections, are satisfied from the absence of any want' (p.5). Work following Jones has tended to be more thorough and thoughtful in dissecting the cultural basis of the aesthetic styles. Washburn and Crowe's extensive study *Symmetries of Culture* (1988) took a two-pronged approach, on the one hand looking at the mathematical basis of pattern design and then how this linked to aspects of culture and knowledge. Critically, the authors use wide-ranging scholarship to show how the travelling of aesthetic motifs and ornamental design may link to the evolution of culture such as the use of complex mathematical concepts. In a later work Washburn and Crowe (2004) expand on their thesis by exploring further how cultural knowledge is embedded in the forms of symmetry that make up ornamental design work. Similar work has more recently been completed by Hann (2013) who analysed the dynamic drift of aesthetic cultures and in an earlier work also detailed the construction of pattern stating that both symmetry and kinds of symbolism through shape are the vital ingredients for patterns to emerge (Hann, 2012).

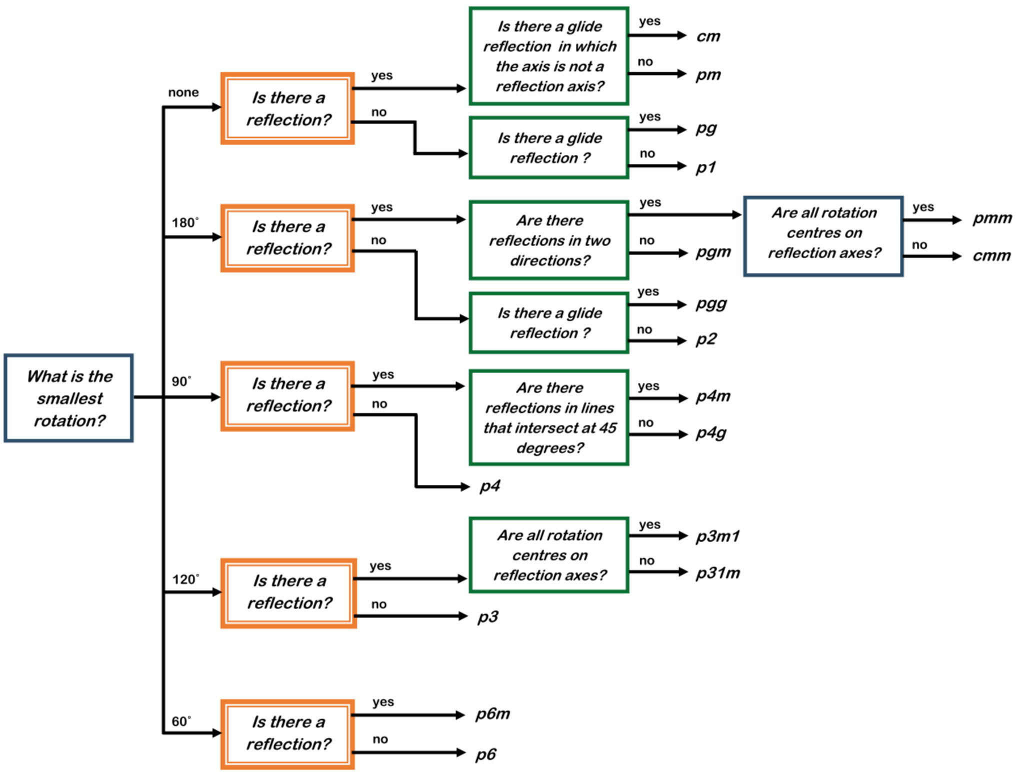


Figure 36 - Classifications for two-dimensional, two-colour patterns based on symmetry operations, adapted from Washburn and Crowe (1988)

Even a very general analysis can show how important pattern work is to the practice of design and making. Ingold (2008, 2009) for instance has studied the processes of weaving extensively, which are, he argues, achieved by systematic patterning motions – the pattern creating form and function through the manipulation of material in a process of gradual emergence. Knitting is another example of this. The making of rugs and carpets also has a direct connection to patterning. Whether intentional or not, pattern structurally defines and is an emergent feature of design and construction. Brick work is structured around a basic grid pattern with glide reflection symmetry and car tyres are debossed by pattern-based texturing or 3D patterns; all manner of simple patterning is present in everyday products.

What properties create a pattern? The most useful answer is *shape,* or a composition of Forms. Ching and Juroszek (1998) defined shape as a 'characteristic outline or surface configuration of a form' (p.23) that can only exist with reference to other shapes; shapes and symmetry are thus the key constituents of a pattern within the context of design. Structural elements are used to define and develop shapes within the context of a pattern such as the symmetry operations mentioned earlier. As Hann (2012; 2013) argues, points and lines are the basis of structure and are the sources from which all geometry is created – points determine position and are dimensionless entities. As explored in chapter 3, line can be considered as a moving point or the path between two points, a change from one state to another. The concept that line can convey some kind of energy or relates to natural forces or states of change has been explored in some depth by Ingold (2015), Barratt (1989) and earlier by D'Arcy Thompson (1917) who conjectured that the form of living creatures could be conceived as a 'diagram of forces' – an idea also intimated by Arnheim (1954) who focused on the visual characteristics of the aesthetic arts. These fundamentals must be considered when developing an understanding of the visual effect of patterns. Patterns are constructed from shape; shapes can be viewed as discrete elements that contribute to an overall *form* and are bounded by structural rules.

4.2 Pattern and the aesthetic perception

4.2.1 Aesthetic cultures

Pattern, as a form of visual expression and design is as open to interpretation and emotive experience as any other art form or designed object. Increased interest in the emotive qualities of aesthetics and the built environment sets a precedent for a study of this kind. Efforts from various strands of design research (explored in Chapter 1) are effectively expanding and enhancing the understanding of the vision theorists by introducing new conceptual frameworks by which to examine material objects. We argue that pattern can be viewed and examined in a similar way to a designed artefact with both relying on well-established rules of structure and constrained within a space of expression. The use of pattern is historically wide-ranging and understanding its emotive depths can have direct application in design, architecture, and other visual languages such as film and game design. This research uses qualitative methods to address the emotive qualities of patterns and uses iconographic methods to establish possible semantic associations behind the emotive relationships. Detailed analysis of patterns has so far only examined their underlying structure and how this relates to geometry as well as cultural changes across time (Hann, 2013). Recent work in experimental aesthetics has suggested that human beings have a very strong and possibly innate preference for particular kinds of forms and associate particular emotive experiences with abstract geometry (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016). For instance, the structural formations of patterns could convey deep semantic meaning to observers extending beyond simply a form preference or a preference for curvature. This preference is contrasted with a demonstrated dislike of angularity and many theorists have suggested these preference factors are at some level biologically predetermined. However, given the diversity of design taste across the centuries, this assertion can be called into question. Assuming, form is presented in a cultural and artistic context, such as a pattern design - will this change the character of any emotive responses? Before we can consider these questions more closely, we must consider how a pattern is defined.

4.2.2 Pattern and meaning

The psychological philosophy known as Gestalt theory mentioned in chapter 3 has offered several insights regarding the nature of visual perception and the interpretation of geometry as a kind of visual experience. Pinna (2010) has sought to extend the Gestalt principles to incorporate a process of semiotics or *meaning making*. The Gestalt principles of grouping forms cannot fully explain the nature of these emergent meanings that manifest for observers but there is what Pinna (2010) described as a 'sense of happening'. This sense is an apparent change in the structure of a known form that is then ascribed a cause. If we consider the forms below in Figure 37, Pinna suggests that our natural response is to ascribe a cause for the deformation of an ostensibly perfect square – it is being compressed by some force or it has been cut by something. This is a method (as Pinna argues) of cognitively processing the geometry. By giving the forms meaning and even some narrative of perfect to deformed what is, in reality, sets of lines, becomes an intelligible image. Following the logic of Gestalt, depending on how an individual might process the pattern forms – what forms are considered dominant within a composition – will directly influence any meaning associated with it. An associated phenomenon, pareidolia, whereby an observer will see a face or other meaningful patterns when none is present has been studied in the context of arrangements of abstract geometry (Salgado-Montejo et al., 2017). The study concluded that distinct emotive states can be represented with simple arrangements of shapes and lines.

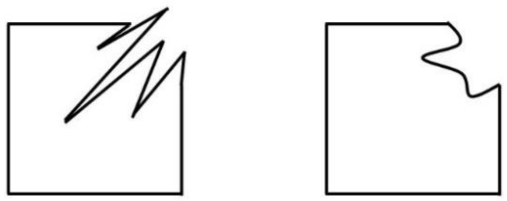


Figure 37 - The proposed 'sense of happening' effect, adapted from Pinna (2010)

These factors will be important to consider in our later analysis of emotive responses to pattern structures. Patterns are built from pieces of geometry and the context within which the geometry interacts may radically affect the interpretation of the forms. Arnheim's discussion of form as an interplay between shapes considered Gestalt holism closely. The interaction of shapes can create a visual energy or language, what Arnheim (1954) referred to as visual or psychological forces. A configuration of shapes may for instance appear 'heavy' or 'light' depending on its context.

The notion that pattern serves both as some form of meaningful symbolism and has use value has been explored by Ingold (2008) in his study of lines. The interesting work of Gell (1998), for instance, argues that the use of pattern in many ancient cultures was an act of warning off the demonic. The evil spirits would be both tantalised and puzzled by patterns and would not enter a home if they could not be unravelled. Gell (1998) notes that Celtic knot work may have been used in this way and Ingold (2008) cites the cultures of southern India who also engage in similar practices. In Western culture, there is a modern equivalent with the appropriation of dreamcatchers which were originally part of Native American culture. This form of pattern making, Ingold argues, is analogous to or representative of a maze or a labyrinth and believes that instead of confusing demonic forces, pattern making is a practice of *trapping* them in an environment of repeating loops. Ingold and Gell's respective analyses are interesting as they suggest that pattern has both a semantic dimension, following Krippendorff (2006) and Norman (1988), but also has a functional dimension (albeit one that transcends the physical world) following Gibson (1991). Ingold (2008) has also strongly argued that forms are not just observed in a prescriptive and rational way, they are modes of expressing change and the flow of energy and material. In this sense, pattern making cannot be seen as simply an ornamental practice, the way Jones (1856/2008) viewed it, but an expression of cultural beliefs and historical journeys – the interweaving of complex threads as conceptualised in the line model of the previous chapter.

Physically and practically, as pattern is embedded within the made, it becomes part of the fabric (literally) of the world. Ontologically, patterning may be the most fundamental method by which form emerges. Ingold highlights the interweaving of material, but this can be expanded further by recognising that visual as well as physical formations are made through patterning; oil painting is produced by the precise and repeated application of paintbrushes on canvases and digital photo prints are the patterning of pixels materialised through printing processes. Pattern is embodied both through process movements (energy transferences) and representation (emergent images, symbols and meaning).

4.3 Pilot study – pattern and semantic value

With close reference to David Wade's (1982) pattern source book, sixteen patterns were chosen based on their form, structure and cultural prominence including Spanish, Celtic, African, and Middle Eastern patterns (Figure 38, used with permission). They were also selected on the basis of the symmetry rules discussed by Hann (2012) meaning there was an adequate range of pattern complexity amongst the sixteen. The patterns were broadly categorised into three groups – angular, curved and mixed depending on the dominant features of each. Overall, six patterns were categorised as structurally angular, six as curved and three as mixed which the authors considered a good range of diversity for considering their respective emotive and semantic differences.

The workshop exercise included 12 student participants from design and engineering backgrounds, selected as a convenience sample. The students were then split into focus groups of either two or three members. This focus group approach meant that the effects of personality type could be mitigated as disagreements in interpretation could be discussed and consensus reached. Each group was required to observe a pattern for a total of two minutes and assign a maximum of three emotive and three descriptive (semantic) values to each using a provided worksheet. The worksheet contained 36 emotive terms ranging from highly positive to highly negative (*anger* compared to *joy* for instance) which would be used to describe the patterns. These terms were selected with reference to the models of emotion found in work by Plutchik (1980) primarily, and by Shaver and others (1987). Not only did this research provide a large array of emotive terminology, but the models also proposed the levels of intensity that each emotion is subjectively experienced, relative to the others - an important factor to consider. A list of descriptive (semantic) terminology was also included but participants were not required to use this, it was only used as a source of inspiration.

The patterns were displayed one by one in a randomised order and were all presented as monochrome – while colour can be an important element of patterns, we were only interested in reviewing the raw form qualities. The sixteen patterns used for the experiment are shown in Figure 38 with a label detailing their assigned category. The order in which they are presented below is the same randomised order used for the workshop.

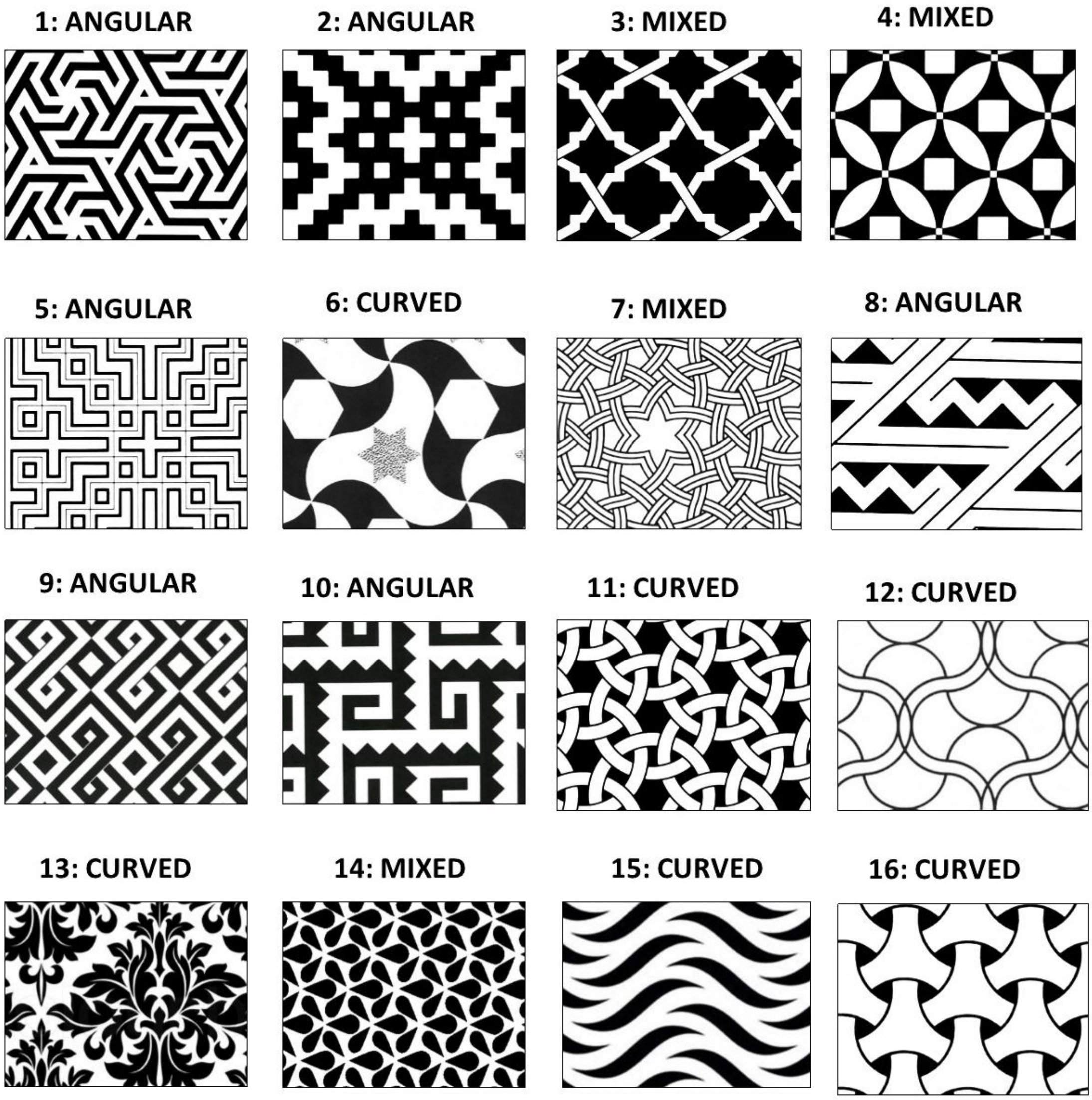


Figure 38 - Patterns utilised during workshop experiment, adapted from Wade (1982) with permission

4.3.1 Results

Following the workshop, an analysis was undertaken where the results were checked for trends. While it was rare for all the groups to produce identical emotive and descriptive values for a specific pattern due to the interpretivist nature of the exercise, we did however observe notable similarities in terms of broad emotion type and experiential intensity, *joy* and *excitement* for example. While these are recognised as different emotions, they can both be categorised as of positive valence and of a generally high intensity. The results from the workshop are summarised in Table 5. For most of the patterns the emotive and sematic values were quite clear and many of the groups converged in their separate interpretations, some results were less conclusive.

Table 5 - Ascribed emotive values and semantic association of 16 patterns

Pattern	Emotive associations	Semantic associations
1	• Strong trend towards negative emotions • Medium to high intensity • Key values: ‘anger’ ‘aggression’ ‘nervousness’ ‘uncertainty’	• Strong associations with angularity and complexity
2	• Moderate trend towards negative emotions • Medium intensity • Key values: ‘indifference’ ‘distraction’ ‘nostalgia’	• Strong associations with simplicity, confusion and instability
3	• Strong trend towards negative emotions • High intensity • Key values: ‘anger’ ‘contempt’ ‘amazement’	• Strong associations with tradition and sophistication • Additional associations included strength and power
4	• Moderate trend towards positive and neutral emotions • Medium intensity • Key values: ‘affection’ ‘joy’ ‘distraction’	• Associated with tradition and decoration • Additional associations included simplicity and playfulness
5	• Moderate trend towards negative emotions • Medium intensity • Key values: ‘uncertainty’ ‘apprehension’ ‘intrigue’	• Associated with confusion and irrationality
6	• Strong trend towards positive emotions • High intensity • Key values: ‘joy’ ‘excitement’ ‘love’ ‘affection’	• Associated with fun, fluidity and instability
7	• Weak trend towards positive emotions • Low intensity • Key values: ‘vigilance’ ‘trust’ ‘serenity’	• Strong associations with power, heaviness and symbolism
8	• Strong trend towards negative emotions • Medium intensity • Key values: ‘nervousness’ ‘uncertainty’ ‘apprehension’	• Strong associations with angularity and spikes • Additional associations included insecurity and instability
9	• Strong trend towards negative emotions • High intensity • Key values: ‘rage’ ‘grief’ ‘disturbance’ ‘uncertainty’	• Associated with evil, power, heaviness and solidness
10	• Strong trend towards negative emotions • High intensity • Key values: ‘fear’ ‘nervousness’ ‘distraction’	• Strong associations with wackiness, instability and confusion • Additional associations included wild animals

11	• Strong trend towards positive emotions • Medium intensity • Key values: 'trust' 'acceptance' 'optimism' 'serenity'	• Strong associations with tradition and symbolism • Additional associations included security and strength
12	• Moderate trend towards positive emotions • Medium intensity • Key values: 'serenity' 'love' 'joy' 'affection'	• Strong associations with fluidity, lightness and curvature • Additional associations included surprise and mysteriousness
13	• Strong trend towards negative emotions • High intensity • Key values: 'disgust'	• Strong associations with decoration and tradition • Additional associations included wealth and sophistication
14	• Strong trend towards negative emotions • Medium to high intensity • Key values: 'uncertainty' 'sadness' 'anger'	• Association with curiousness
15	• Strong trend towards positive emotions • Medium to high intensity • Key values: 'serenity' 'ecstasy' 'love' 'joy'	• Strong association with waves, fluidity and lightness
16	• Strong trend towards positive emotions • Medium to high intensity • Key values: 'trust' 'excitement' 'interest' 'anticipation'	• Association with strength, power and solidness • Additional associations included organic

4.3.2 Key findings

Given the limited scale of this study, we cannot claim to have made categorical discoveries regarding the nature of pattern interpretation. We can, however, offer two key qualitative insights based on the results that can be used as a foundation of further exploration of pattern.

1) *The more complex nature of pattern form and the structural relationships of the form influence the emotive feedback. This is a logical extension of Gestalt holism where the contextual nature of form alters how it is visually interpreted - its aesthetic meaning is changed. Our results largely corroborated with the previous studies analysing curvature and angularity but differed in terms of emotive intensity between the patterns and presented radically different semantic values*

2) *Patterns that included curved interlocking features were notable for the strong feedback they received. This study suggests that curved interlocking features are emotively associated with 'trust' and semantically associated with 'power', 'security' and 'solidness'. We speculate this may be due to a certain structural view of emotive visualisation - the forms look structurally secure in context and by extension relate to the concept of trust. By contrast, the angular patterns that may appear structurally disjointed were emotively associated with 'nervousness' semantically with 'confusion' and 'instability'*

4.4 Pattern study – emotional responses to pattern

We consider that form can be interpreted and understood at the emotive and semantic level by human observers. The philosophical underpinnings of aesthetics have been debated for centuries with critical contributions regarding the nature of aesthetic taste coming from Kant (1790), Hogarth (1753) and Hume (1757). These works consider that aesthetic value comes not from innate reasoning capacities within the human animal but from aspects of human sentiment and emotion. From the perspective of vision psychology and experimental aesthetics, work by Foster (1984) has established that four features can be coherently studied with clear links to the experience of vision.

1) *Recognition of local features* – straight lines versus curved lines, acute versus obtuse angle differentiation
2) *Local spatial recognition* – whether the shapes are arranged to the left, right, above or below a reference plane
3) *Global feature recognition* – awareness of symmetry and orientation
4) *Global spatial relationship recognition* – awareness of the position of geometry within a given field

Foster's (1984) criteria can help in the decoding of pattern perception. These earlier studies have been reliably repeated and reinforced in later work by Collier (1996), Bar and Neta (2006) and Bertamini et al (2016). In a wide variety of contexts and experimental conditions, it seems that there is a broad association between form and psychological states. This does not necessarily devalue an art-experience, it defines it. Considering the qualities of pattern form, we make this philosophical assumption – that form can be meaningfully interpreted by observers but that this experience is guided by emotive drivers. We also take Dewey's (1934) conceptualisation of an aesthetic experience as a basis for analysing the emotive character of pattern design. Dewey argued that the process of viewing art can equate to a wider experience of its formal qualities whereby the observer engages with distinct aesthetic properties. This notion of experience connects to Arnheim's (1954) thesis that forms of artistic expression relate to tangible qualities of human nature – they may express fundamental emotions. Concerning emotions, we utilise the appraisal models where emotive experiences are viewed as forms of responses to stimuli. This foundation is the most useful for our subsequent analysis examining the emotive responses and the possible explanations for these responses.

4.4.1 Experimental protocol

This study took a qualitative approach and latterly incorporates a quantitative assessment of data to distil the key information. As described, 16 patterns from a variety of cultural sources were analysed against emotive terminology using an ordinal scale of 0 - 5. The scale consisted of a list of 16 emotive terms initially proposed by Plutchik (1980) as a description of the primary human emotions. These are effectively semantic terms that describe an emotive experience and were used in the building of the line model and as part of the form expression experiment described in chapter 3. The scale was configured as 0 through to 5, with 5 representing an intensity of explicit emotive experience or sensation and 0 representing no emotive sensation. The study included 30 participants consisting of 16 females and 14 males varying in age from 20 – 60 years, selected as a convenience sample. Each participant took the test individually – every pattern was shown in turn for a maximum of 90 seconds in the same order as presented in Figure 38. During this period, each participant indicated the experiential intensity of each emotion listed. The order of patterns presented was generated randomly to minimize possible biases. The method of display was a 15-inch laptop screen with high-definition resolution. Before the test was conducted, everyone was asked if a definition of any emotive term was required – usually this was not needed. The list of emotive terminology used for the experiment is presented in Table 6 below.

Table 6 – Details of emotion terminology from Plutchik's (1980) 'Wheel of Emotions' model with working definitions, valence and intensity

Emotive term	Working definition (OED/CED)	Valence and intensity
Acceptance	Toleration, approval and integration	Positive valence / low intensity
Anger	Displeasure or hostility	Negative valence / primary emotion, medium intensity
Annoyance	Irritation and exasperation	Negative valence / low intensity
Anticipation	Excitement or preparation for future event	Positive valence / primary emotion, medium intensity
Apprehension	Anxiety or angst for future event	Negative valence / low intensity
Boredom	Apathy and unconcern	Negative valence / low intensity
Disgust	Revulsion and aversion	Negative valence / primary emotion, medium intensity
Distraction	Disturbance or interference	Negative valence / low intensity
Fear	Terror or fright associated with danger	Negative valence / primary emotion, medium intensity
Interest	Engrossment and attractiveness	Positive valence / low intensity
Joy	Pleasure or happiness	Positive valence / primary emotion, medium intensity
Pensiveness	Reflective or contemplative	Positive valence / low intensity
Sadness	Unhappiness, dejection or sorrow	Negative valence / primary emotion, medium intensity
Serenity	Calm or peaceful	Positive valence / low intensity
Surprise	Shock or amazement	Negative valence / primary emotion, medium intensity
Trust	Confidence, belief or faith	Positive valence / primary emotion, medium intensity

4.5 Discussion

Many of the patterns were interpreted in ways that conform to the existing paradigms in vision research, there are however some interesting results that can possibly be explained through other more theoretical means such as Gestalt psychology, iconographic modes of interpretation following Panofsky (1939) and other concepts in the study of design and emotion.

The presented study took 16 culturally prominent patterns and subjected them to an emotive analysis. The overall aim was to establish how the context of form as decoration may vary the emotive interpretations and how cultural factors such as symbolism may play a role in the overall holistic experience. This section will discuss several key results that may give us some insight into the complexities of form perception at the level of patterns. Here we employ iconographic methods from the study of art history to aid our analysis. This consists of isolating formal elements of composition or motifs and speculating upon their significance or embedded meaning. This effectively links our discussions regarding form characteristics and definitions, perception, emotion, and semantic theory.

The findings are generally consistent with the previous research findings where curvature was preferential and associated with semantically positive emotions. Considering our study, all the patterns that contained form compositions with dominant curves were considered positive. Patterns 3, 4, 6, 11, 12, and 13 are unambiguously positive for observers due to the high average ranking for the semantically positive emotions of *acceptance*, *trust*, *interest*, *joy*, and *serenity* seen across all the results. By contrast, low averages were found for the semantically negative emotions such as fear. Pattern 7, while being mixed in its form qualities showed very high levels of *annoyance* (3.30) indicating its high score for *joy* cannot be considered as a concrete indicator of a positive interpretation. Similarly, for patterns 14, 15 and 16 – while containing dominantly curved elements, the scores were unexpectedly low for *joy*, an indicator of a positive emotive interpretation (see Figure 39). Other semantically positive factors remained high, *serenity* and *interest* being notable examples, but these results suggest a certain ambiguity – some design or compositional element that hinders the positive interpretation. An obvious answer might be that the angular elements are being viewed as more dominant in the design overall (to use Reed Kostellow's compositional terminology) but it is possible that other cultural factors may be significant.

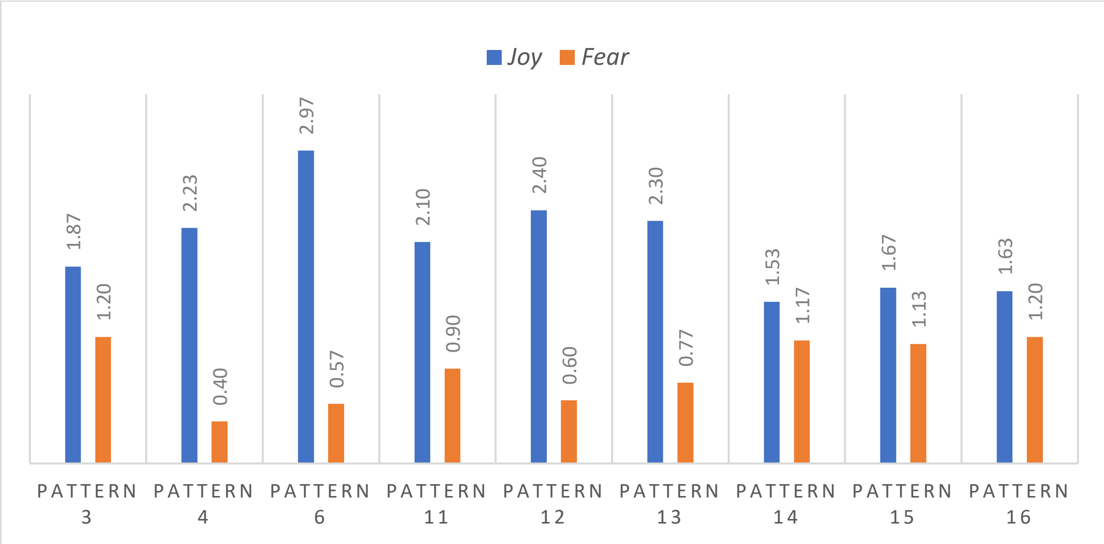


Figure 39 - Comparison of Joy versus Fear response for curved and mixed patterns

One feature we have drawn attention to is the compositional element of curved interlocking features. Wherever this is seen, a high score (>2) is recorded for the emotion of 'trust'. As an aesthetic element, the interlocking rings may also suggest a sense of rigidity and by extension reliability. The rigid structure of a tied knot for instance or a set of chain-links all have thematic and aesthetic similarities. Additionally, it is worth noting the unity of two rings was for centuries used in Western Christianity as a symbol of Christ. Figure 40 shows the 'Vesica Piscis', the symmetrical symbol is first recorded in Euclid's *Elements* and is then used widely as a feature in Catholic symbolism and Gothic architecture (Hiscock, 2007). Other related motifs featuring interlocking curves and rings can be seen in Romanesque Christian architecture also (Munari, 1960/2015). It is possible that this cultural symbol is influencing the emotive interpretation on some level – of the patterns assessed to be emotively high in trust, four contain this symbol in some form (pattern 4, 11, 12 and 16). Following the logic of Arnheim (1954), this symbol may reflect a deeply embedded trust-response within human nature - this symbol is an emergent quality of a naturally understood human emotion.

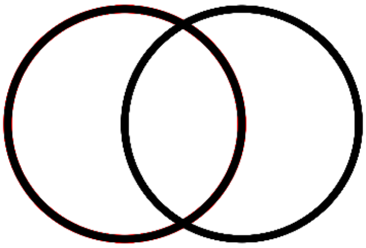


Figure 40 - A 'Vesica Piscis', two interlocking rings

We would also like to draw attention to the apparent link between certain emotive concepts. One notable example is the apparent relationship between acceptance and trust (Figure 41). When a high score (>2) is recorded for trust, a high score for acceptance is also recorded indicating a conceptual link that is made by the observers – a sense of coherence is instructing the emotive analysis; there is an underlying logic within the interpretations. The concept and definition of trust indeed suggests an implicit acceptance; trust in somebody or something means to accept or put faith in an aspect of their being.

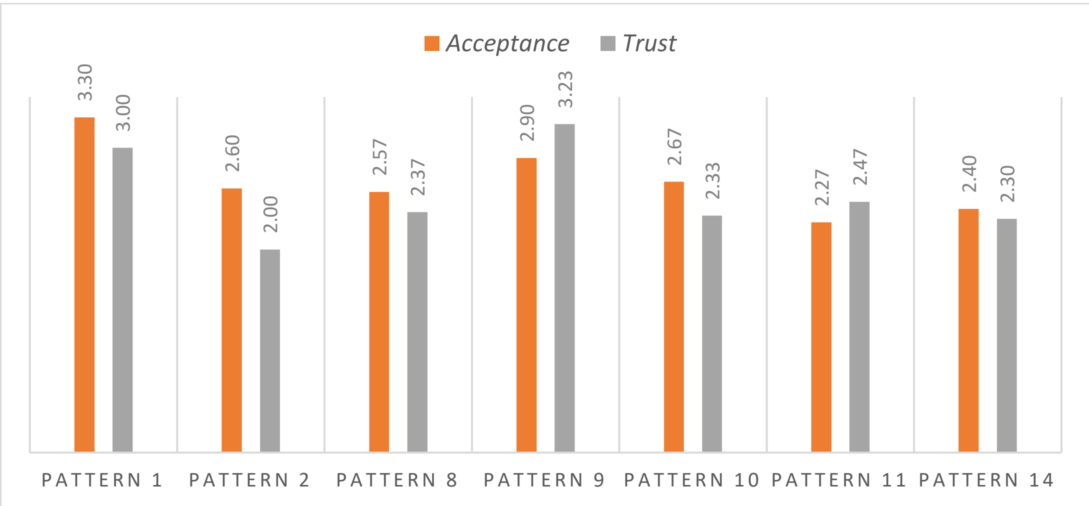


Figure 41 - Noted Acceptance and Trust relationships in 7 patterns

Design theorists Norman and Coates can also be considered here. Coates' concept of 'objective concinnity' may be a useful point of analysis where he proposes that highly ordered curved objects of a G-2 curvature continuity are more cognitively intelligible (Coates, 2003). By implication, the curved and symmetric properties of this structure may be a guiding factor in the positive emotive interpretation. This is what Norman

(2004) has characterised as visceral design where there is a naturally positive reaction to a composition of form based on an innate cognitive preference.

Another result we can consider within the spectrum of curved geometric elements is the illusion of movement from the context of the discrete shapes and lines. Visual illusions were considered in some depth by the Gestalt theorists who proposed that the perception of shapes themselves is altered by surrounding elements or compositional design. The responses towards patterns 4, 6, 12 and 15 all contained high averaged scores for 'serenity' (> 2.3) suggesting that they calmed the observer to some extent. If we consider the compositions of these 4 patterns, all feature forms of waves similar to the mathematical sinusoidal wave. Following the logic of the Gestalt theorists we can consider how this structural element may contextually lead to an illusion of movement – a sense of flow or change or energy – what Pinna (2010) described as a 'sense of happening' and Arnheim (1954, p.6) described as a visual or 'psychological force'. Indeed, we propose that these compositional elements relate very strongly to an idea of a fluid or running water. At a micro level, we can consider the form aesthetically like a wave that might be produced naturally by the rising tide. At the macro level, the form is similar to that of a meandering river as seen in cartographic representation (maps). This aesthetic similarity to water, we suggest, is leading in part to the high results for *serenity*; the flowing nature of water is a powerful and transcendent cultural symbol (Clarke, 2010) and has long been associated with positive notions of peace, harmony or the notion of the sublime as described in the tradition of European Romanticism (Bietoletti, 2005) (Figure 42).

Figure 42 - Sine wave, or an abstract representation of water, flow or change

While there certainly appears to be some coherence between curved compositional elements and a positive emotional interpretation – the character of the interpretation is somewhat more changeable (Figure 43). We have just considered some unity between aesthetic elements and emotional experience but some of the results are more challenging to examine.

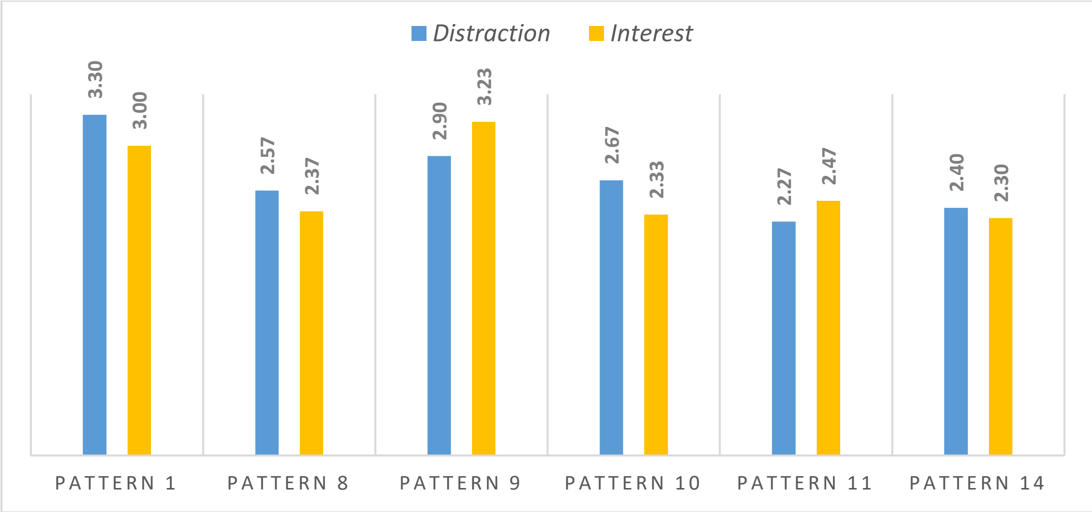


Figure 43 - Noted Distraction and Interest relationships in 6 patterns

When we considered angularity or positional (G-0) curvature continuity, there is much more ambiguity in the results than seen in those based on curved structural compositions. While there was a general trend towards a more semantically negative emotive response which conforms to the existing paradigm in vision research, there are responses that we would like to examine that appear to contradict these existing studies. The main relationship we would like to draw attention to is the apparent relationship between the experience of *interest* and that of *distraction*. Our results recorded this relationship in ten different patterns both within the curved and angular categories. Our interest here concerns aspects of visual complexity. As these results suggest that the context of these angular forms actually make them more engaging or stimulating for observers, is it possible that compositional factors are playing a role? Pattern 1 and pattern 5 are both highly angular (contain no curvature) and both display this relationship between *interest* and *distraction* – interest being semantically more positive than distraction. We suggest that that the natural negative interpretation of the angularity is being curtailed by the compositional features of the pattern – the arrangement of the elements. Pattern 1 for instance is aesthetically comparable to a spiral and pattern 5 similar to a maze or labyrinth (see Figure 44).

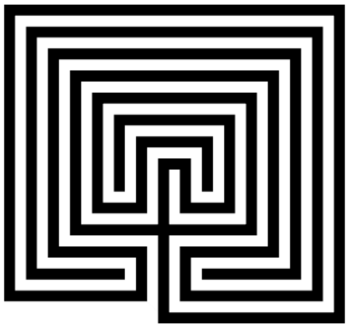


Figure 44 - Cretan labyrinth design

These cultural factors may inspire more positive feelings of adventure and general visual stimulation meaning a distracting but a simultaneously interesting emotion, if experienced. Similar maze and spiral motifs are seen elsewhere in the other angular patterns that show this same result, notably patterns 8 and 10. Ingold's (2008) and Gell's (1998) comments on maze motifs as kinds of spirit traps is instructive – the maze is culturally associated with dark and dangerous forces. A Freudian analysis might say that people on some level desire the danger that the angularity might bring, what Freud (1920) characterised as the 'death drive' or drive toward destruction. This can be challenged, however, by noting the relatively high ratings for annoyance (> 2) seen in the results for patterns 1, 5, 8 and 10 – the visual composition may simply be irritating or aesthetically unpleasant. Pattern 7 notably recorded the highest average for annoyance. Considering that this pattern is the most structurally complex, it may present a challenge in cognitive processing (following Coates 2003) resulting in an irritation visual experience. What is clear however, is that the dominantly angular pattern designs are not categorically negatively interpreted – a point that was also established in the analysis of lines in Chapter 3.

4.5.1 Implications for design practice

This work considers the emotive experience of observing form, more specifically, form arranged as a decorative pattern. Our qualitative study suggested that particular forms relate strongly to emotive experience and feeling and possibly semantic ideas of meaning and context. Considering that there is a growing interest in designing for an emotive experience (Desmet, 2012; Desmet & Hekkert, 2014) this work could be tangibly applied to the creation of more emotively sensitive products. Given the increased capacity for customizability and bespoke, individual designed parts using advanced manufacturing technology such as CNC machining or additive approaches, there is scope for utilizing pattern as a basis for surface texturing designs. Architectural practice has applied pattern throughout its long history, but industrial design has yet to make such focused and explicit use of it. Practices such as Kansai engineering are directly orientated around creating emotively engaging products through understanding cognitive experiences (Lévy, 2013), and these findings and methods can be utilized directly within Kansai frameworks.

In terms of constructing an emotive pattern our insights offer some obvious starting points. Utilising iconographic methods, where significant motifs are isolated, we can understand which form properties are the most important for achieving an emotive effect. Once an isolated geometry has been identified as emotively significant, this can then be configured into a bespoke pattern design. Variations in orientation, scaling and overall composition may enhance or change the emotive characteristics, but the method of motif isolation could be a valuable tool for design practitioners. Notably, as has already been explored, types of patterns have been applied quite directly by researchers investigating interaction and functional mechanism (Jensen, Blindheim, & Steinert, 2017).

4.6 Creating bespoke emotive pattern designs

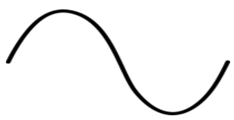
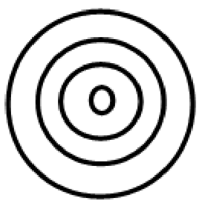
How can this knowledge gained from the study of pattern and aesthetics more generally be applied? The line model developed in Chapter 2 illustrated how discrete geometric elements could be used within the framework of design to create both emotively and semantically resonant products and product stylings. The next logical step is to validate these initial findings by creating and testing bespoke emotive patterns. This could have wide applications in design styling and aspects of product function. This section will describe the creation of the bespoke pattern designs by firstly deriving what are considered emotively resonant geometric shapes, lines and motifs and then applying these to a symmetric rule structure.

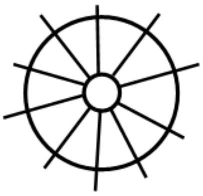
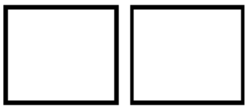
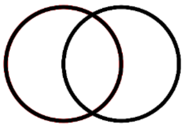
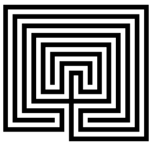
4.6.1 Deriving emotive shapes

Experimental aesthetics has demonstrated that 'emotional' geometry exists. Dependent on aspects of culture and possibly evolutionary reasons, aesthetic motifs can have strong semantic associations. The study presented in the previous section and the Line model presented in Chapter 3 allows us to distil a set of principal aesthetic ideas that can be used in the creation of pattern. Given that most studies in experimental aesthetics explore the experience of abstract shapes, geometry that is encountered in the everyday makeup of things, only abstract shapes will be used for the designs. This additionally attempts to minimise cultural biases and the recognition of culturally deep-rooted symbols.

From an overview of the previous discussions, a set of emotively resonant and symbolically meaningful geometry can be presented, what can be considered archetypal forms within a given domain. They are presented in line form to continue the thematic concept of line that was established to be so important and useful for the wider perception of shape. Table 7 thus provides discrete motifs with their emotive and semantic relevance:

Table 7 – Emotive and semantic relevance of discrete aesthetic motifs and geometric elements

Aesthetic motif / Form archetype	**Name / description**	**Emotive and sematic relevance**
	Wave motif, transitioning curved form	Associated with feelings of joy, happiness or calmness. Semantic relations to water, fluidity and serenity
	Spike motif, angled transitions	Associated with feelings of fear, anger or excitement. Semantic relations to danger and instability
	Layered spike motif	Associated with feelings of nervousness and fear. Semantic relations to danger and mysteriousness
	Growth in size motif, building outwards	Associated with joy and anticipation. Semantic relations to growth, expansion, introversion and extroversion

	Bursting outwards motif, outward energy	Associated with surprise, excitement and anticipation. Semantic relations expansion, seeing or focus
	Structured box motif	Associated with trust and contentment. Semantic relations to stability and rationality
	Interlocking rings motif, a 'Vesica Piscis'	Associated with trust and joy. Semantic relations to unity, security and strength
	Labyrinth or maze motif	Associated with confusion, fear and excitement. Semantic relations to the unknown and the mysterious

4.6.2 Final designs

As we have seen, form has strong emotive associations. This was the foundation for beginning the design work. The goal was to create four bespoke patterns that could be associated with categories of emotion. Following the emotive categories developed by Plutchik (1980), it was established that four patterns would be created to broadly represent sematic concepts of *trust*, *joy*, *fear* and *surprise*. Trust and joy have an unambiguously positive valence and fear a negative one. Surprise was explored as an example of a marginally more ambiguous experience as it is possible to be surprised by something that is unpleasant. Generally, the principles of angularity versus curvature were explored as well as concepts of visual energy where a transference of a physical energy present in emotional feeling was translated into abstract representations. The created patterns are presented as follows and were developed through many iterations and refinements. Figure 45 below illustrates the pattern designs; these are followed by descriptions of the inspirations and logic behind each of the designs.

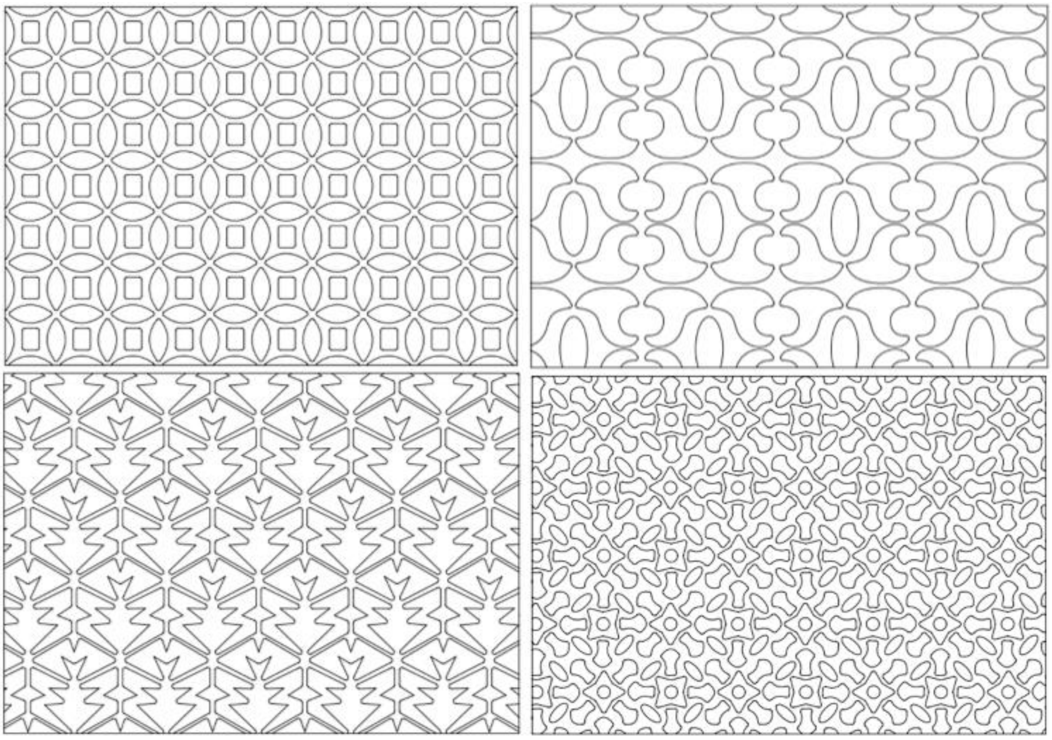


Figure 45 – Clockwise round, representations of Trust, Joy, Surprise and Fear

1. *Positive valence – representation of 'trust' or a sense of connection - Pattern type: p4m*

The motif of two interlocking rings and interlocking shapes generally was consistently associated with subjective feelings of *trust*. This was the principal inspiration for this design and the structural foundation of the pattern is the Vesica Piscis mentioned earlier that was a key aesthetic and structural motif for architecture of the High Gothic era and many of the later stylistic variations. The pattern is heavily reliant on multiaxial symmetry and makes dominant use of curvature to inspire a more positive experience of the shapes. The pattern is also notably like the visual appearance of a flower – a central element enclosed by petal-like shapes. In terms of its visual effect, the goal was to bring out a connected structure that was reliant on its links to other parts – an embodiment of trust in a structural and architectural sense.

2. *Positive valence – representation of 'joy' or a sense of happiness - Pattern type: pmm*

This pattern drew principally upon the work of previous studies that had made strong associations with curvature and aesthetic preference and curvature with subjective representations of happiness or elation (following Collier, 1996, Bar and Neta, 2006 and Bertamini et al, 2016). Additionally, Arnheim's (1954) ideas around perceptual forces was a strong guiding element and motifs from mid-century modernist design which was noted in earlier studies to be an embodiment of post-war American optimism (see Wendy Kaplan's, 2011 study on the work of California based industrial designer Greta Magnusson-Grossman who emigrated from Sweden in the 1940s). It was found that the patterns most associated with joy were also associated with feelings of 'fluidity', 'serenity' and 'lightness'. With respect to this, the forms within the pattern were designed to be larger, bulbous and organic.

3. *Negative valence – representation of 'fear' or a sense of unease, unpleasantness or danger - Pattern type: pm*

The central geometric principle explored in this design is angularity. Following the numerous studies cited earlier, angularity was consistently associated with negative emotional experience or was at least not the preferred geometry when compared with curvature. It was additionally established that angularity was a diverse tool for the aesthetic modernists of the early 20th century and was used as a kind of antithesis for organic representations within ornamentation. While it cannot be argued that Modernist architecture was an expression of negative emotion, it can be viewed as an explicit rejection of the ornamental design and the symbolism within that design that preceded it. With respect to this, the pattern design drew structurally from Modernism as the shapes were arranged within uniform cubes. The shapes were designed to have some sense of directionality, pointing inwards as if to seem imposing and aggressive, something like a predator insect or a hazardous trap or maze, alluding to Ingold's (2008) and Gell's (1998) discussion of pattern.

4. *Ambiguous (positive/negative) valence – representation of 'surprise' or a sense of excitement or shock - Pattern type: pgg*

Perhaps the most ambiguous of the emotions explored so far, surprise presented the biggest challenge for a coherent representation. Additionally, the experience of surprise is often extremely visceral where there is an implied temporality and state of change – where once a person is calm, they are then shocked by the onset of a new experience. This temporal transition or sense of sudden change was the key feature in the design with the central aesthetic motif explored being that of an explosion or outburst. The modernist artist Paul Klee explored the visual idea of growth and energy through radiating concentric circles, increasing in size or lines moving from a central point to an outpoint point (Munari, 1960/2015) With a shape that looks something like a star in the centre (itself a culturally important motif, especially in Islamic decoration), the surrounding forms create the visual illusion that they are exploding away from this centre. This motif is repeated with a small variation and is then intersected with the other to create the overall pattern effect. The pattern uses multiaxial symmetry and was constructed to be aesthetically busy, reminiscent of the illusions explored by the Gestalt theorists, to create feelings counter to calmness. A mixture of both curvature and angularity was used in its geometric creation to enhance the ambiguity of the pattern.

4.7 Summary

This section presented work in experimental aesthetics by developing a set of bespoke pattern designs through a process of interpretivist pattern analysis. In a set of two experiments, key aesthetic elements within pattern configurations were identified as emotionally and semantically resonant. These motifs were then assessed with respect to aesthetic and psychological theory and were used as a basis to design a set of bespoke 'emotive patterns'. A justification for each design - named trust, joy, fear and surprise after the emotion that most inspired it - was set out as guided by experimental aesthetics scholarship, Gestalt principles and art-historical analyses.

But how can this be linked to object materiality and textility? In design method terms, the development of the pattern designs was driven by a human-factors approach to aesthetics and presents a significant challenge to the orthodox linear ontologies of emergence. The next section of the work will further explore these questions of design and emotional experience and the fundamentals of object materiality and form emergence.

5. Patterning through material

The flatness of today's standard construction is strengthened by a weakened sense of materiality

- Juhani Pallasma

This chapter will consider how technological processes create the material basis of objects with the overall aim to bring concepts within Kansei engineering, design for emotion and materiality together with advanced production methods, creating not just new psychological experiences but new modes of object materiality. Pattern will be used as the principal medium to do this being both the output of and the critical input to processes of making, as explored in the previous chapter. Focusing on advanced fabrication processes, with a direct emphasis on modern industrial machining operation this chapter will explore the experiential facets of artefact interaction through the lens of machining protocol. The chapter is split into three sections. Starting with an introductory section where the concept of 'advanced' manufacturing is explored both as a technical and cultural phenomenon. This will be followed by an examination of standard machining operation and a review of the state-of-the-art developments within the technological area. Lastly, machining is examined by which a two-dimensional concept can become material and achieve a kind of physicality and material embodiment. The implications of this, how it relates to pattern and materiality at large are considered. This chapter also reveals how patterning is a core concept in the structuring of computer-aided manufacturing systems (CAM) adding weight to the principle that abstract perceptual experiences can be elicited from pattern formations deployed at a macro process level and a micro symbolic level.

5.1 'Advanced manufacturing' – a working definition

Much of the discussion so far has spoken of *making* as a form-giving activity that, in Ingold's (2008; 2010; 2012) view, is a manipulation of energy and flows of material that interact continuously with human life. What has not been discussed so far are the processes that constitute making or modes of production. Much of the work in material culture studies has tended to focus on craft, craftspeople, or artisans with little regard for industrial scale production – the production that tangibly affects most people's lives and creates most of the world's products. This introduces a question; at what point does a piece of craft become an industrially produced artefact? The issue being that, despite the rational flattening of materiality that was described earlier, industrial machinery is still a distinct mode of *human* making. While it may be somewhat attenuated, the imprint of the process is still interwoven through the material and is evidenced through its form. Unlike craft, modern manufacturing is intensely reliant on automated machine robots, though this does not mean that object materiality should necessarily be lost. In order to understand this problem, a working definition of advanced modern manufacturing must be refined and from there we can explore what modes of manufacturing can be explored within the confines of this work. In order to maximise the value of the research, it was proposed to focus on processes that are or can be readily used by practising designers and manufacturers.

5.1.1 Numerical control and automation

Todd, Allen and Alting (1994) provided a useful taxonomy of manufacturing that included a set of broad categories such as mass reducing processes or mass conserving processes. While a useful tool for categorising different processes, it does little to fully explain what constitutes an 'advanced' process or 'advanced manufacturing technology' (AMT). Several definitions for AMT have been proposed coming from different perspectives. Some such as Nambiar (2010), in a comparison of different manufacturing paradigms, argues that the success of a process should be seen within a larger framework of quality measurement, lead times and flexibility (amongst other factors). Zammuto and O'Connor (1992) define AMT as a socio-technical system that is heavily reliant on organizational culture. Others take a narrower, technology focused, view where a particular process might be 'innovative' or is in some sense pushing the limits of traditional approaches. Most however point to processes that have been integrated with computing technology and systems of automation that fundamentally differentiate them from more traditional methods. In work from Baldwin and Diverty (1995), AMT is defined as 'a group of hardware-based and software-based technologies, which if properly implemented, monitored and evaluated will lead to improved efficiency and effectiveness of the firm in manufacturing a product' (p.40). More specifically, Small and Chen (1995) classified AMT into five groups: design and engineering technologies; fabrication, machining, and assembly technologies; automated material handling technologies; automated inspection and testing systems; and information technologies. A similar classification of AMT is provided by Percival and Cozzarin (2010) who include other themes such as process integration and control. Notably, many contemporary definitions are beginning to integrate concepts from so-called 'Industry 4.0' and include intelligent feedback systems and information exchange between machines within the frameworks of understanding AMT (Preuveneers & Ilie-Zudor, 2017; Wang, 2019).

Overall, the culture around AMT puts computer integration as one of its primary markers. While some have discussed social and economic factors, there is widespread consensus that an *advanced* process is in some way informed by the input of computers and in turn, forms of automation and process control. Indeed, statistics regarding technological use and uptake show that processes deemed 'advanced' have dramatically risen in the last decade or so with similar uptake of emerging smart systems such as smart manufacturing and smart production associated with Industry 4.0 (Brocal et al., 2017). This work is interested in how notions of user-experience and materiality can influence AMT and protocol for advanced methods of production. With respect to this, it is possible to narrow our focus and explore one distinct family of advanced manufacturing, namely, design and engineering. Goyal and Grover (2012) for example point to a set of design and engineering technologies that are associated with advanced methods of production; *computer-aided design (CAD), computer-aided manufacturing (CAM)* and *computer-aided process planning.* Percival and Cozzarin, (2010) also agree with this formulation but incorporate modern modelling and simulation technologies as well as the physical exchange of geometric data in the form of CAD files. Additionally, work by Youssef (1992) frames numerical control and programmable automation as a key component in AMT and notes how the percentages of use within industry have steadily increased.

It is possible to build from this literature and the observed cultural trends within industry a useful working definition of advanced manufacturing technology that can be taken further. Our working definition, within the narrowed working space of design and engineering can be *any mode of production incorporating CAD, numeric control (CNC), CAM, process simulation and programmable automation.* A process of making incorporating more than one of these elements may necessarily be viewed as more advanced due to fundamental increases in data and computational energy associated.

5.1.2 Focusing on advanced machining processes

At this point, it is also possible to narrow the scope of focus and consider processes that can be considered technologically *advanced* more closely. With respect to practising designers, CAD technology, CNC technology and automation (when manufacturing is required) all have tangible benefits and are widely used within industrial design and engineering. In terms of manufacturing specifically, Wang (2019) has studied the economic dynamics of various types of manufacturing noting sharp drops in the price of subtractive approaches and particularly formative approaches. The relative cost of additive approaches has remained approximately level, currently significantly more expensive on average than other types of manufacturing to produce the same number of parts. For this reason, additive remains a restrictive technology for high-quality manufacture and machining remains attractive.

From the point of view of practising designers formative manufacturing approaches are arguably the least accessible but also the least reliant on the kinds of advanced technologies that have been discussed this far. From the point of view of accessibility, we can more narrowly focus on subtractive processes deemed as advanced – integrating types of CAD, CNC, CAM, and automation. The family of processes that best fits this niche, and a process which is widely used in modern product manufacturing is numerically controlled machining. Additionally, there is more access to advanced subtractive machining technologies (Wang, 2019), and from an economic point of view, the technologies are currently superior as costs of part production steadily falls after initial design and equipment costs. On these bases, numerically controlled machining processes will be focused on given they have the most relevance to the practising designer or manufacturer and its suitability for the creation of localised detailed features (such as stylised ornamentation or texturing). It should be noted at this point that a full review of different machining approaches was conducted encompassing technologies with and without numerical control and forms of automation. This can be found in Appendix 11.3 but from here, the discussion will be oriented around technologies with capabilities in computer-numeric-control which satisfy the established definitions of advanced processes and AMT established earlier.

Modern machining encompasses a range of technologies and approaches. Three types of machining process were identified for further review: milling, electrical discharge machining and ultrasonic machining. There are many variations of each type of process and a variety of machine designs, but these are discussed here as more general categories and not a specification of a singular machine or process variety. Ultimately, this work aims to explore one kind of machining process, to establish this, each type of process was reviewed against a set of criteria deemed important for technological applicability: applications, geometric range, costs, and material range. A summary is provided in Table 8.

Table 8 – Description of different modern machining approaches

MILLING	
Description	Rotary cutting by machining tools (typically end mills, ball nose cutters and side/face cutters) remove material to form desired shape. Modern milling machines use advanced mechanical and robotic designs to position the path of the cutting tools
Applications	Wide range of applications; machined parts are used in aerospace, automotive and other large-scale industrial applications. Smaller scale applications include consumer electronics, furniture, clothing, and jewellery
Geometric range	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling equipment and path. Angled edges may be impossible to produce due to intrinsic geometry. CAM technology is required to simulate tool paths before production
Costs	Costs range from very cheap to very expensive. Function of the tooling requirements and material usage

Material range	Excellent material range: virtually any material can be used that has a suitable hardness and is not prone to fracturing under strain (wood, plastics, metals, alloys)

ELECTRICAL DISCHARGE MACHINING (EDM)

Description	Material is removed by a process of electrical discharges (sparks); Rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. Process is 'unconventional' as it is not based on removal by mechanical forces.
Applications	Applications are limited; commonly used within the die and mold-making industries. Also used in producing dies for coinage and jewellery, and small hole drilling where tapered holes can be produced
Geometric range	Geometric capability is excellent as the process is not constrained by the geometry of tooling. Very complex shapes and very fine holes can be produced
Costs	Costs are generally very high when using this process; expertise can be difficult to source; material removal rate is slow and overhead costs are high
Material range	Good material range – limited to metals because the workpiece must be conductive. Virtually all metals, alloys and super-alloys can be used including steel, aluminium, and brass

ULTRASONIC MACHINING (UM)

Description	Material is removed through high frequency, low amplitude vibrations of the tool against the workpiece in the presence of fine abrasive particles. Two typical types of ultrasonic machining – rotary and chemical-assisted
Applications	Often used to machine more brittle materials that may be more sensitive than other machining metals. Process is often applied in electronics and optics production. Its high tolerances mean it can be used for important structural components
Geometric range	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling

	equipment and path. Angled edges may be impossible to produce due to intrinsic geometry. CAM technology is required to simulate tool paths before production
Costs	Costs are generally very high when using this process; tolerances are very high; material removal rate is slow and material limitations can cause difficulties in the process
Material range	Good material range: the process is not limited to the intrinsic conductive properties of the material, but it is preferable to use a material with low ductility. Hardness of the material used must be above 45 HCR (Rockwell hardness); ceramics, carbides, glass, precious stones, hardened steels

Following this general review, several technical, economic, and material constraints can be established. From the point of view of machine sophistication and geometric capability, EDM is the superior process considering it can form complex shapes and is not constrained by the shape of a tool. By contrast Milling and UM are constrained by intrinsic tool geometry. From a material range perspective, milling and UM are superior although UM is limited by a minimum material hardness, discounting some materials that can be formed using more conventional milling methods. Costs are not simple to measure as they can vary depending on material uses, part complexity and tooling requirements. On a general level however, EDM and UG are considerably more expensive than most milling operations due to machining tolerances, energy consumption and externalities such as required expertise. Many milling operations can be completed with limited professional expertise and there exists a huge range of milling machine options from micro-engravers to large 5-axis machines. Accessibility is also a factor; milling machines are much more readily accessible than UM machines or EDM machines given their more technical operation and application range. This makes milling a more attractive set of processes to examine further. Moreover, practising designers are more likely to use milling technology given its relative ease of access, its material range, its geometric range and its application range. Some forms of milling utilising 5 or 7 axis geometric capability can incur significant costs due to factors such as programming expertise and equipment and may only be used for specialist engineering applications such as aerospace componentry. Many 3-axis CNC mills are however widely used for professional design work providing both advanced geometric command, process automation and superior part quality in many cases. It is for this reason that the work will be focused in this domain; deemed to have the largest impact and most relevance for people working within the design industry. It is however hoped that the findings of this work will have a more general applicability across the entire range of machining processes and beyond to other advanced manufacturing processes and technologies.

5.2 General principles of milling

At this point, having established a focus for further investigation based on a set of criteria, we can talk more precisely about machine milling. More specifically this section will discuss the principles of machine milling and of numerical control and then discuss recent research into machining operation.

5.2.1 Principles of machining operations

Different forms of machining operation have been used since antiquity, but it has only become a widely used process with the advent of industrialisation. Woodbury (1960) states that the first true milling machines came into use between 1814 and 1818 with a number of critical developments in machine control throughout the 19th century. Pre-automation, the machines were controlled and positioned through forms of mechanical 'indexing' using cogs though this process could be prone to dimensional inaccuracies. Numeric control of manufacturing operations was first developed in the 1940's and subsequently applied to machining operations. In addition to this, the introduction of computer-based 3D modelling techniques, generally referred to as 'computer-aided design' or 'drafting' – CAD - allowed for new numerical control to be introduced into the machines. Over the course of the twentieth century, the capability of CAD and the subsequently developed 'computer-aided manufacturing' (CAM) technology advanced massively giving numerical control a new power. Numerical control that is reliant on computer systems (CNC) uses Cartesian geometric coordinates to position cutting tools relative to a workpiece and in most cases CAM technology communicates to the milling machine to perform an operation in a specifically defined special location (Madison 1996).

Much of the geometric capability of a CNC milling machine comes from its axial design which can get extremely advanced depending on the scale and cost of the machine.

Generally, there are three commonly used configurations - 3-axis, 4-axis and 5-axis - though there are others such as 7-axis machines which have been mentioned. More geometric options such as overhangs are possible with the higher axis machines as they, by definition, have more degrees of freedom by which to articulate toolpath movements and to orient cutting tools. The milling process itself is one of non-abrasive material subtraction relying on advanced cutting tools (Mair, 2019), often treated using advanced surface engineering. The central principle is to create material chip formation, either continuous or discontinuous, as the material is removed. Cutting tools, following computer commands, are guided to a position defined by a specific Cartesian X, Y, Z point and use closed-loop control systems that provide feedback both of tool location and tool operation speeds (Madison 1996). The key mechanical considerations include *tool cutting speeds and feed rates ('feeds and speeds'), tool path strategies, tool wear, properties of work material* and *cutting configurations.*

In terms of machine configuration, there are many kinds of milling machine, but these can generally be classed in two main categories - *horizontal milling* and *vertical milling.* The definitions are defined by the orientation of the spindle axis relative to the workpiece. While essentially using the same principles of geometric control, some orientations are favoured depending on what is being made. A typical schematic for a vertical CNC milling machine is shown at Figure 46 below.

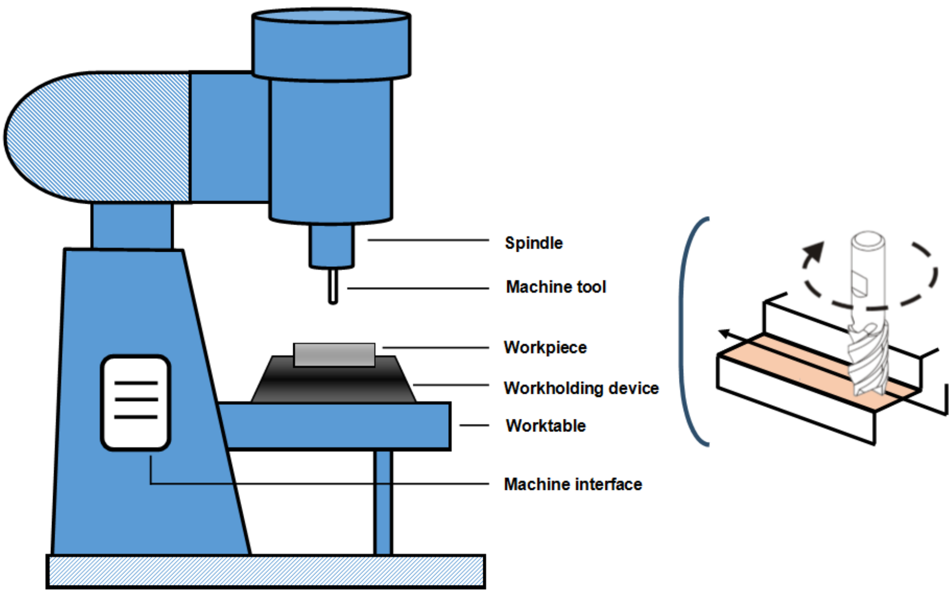


Figure 46 – Vertical mill schematic with cutting principal detail

5.2.2 Cutting tools and toolpaths

Perhaps the most fundamental aspect of the overall process comes from the properties associated with the cutting tools. Mair (2019) has referred to machining as a process of cutting material in a definition more specific than 'material subtraction'. The process of cutting is achieved through the use of cutting tools which can vary hugely in design depending on the manufacturing requirements. Consequently, the process of choosing cutting tools is complex. The cutting tool consists of several fundamental parts or elements; *shape, flutes and teeth, helix angle and the shank* being the most fundamental (Figure 47). Flutes and teeth, mechanically, act in unison – as the teeth cut into the material, the flute creates a path for material removal. Typically, there is one tooth per flute, but variations do exist, sometimes doubling the number of teeth per flute. The flute geometry is almost always that of a helix, this is done to reduce tool vibration and improve surface finish and dimensional accuracy of the cut.

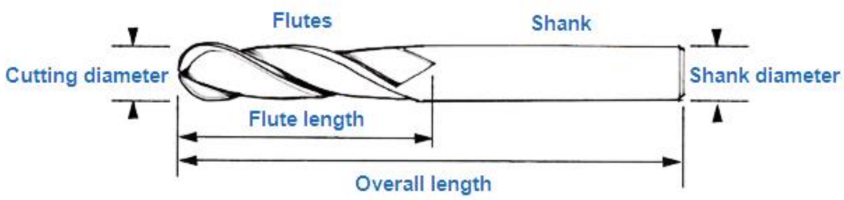


Figure 47 – Diagram of ball nose cutting tool

Different cutter shapes achieve different cutting geometries. The various types of cutters include end mills (flat faced cutter), ball end mills (ball nose) and threading mills amongst many others. End mills and ball nose mills are some of the most widely used with a hugely diverse number of designs. For face milling operations and other operations where a flat surface is desirable, end mills are used. Figure 48 illustrates a pocketing operation using an end mill (A) and a facing operation (B). For operations that involve more complex geometry such as small fillets or freeform surfaces ball nose cutter are more desirable but perfectly flat surfaces are impossible to create with this type of tool.

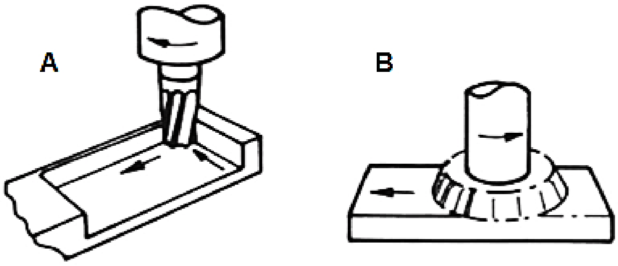


Figure 48 – A) End milling schematic B) Face milling schematic, adapted from Mair (2019)

Machine tool cutters move in a pre-programmed path as they rotate and interact with the work material – this is called the *toolpath*. Toolpaths are important and are the subject of much study in machining research some of which will be explored in the sections to come. The toolpath relates to several important elements such as the efficiency of the machining job and the resultant surface finish each of which can be affected by changes in strategy. Typically, toolpaths can be categorised as two-dimensional, three-dimensional, 4-axis, 5-axis and so on. The complexity of a toolpath strategy depends on the surface being created and what surface finish is desired. Many kinds of toolpaths can be programmed but the most widely used are the *trichodial* strategies most commonly used in face milling, varieties of parallel and 'zig-zag' milling strategies, contour-based strategies and strategies following curvilinear or radial paths (Figure 49). Multiple strategies may be applied within a single job. The feed rate and the radial speed (rpms) of the milling cutter combine with a programmed toolpath strategy to carry out the milling operation. Critically, the feed rate, cutting speed and depth of cut have a major influence on the quality of the cut (Kumar & Dvivedi, 2019) as well as the determined *stepover*. The stepover is an extremely important element for the resultant surface finish including the aesthetic and textural properties of the surface and is a paramount consideration when using ball nose cutting tools. Stepover is defined as the distance from the tool centres between two cutting passes. A larger stepover can decrease machine time but will reduce surface smoothness. Finishing passes typically will have very small stepovers in order to achieve a high degree of surface smoothness. Figure 49 below illustrates the stepover principle – if each circle represents a separate parallel cutting pass, the resultant surface takes on the smoothness of the defined stepover. The small grooves that are created are known as *scallops*. Scallops and other trichodial machining marks are the fundamental imprint or trace this process leaves on a material after cutting – the ductus of the process. This will be explored in more detail later when the relationship between stepover and surface properties are examined further.

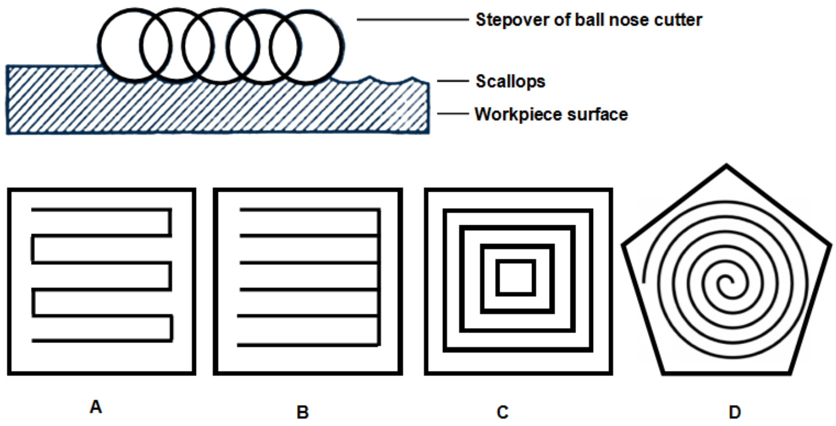


Figure 49 – The effects of tool stepover and toolpath variations; A) Zig-zag path B) Zig path C) Contour-parallel path D) Curvilinear spiral path

5.2.3 Geometric control

The geometric capabilities of CNC milling machines have been the subject of much engineering research over the past fifty years. Now that CAD technologies are used ubiquitously across the design and engineering world, a lot of the work has been focusing on fully integrating CAD systems with CNC machining tools to a good deal of success. In contemporary manufacturing, the most widely used system of numeric control is G-code which was first developed in the 1950s. G-code is a programmable language that uses defined commands and location coordinates to instruct a machine tool – specifically, it defines the location of the spindle holding a cutting tool. The geometric information taken together defines the toolpath strategy and which machining operations to carry out at which point. One of the challenges that remain is the machining of 'freeform' surfaces. Freeform surfaces are generally defined as techniques used in 3D computer modelling and are represented using parametric curved surfaces such as Bezier surfaces and NURBS (non-uniform rational B-spline) surfaces (Hughes et al., 2005). At this point, we can move on to examine some of the more advanced machining principles and consider how these can be taken forward within the context of this work.

5.3 Advanced machining principles

The scope of machining technology has advanced in its recent history. Since its integration with CNC and CAM technology, the process and process mechanics have been subject to new frontiers of investigation using both empirical and simulation-based approaches. Additionally, new frontiers in CAD technology, coinciding with CNC and CAM developments have further pushed the limits of machining technology, the most notable example of this being the creation of freeform surfaces.

5.3.1 Freeform surfaces and advanced toolpath strategies

Freeform surfaces are used within CAD packages to describe geometric elements that cannot be defined as a piece of linear or rational geometry (cube, cylinder, cone etc.) (Farin, 1997). Several problems exist when trying to machine these types of geometries, one of the most fundamental are gouging errors at the cutter contact point. These are errors in toolpath generation and more specifically in the path topology selection and the path parameter selection (Choi & Jerard 1998). The important point is that these can have serious repercussions in terms of surface geometry construction and quality. Lasemi and others (2010) developed three different tool path topologies that were successful in subtracting a freeform surface from the workpiece – *directional parallel topology, contour parallel topology and adaptive curvilinear space filling curve topology*. The paths are generated with reference to a triangular polyhedral surface derived from CAD data. Each method has advantages and drawbacks, but the space filling curve topology was shown to have some of the best geometric capabilities. Work by Ramos and others (2003) studied the textures of freeform machined surfaces by comparing different finishing techniques. The practical analysis consisted of the construction of a piece of complex geometry with concave and convex surfaces from an aluminium alloy – a fan blade. Three surface finishing methods were studied: radial, raster and 3D-offset. From a sample of 233 measurement points, it was established that the 3D offset strategy showed the least dimensional variation with 76% achieving no dimensional deviation (Ramos et al., 2003). A similar optimisation for 5-axis machines has been presented by Wagner et al. (2015).

Another study by Lavernhe and others (2008) focused upon surface topography in ball end milling and examined the surface roughness parameters for machining freeform

3D surfaces. The researchers conducted an experiment to determine surface patterning on concave, context and tight regions of a machined automotive die consisting of freeform surfaces. Using a defined set of cutting conditions, the experimental data showed that surface roughness (μm) was highest (12.4 μm) in the convex region of measurement and lowest in the concave (8.45 μm) (Quinsat et al. 2008). Notably this work is on the micro-scale, however it is possible to logically extrapolate that similar results may be seen at the macro-scale, so could conceivably be applied to machining parameters in the production of consumer products with metal components.

Since the turn of the twentieth century, many research efforts have taken a serious interest in toolpath topologies with a view to enhanced control and machining optimization (Held, 1991). Park and Choi (2000) for example developed a planning algorithm for parallel milling to solve toolpath linking errors when machining complex surfaces. Kim and Choi (2002) investigated the machining efficiency of contour-based versus parallel based toolpath strategies. In a series of detailed simulation-based experiments considering tool feed rates and toolpath intervals, it was found that a smooth zig-zag approach was the most favoured in terms of time efficiency. Curvilinear approaches have been explored by Bieterman and Sandstrom (2003) who investigated it in the context of pocket milling. Their work concluded that a novel curvilinear approach, not only enhanced the geometric outcome but in some cases reduced machining time by as much as 30%. More recent work has explored toolpath approaches for free-form surfaces. Takasugi and Asakawa (2018) developed a method to reduce feature data loss when parametric CAD data is interpreted, and toolpaths are generated. Their approach involved the generation of spiral toolpaths that optimised cutter contact with the workpieces. The approach was tested through simulation followed by part production. A similar study by Patel, Patel and Saladi (2018) considered how toolpath variation would affect the finish of 'sculpted surfaces'. These surfaces – essentially free-form geometrically – were subject to machining simulation. The researchers concluded that the tested spiral strategies created better surface finishes due to a reduction in scallop height during the cut. A similar conclusion was reached by Shchurov and Al-Taie (2017) who developed an approach for achieving uniform scallop height in 3-axis milling with ball-nose cutters. In other studies, Fountas et al.

(2019) have also explored toolpath from the perspective of optimisation while Masood and others (2015) investigated toolpath generation form point cloud geometric data.

5.3.2 Minimising defects

Defects are part of any manufacturing process and understanding them can have many positive implications of quality of part production and production efficiency for instance. While the focus of this work is not about the defects that can arise from the machining process, of which there are many, it is important to consider some of the recent work in defect minimisation to better grasp the complexities of machining as a whole. Many errors are the result of fundamental mechanical errors and not from toolpath programming problems. The most typical errors for machining operations are associated with mechanical tool wear and machine-tool dynamics such as chattering (Mair, 2019). The most common types of tool wear are forms of *flank wear, crater wear and built-up edge.* By far the most common are forms of built-up edge which is caused by material particulate coagulating on the cutting edge of the tool and seizing to its surface (Rao, 2014). This can subsequently decrease surface quality and dimensional control.

A large amount of research has historically focused on the reduction of chatter which is a self-exciting vibration between the tool and the workpiece. In a detailed review, Quintana and Ciurana (2011) detail that numerous defects including poor surface quality, geometric inaccuracies, noise, reduced material removal rates and increased costs associated with production time. While the amount of work focusing on chatter problems has been increasing steadily, there still exist problems in terms of mathematically modelling chatter dynamics and hence accurate simulation of the effects has proved elusive. At the level of micro-machining, some results in chatter suppression and stabilisation have proved positive (Park & Rahnama, 2010) with other successfully modelling the influence of cutting-edge geometry on chatter vibrations (Biermann & Baschin, 2009). A recent review by Munoa and others (2016) has suggested a range of avoidance techniques including dampening technologies and spindle speed variation for a wide selection of metal cutting processes. Aguado and others (2016) presented a method using laser tracking to detect geometric errors indirectly – an approach that is growing in popularity.

5.3.3 Milling uses in contemporary manufacturing

The use of milling in contemporary manufacturing is widespread as access to the requisite equipment is relatively easy and 'hobbyist' variations of the technologies have become more widely used. While their use in the craft sector is important, the central applications for machining technologies lie in technical componentry for the aerospace, automotive and energy sectors. The Correa machining company for example has specialised in creating light-weight aerospace parts and other structural elements for aeroplanes. Large turbines for energy sector applications are also produced using advanced 5-axis machining techniques. Another notable application is the creation of dies and molds for a wide variety of product types.

From a more commercial angle, machining has been used extensively in personal computing and smart phone embodiment notably by Apple. To create the casings for the Macbook family of laptops, machining technology is utilised creating a unique visual and material quality. Furthermore, Apple have used machining technology to create the casings for many of their iPhone models in a striking departure from the trend towards modular plastic casings of other contemporary manufacturers.

From the perspective of more craft based or artesian practices, machining has been widely adopted for the creation of various products. For example, there is now a trend amongst jewellery designers and makers to incorporate milling techniques into the production processes. Most typically, machining is used as an effective and reliable method for detailed engraving. Engraving, as a process, has its own complex history that is deeply embedded in traditional craft practices, and it is now commonplace for jewellers to employ micro-milling techniques to personalise pieces of jewellery design. A similar trend in machining-based engraving can be identified in furniture design where tabletops may be embellished with forms of personalised ornamentation. As machining is a versatile process with a large material range it has been widely utilised for sculpting and embellishing wood, other dense fibre-based materials and even plastics with a sufficiently low brittleness. The creation of entire building sections has also been achieved using machining methods specialised in forming stone. Breton for example, a milling services company based in the UK, has demonstrated the production of ornate building sections for use in architectural restoration with its ShapeMill NCF 1600 and 2000 machines (Figure 50).

Figure 50 – Breton ShapeMill machining a stone column[18]

5.3.4 Milling qualities and material experience

From these examples, it is clear that numerically controlled machining has a great relevance in contemporary manufacturing and design. These forms of modern manufacturing technology offer new paradigms for the exploration and creation of form and hence, emotive experiences for users drawn from visual and material interaction. The previous chapters have explored how form is one of the critical aspects for a discrete aesthetic experience and how materiality also contributes to tactile interaction and the semantic framing of objects. At this stage we can consider how the process of machining might contribute to an overall material experience. It has been previously stated that the *ductus* of the machining process – the traces left from the process' interaction with a material, the 'map' into the process of making in Ingold's (2008) terminology – are the marks left by the cutting tools. As discussed in chapter 1, work by Karana et al. (2010) and the important studies by Ashby and Johnson (2002) has drawn attention to the importance of material experiences and the textural qualities of products that contribute to meaningful emotive experiences. This chapter so far has explored machining technology and the culture around advanced manufacturing, much of which is oriented around minimising defects and maximising

[18] Source: Still from video, Sergio Prior via YouTube: Breton ShapeMill

efficiency and dimensional accuracy. There does exist a counter current that is interested in exploring milling processes in new ways. The notable lack of academic interest in these approaches represents a significant gap in knowledge.

Some of the best examples of unorthodox machining use comes from the worlds of interior design, furniture, and art. The Mexican American sculptor Robert Graham for example has explored the use of 5-axis CNC milling to create sculptures of human forms. His work lies at this junction between craft-based practice and machine-based technical practice. Indeed, Graham views machining tools as an extension of the human hand and has explored toolpath variations as a means of artistic expression and styling. One piece was created to reflect the style of the French sculptor Auguste Rodin whereby the toolpath was edited in order to create this complex aesthetic (Eberhard, 2003). Graham uses CNC milling technology to advance his artistic explorations, liberally exploring changes in toolpath, mill bits and cutting depths that ultimately create a distinctive set of lines and patterns on the surface of the material.

Similarly, the architect and designer William Massie used milling to not only achieve a functional goal but also to explore materiality and Form. Massie's approach to building and making is one of utilising technology and computing power to explore what is possible within a space. His project in Montana known as the 'Big Belt House' made explicit use of CNC milling with the design of the concrete sink (Figure 51). The mold that created the sink was shaped using 3-axis milling technology. Massie noticed that the Form it would take would perfectly describe its process of creation – representing how the material had been shaped by a tool. While achieving a functional goal, the piece also reflects materials and process. Its direct use of advanced machining technology to achieve this innovative kind of material ornamentation has led one scholar to state that the ridges left from the machining process are a 'new ornament of 21st century technology' (Eberhard, 2003, p.25).

Figure 51 – Concrete sink created by William Massie using 3-axis CNC milling[19]

These examples help us recognise the interesting aesthetic and material effects that can be achieved by exploring the CNC milling process more openly. Instead of looking to explore process efficiency, there exists a substantial gap in establishing the aesthetic and textural qualities of distinct process parameters such as toolpath strategies and cutter geometry. Throughout this work so far, the motif of the *line* has been important, representing an element of form and shape, an embodiment of visual energy and even culturally bounded semantic ideas. Is it possible to explore how the trace of the machining process, the lines produced from material-tool interaction affect a user experience and aesthetic preferences? And can this be differentiated from a more general form experience? These are the questions that the next phase of the work will explore. It has been demonstrated that pattern based on abstract shapes can coherently represent emotion concepts with some visual motifs being closely related to emotional concepts. With this data and the two studies focused on lines presented across chapter 3, a number of bespoke 'emotive patterns' were created. The principles of computer-aided design and manufacturing facilitate the production of 3D objects, giving a physicality to a conceptual design. The reframing of CNC milling as a potential means of new creative and artistic expression or as a means of product customisation is something that has been developed by a number of professional artists and architects as projects of subjective design exploration. We can now explore this reframing in more detail by taking the pattern designs into a physical textural space utilising these modern manufacturing technologies.

[19] Source: Richard Hammond via Pintrest: William Massie concrete sink

5.4 Creating pattern-based textures

Section 4.6 described the creation of bespoke emotive patterns that were configured to signify or embody emotive concepts. With the four patterns that were designed, it is now possible to describe a process of transformation where the two-dimensional design is translated into three-dimensional objects. Pattern lends itself to the creation of texture quite readily as pattern configurations are bound up in *positive and negative space.* Pattern can effectively be viewed as a contrast between sections of positive space against sections of negative space. Accordingly, the geometry of the pattern can either become the positive space of the texture or its negative space and this is achieved through a process of form subtraction or form extrusion (in CAD terms). The concept of positive and negative space more generally is complex and is determined by how a person sees a subject within a broader aesthetic or composition, a point made by the Gestalt theorists in their analysis of optical illusions. Outside of the Western traditions for instance, the concept of '*Ma'* is used in Japanese art to describe the use of spaces or gaps that gives meaning to works of art, hence one use of positive and negative space may have a completely different effect to its inverted use. After some consideration, it was decided that the positive space of the pattern – the discrete shapes that create the overall effect – would be the subtracted elements, leaving the negative space raised to create the texture upon the surface. Interestingly, Anusas (2020) has cited surfaces as a key interface where design articulates with the processes of forming material and has described design fundamentally as a 'surficial practice' (Chapter 11). These surfaces allow us to interface and interact with the conceptual architecture of design processes but also with the world of materials and forces in which we are intertwined. Thus, the process of creating a pattern-based textured surface was split into several phases: 1) development of CAD models giving a physical basis to the pattern designs, 2) machine simulation and exploration of machining protocol, 3) equipment procurement and machine setup, 4) machining operation and part creation. Each phase will be discussed in turn in the sections to follow.

5.4.1 Development of CAD models

The main tool used for the translation was the CAD software SolidWorks, the process of which can be split into two critical steps: shape drawing and patterning. Firstly, the geometry of the designs had to be drawn as closely as possible within the drawing package. This took some time as, despite being abstract design, some of the features were quite detailed. Figure 52 shows the drawing of the discrete elements that created the ‘fear’ pattern. The symmetry operations within the CAD package aided the creation significantly

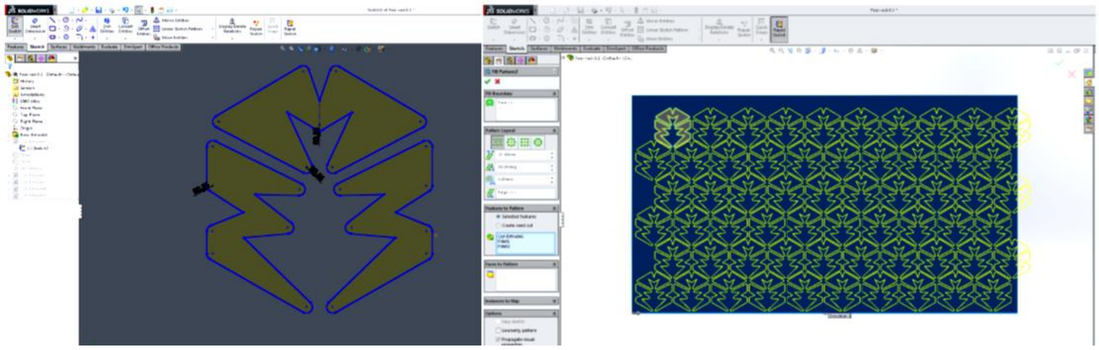


Figure 52 - Drawing of discrete shape elements (left) and generation of uniform 3D pattern (right)

Following the drawing of the geometric elements, these could then be subtracted from the surface using the ‘extruded cut’ function. Despite the control that is afforded by numerically controlled milling, there are a number of constraints that must be accounted for in the initial designs. Firstly, is the impossibility to create interior corners. Within a given cutting space, the geometry of corners must be at least as large as the diameter of the cutting tool. Drawing attention to Figure 52 once more, the highlighted geometry has deliberately been designed with small corners to comply with this rule. Once this critical constraint had been addressed, the three-dimensional uniform pattern could be generated across the whole plane. Essentially, only a small portion of the overall pattern was drawn as the shapes could then be repeated uniformly across the sketch plane using the SolidWorks patterning function – this is shown to the right of Figure 52 and the complete pattern shown below in Figure 53.

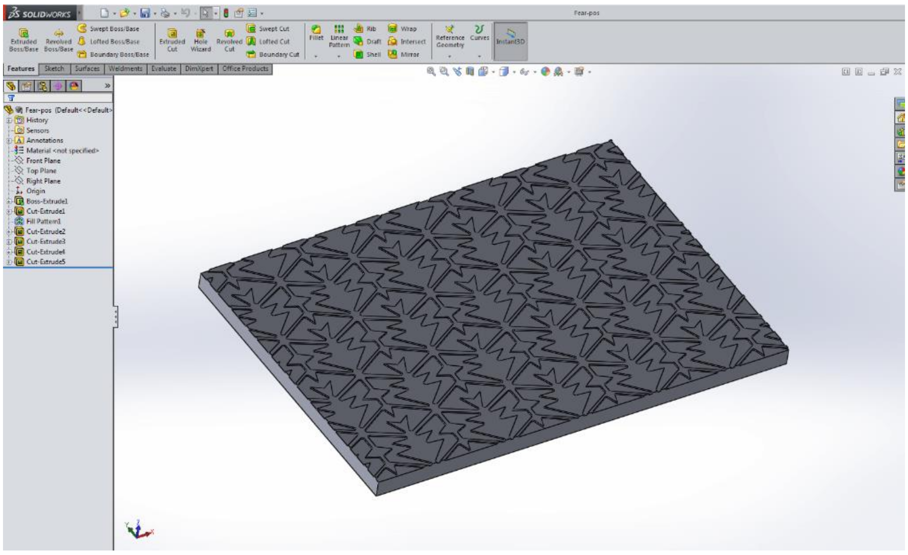


Figure 53 – Final pattern-based texture after uniform patterning function

5.4.2 Machining simulation and process protocol

Following the successful creation of the CAD components, CAM based simulation could take place. The purpose of CAM is to explore different strategies and protocol for a manufacturing process facilitated by computer data. Typically, CAD data is used combined with simulation software – the CAD data allowing for geometric representations and visualizations of processes. In this case, machining simulations using CAM software was carried out to explore a number of process parameters that could be examined further in terms of their effects on aesthetics and materiality. EdgeCAM was used to carry out the simulations, with each texture design subject to simulation efforts. EdgeCAM is a fully featured CAM software and allows for a diverse range of technical analytics. The software will also create a visualisation of the milling machine (the virtual machine), the clamp and the workpiece. The virtual milling machine was aligned to available equipment, a 3-axis milling machine, the Haas TM2 vertical mill. The simulation configuration is shown below in Figure 54.

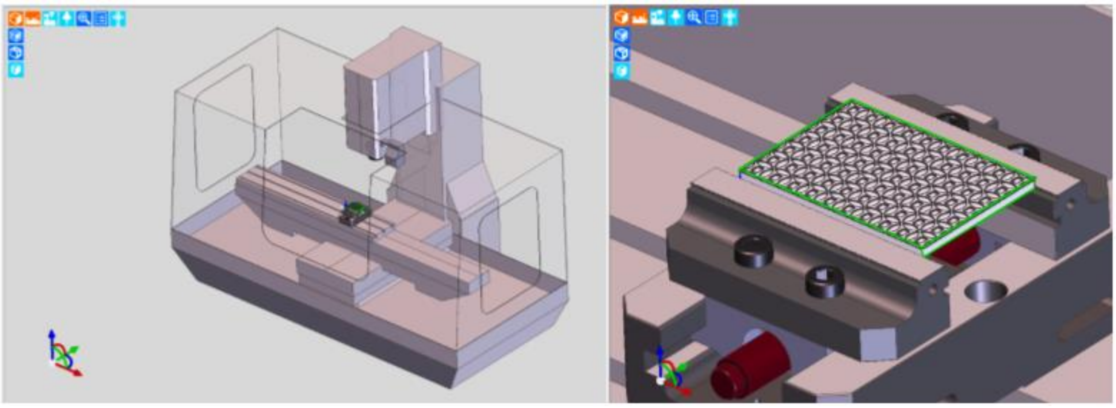


Figure 54 – EdgeCAM simulation setup showing virtual machine, clamp and component

Following this setup of the simulation, several parameters could be explored. With respect to the earlier discussion on the fundamentals of machining and the arguments around the physical traces of process - the processes *ductus* - toolpath strategy parameters were considered as the best areas from which to launch an analytical simulation. EdgeCAM facilitates dynamic simulation of toolpath strategies, allowing the user to edit factors such as the angle of cut and stepovers. There were some initial problems with the simulations when a ‘Parallel Lace’ (bi-directional zigzag) strategy was attempted. It was discovered that to work effectively, this strategy requires curvilinear geometry implicit within the SolidWorks CAD model. This was corrected accordingly by adding fillets to the features of the texture and from here, the simulations could progress as normal.

It was clear from the EdgeCAM visualisations that small edits in toolpath strategy would have a significant impact on the overall aesthetic of the object. While the granularity of these visual renderings is imperfect, they still provided some insight into what to expect from a physical build. The principal parameters that were explored with respect to toolpath strategy were the *stepover size* and the *cutting approach angle*. Due to the scale of the components and the type of machining strategy, 1 mm diameter cutter size of a ball nose geometry were used in the simulations allowing for the creation of small-scale detailing. The set of images shown in Figure 55 illustrates the general process for developing a simulation within EdgeCAM. Firstly, the top image shows how the process parameters can be edited. The Parallel Lace strategy was used as it is specialised for creating freeform or curvilinear surfaces in a continuous path dynamic. This kind of strategy does not identify particular features within the CAD data but treats the whole surface as one geometric feature and programmes accordingly. Changes in stepover could be applied to change the resultant surface finish – a small stepover would achieve a smoother surface but would in turn increase machining time, larger stepovers would create a rougher finish. From the simulations it was established that a stepover of between 0.15 mm and 0.3 mm could both create an acceptable finish and allow the traces of the cutting process to still be noticeable thus enabling the detection of the making process. A larger toolpath could potentially create too rough a finish and impede the primary effect of the pattern. The images to the bottom left and right illustrate the generated toolpath and the cutting process visualization video respectively (Figure 55).

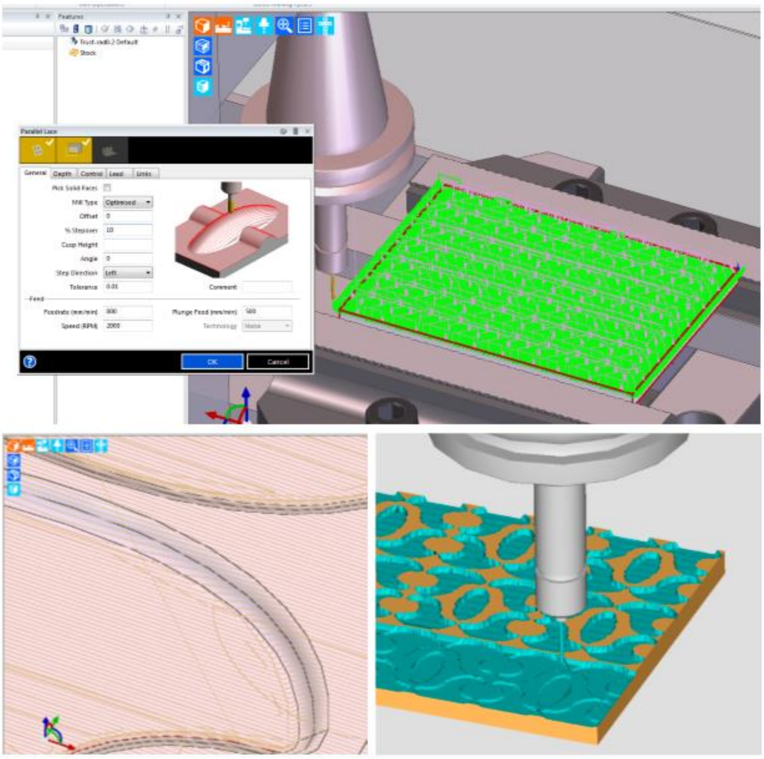


Figure 55 – EdgeCAM simulation processes

As well as the stepover size, the direction of cut was explored as a parameter of toolpath strategy. Unsurprisingly, the interference between the cutting marks and the textured surface created some interesting aesthetic effects, especially when the cutter took unconventional, non-orthogonal approaches. A range of angles were tried including a 15° and 45° offset. While varying the fundamental efficiencies of the process very little, this step in the process revealed the aesthetic potential of angled toolpath offsets from which the critical areas of the subsequent investigation were formulated.

5.4.3 Machine setup and equipment

Within EdgeCAM, a Haas TM2 vertical mill was used as the virtual machine to facilitate the simulations. The Haas TM2, while being an advanced CNC milling machine, is more specialised in larger scale machining jobs. It had been initially considered to use this machine to produce the components, but it became clear that this machine was of too large a configuration with respect to the scale of the work. As the elements of the process that were to be explored did not directly depend on the machine, it was deemed necessary to change to a micro-milling machine, more capable of dealing with complex detailing.

The machining was ultimately carried out utilising a Denford Microengraver Pro CNC router. This machine is specialised for fine machining work with a maximum RPM of 20, 000 making it ideal for creating texture detailing. Aluminium was chosen as the work material given its machinability and its applicability in multiple areas of consumer design (Apple computers for example). Each aluminium plate measured 120mm x 84mm x 5mm making them small but large enough for clear visual interactions and aesthetic judgements. The scale was selected to be tangibly ergonomic, something that could fit in the human hand and be interacted with. As per the simulations, a very small cutting tool was used in order to achieve the fine geometries of the designs; *ball nose cutter, 1 mm diameter, carbide steel*. The CAM software used by the machine, Quick CAM Pro has much less sophistication than EdgeCAM but was satisfactory for the manufacturing requirements. The setup of the machine is shown in Figure 56 below. Efforts were made to make the process as consistent as possible though this took a significant amount of time to achieve and there were many failed attempts at producing usable parts. Some of the problems were associated with tool speeds which caused milling cutters to break and an extremely poor surface finish. Other issues were associated with clamping methods where material slippages were recorded.

These problems were address systematically by a process of trial and error. There were several defective parts produced in the creation of the set of textured components. While it may have been interesting to explore these defects as well as a kind of subversion of what machining is intended to produce, the goal was to explore toolpath variations. This meant a minimum quality for the parts was required. Project resources meant that a more basic CNC device was being used, but the principles could still be tested easily. The initial failures in the parts were a result of a learning process whereby a set of cutting parameters was poorly calibrated to the raw material being cut. It was realised that the process required a relatively slow cut after several failed experiments using a higher tooling speed in which surface quality of the pattern was poor. This was altered by using a slower tooling speed and a higher spindle speed. While this produced better results, the surface finish would worsen over the course of the cut indicating that there was tool wear. This was addressed by the application of lubricant on the surface of the material that was periodically reapplied throughout the cut. Though this did not remove all the defects, it helped significantly in the overall process and increased the longevity of the cutting tools.

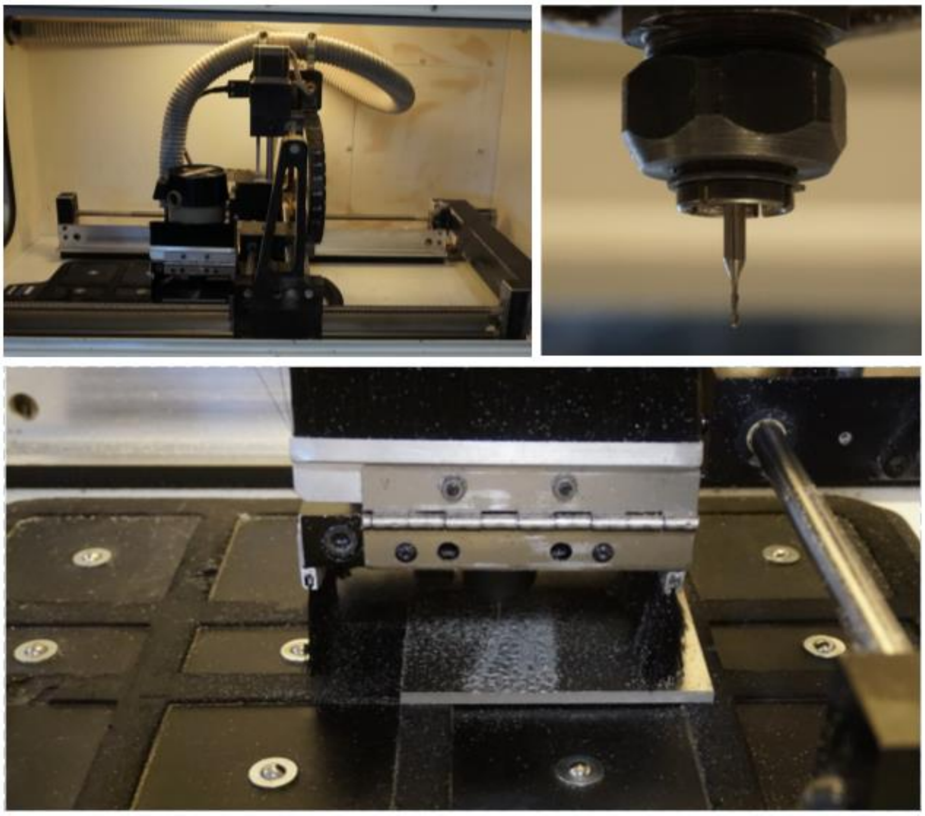


Figure 56 – Setup for Denford Microengraver Pro with detail of cutting process and 1 mm ball nose cutting tool

The images above show the final setup of the machine with detail of the ball nose cutting tool and of the cutting process. A basic lubricant was periodically applied as the machine unfortunately did not have an internal lubrication system. The technical setup of the machine was kept consistent and is detailed in Table 9 below.

Table 9 – Breakdown of process parameter and chosen settings

Process Parameter	**Setting**
Machine	Denford Microengraver Pro
Material	Aluminium 1060 plate (120 mm x 84 mm x 5 mm)
CAM software	QuickCAM Pro
Cutting tool	1 mm ball nose carbide steel
Feedrate	400 mm
Spindle speed	20, 000 rpm
Clamping method	Vacuum bed
General toolpath strategy	Bi-directional parallel lace / zig-zag / 'raster finishing'
Stepover	15 % / 0.15 mm
Lubricant	Swantek Gold

Due to constraints with machining time, the size of the textured area of the plate was halved allowing each job to be completed in approximately 2-3 hours. Figure 57 shows the generation of the 'raster finishing' zig-zag toolpath strategy within QuickCAM Pro. A basic lubricant was used during the machining sequence and all the parts were carefully cleaned and polished following production. Of these settings, the toolpath raster angle was the one that was varied. The general strategy remained a bi-directional parallel lace, but the cutting directions were altered. To explore how these changes may affect aesthetic, textural and material outcomes a range of rastering angles were selected totalling *seven variations:* ***0°, 15°, 30°, 45°, 60°, 75° and 90°***. Figure 57 illustrates a texture being produced with a 75° rastering angle.

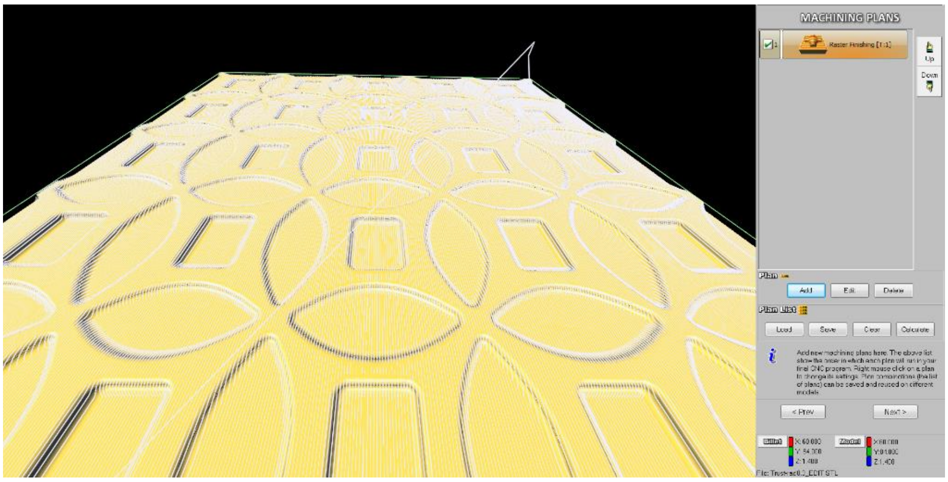


Figure 57 – Toolpath generation for trust texture within Quick CAM Pro

5.4.4 Part creation

Following several failed trials, all the required parts were successfully produced. Because the process conditions were not ideal (no internal lubrication system), some of the parts had minor defects, but were however considered usable. Overall, 28 separate parts were created, seven variants of each, a sample of which is shown in Figure 58 below. Detailed pictures of all the produced parts can be seen in Appendix 11.5 which also shows defects and geometric inaccuracies, though none of these defects were viewed to be severe enough to hinder the progress of the study but would be considered within the context of the overall analysis.

Figure 58: Machined aluminium plates for 'fear', 'surprise', 'trust' and 'joy' designs with perspective view of 'fear' plate

5.5 Summary

This section developed a working definition of advanced manufacturing with a view to exploring modern procedures of making. This exploration considered the fundamentals of the machining processes as emblematic of a modern example of an 'advanced' process (as defined, one involving some form of computational architecture that necessitates its functioning). In addition, the machining process was unpacked to explore its operational architecture – the general design of CNC machining devices as well as the range of tools used to shape the material. In essence, this understanding represents the *ontology* of this making process or how it manifests – conceptually and physically – within the world. Following this overview, a discussion of more sophisticated developments in machining technology was conducted looking at advanced toolpath approaches and the creation of freeform surfaces. Through a review of this literature a common culture within CNC machining as underpinned by process efficiency and the minimisation of so-called 'defects' was identified. While this element of the discussion remained strictly technical, it segued into a consideration of how the machining process can be tied to qualitative experiential factors with a range of interesting examples explored that seem to reinvent what the machining process (as conventionally conceived) can achieve for the designer.

Given the important discussions developed around the experiential properties that manufacturing processes imbue upon objects, a set of pattern-based textures were created to explore these principles further and more specifically to explore the experience of emotion as tied to or mediated by a certain object-interaction. The objects created are in a sense a conceptual grouping of the useful and the useless – while they have no intrinsic function, they are ornamental, decorative, and symbolic. Thus, making them simultaneously meaningless (from a strictly functionalist-modernist perspective) and meaningful (from a perspective of aesthetic and material perceptual experiences). This conceptual grouping or equivalence may be viewed as necessary, as no 'object', fabricated or known to already be in the world, can strictly be viewed as value-less (i.e. devoid of any conceptual value formation or description) but is by definition value-laden (i.e. the architecture of human will is imposed upon it immediately).

The creation of the parts meant that a new phase of exploration could be initiated. This part of the work has essentially argued that certain advanced processes flatten many of the aesthetic and textural qualities of the material and that the trace of the process (effectively its ontological core) is lost during the embodiment or *materialisation* of a piece of CAD data. A number of examples have been explored that take an unconventional approach to manufacturing protocol in the context of machining, including the work of artists and architects. From here the next phase of the work was carried out where these various protocols were examined within the frameworks of human-centred design, design for emotion and Kansei engineering. Tying this in with the methodology presented in Chapter 2, this stage will develop the subjectivist properties of the work. While this chapter has unpacked the technical aspects of the work from taking a certain position that is roughly defined as weak-positivism, this sets the stage for a conceptual bridging between manufacturing/processes of making and experiences of interacting with made artefacts; the human factors of design. This will be explored experimentally in the next chapter.

6. Human factors and machining strategy

I like the concept of 'wearing in' instead of 'wearing out'

- Bill Moggridge

By narrowing in on machining strategy, strategy that can been seen today as a variety of modern 'making' process, this section aims to show how drawing on the traces left by production, tangible user preferences and enhanced material experiences can be achieved. Two stages of experimentation, grounded in the philosophy and methods of Kansei engineering, were developed to explore this proposition. The first stage of experimentation focused on comparing two-dimensional and three-dimensional form, bridging the gap between the conceptual pattern and the made tangible embodiment of the textured object. This study revealed subtle differences in the perception and emotional impact of the visual interactions. The second stage of experimentation focused on visual and tactile preference of the pattern-based textures further revealing tangible preferences between different manufacturing approaches. This subsequently opens up discussions around a unifying ontology of emergence explored in the next chapter.

6.1 Principle questions for experimentation

This experimental protocol seeks to unify aspects of qualitative aesthetic theory and the paradigms existing in vision research psychology, with understanding of technical procedure for CNC machining operations. Accordingly, this section presents justification for, and description of, the proposed experimental plan consisting of a two-stage experiment. So far, this research has taken a broadly qualitative approach in attempting to analyse emotional interactions with form (geometric shapes and objects) and more specifically pattern. This has consisted in visual examinations of sets of defined forms. The paradigm view of research into vision, form and emotion posits that angular forms tend to be associated with what are subjectively understood as negative emotions and curved forms tend to be associated with subjectively more positive emotions, suggesting a curvature preference. As a continuation of the previous studies, the proposed experiments will assess the emotive value of both the 2D pattern designs and the physical 3D translations. Following this, the proposed experiments will establish if differences in machining strategy can influence aesthetic and tactile preferences.

With this line of argumentation already established, a consensus to explore both aesthetics, emotion and object materiality was reached. Whether the scope of this theoretical work can interact with the technical protocol of advanced manufacturing is the critical question of the investigation. The surface texturing designs that have been developed have a broad scope of applications and could be used in a variety of contexts in the consumer product sector – laptop or smart phone housings designs for example. The key benefit is customisation and user choice as set by the philosophical and research contributions of HCD and Kansei engineering; the sets of surface texturing designs may offer a richer product experience for users if designers chose to apply them. The move to 3-dimensions also provides a quantitative element to the discussion and examination of form. Thus far, form has remained in a more abstract 2D realm – the actual production of physical form facilitates a much more focused consideration of geometry, structure, and material interaction. The diagram broadly represents the narrative, moving from 2D into 3D physicality that has so far been covered over the course of the work (Figure 59).

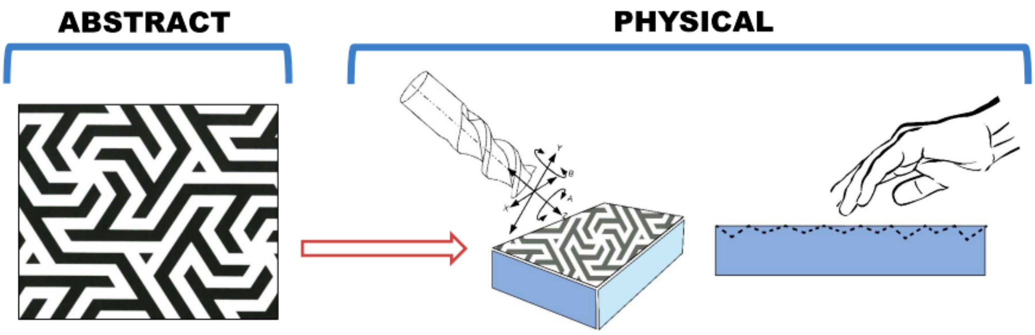


Figure 59 – Critical narrative of the work has moved from an analysis of aesthetics to aesthetic representations in physical objects

The critical elements of this work demand the mixed-method protocol that was developed in Chapter 2, bridging a gap between an empirically established machine-output with a subjective emotional experience. The previous chapters have so far documented the design of emotively resonant patterns and the creation of surface texture designs through CNC milling based on these designs. Of each design, seven variations were created using variant toolpath strategies, potentially creating divergent visual and tactile preferences for users. Considering this, a process of examination and validation must now take place where several key questions can be explored:

1) *Do the 2D pattern designs have the emotive responses that are expected in the visual domain with respect to the previous studies in aesthetics and emotion?*
2) *Do the 3D textures based on these patterns have the same or similar effect on emotive response in the visual domain as the 2D designs?*
3) *Can variations in toolpath be linked to any visual preferences with respect to the separate texture designs?*
4) *Can variations in toolpath be linked to any tactile interaction preferences with respect to the separate texture designs?*

The next sections will aim to answer these questions by firstly presenting an experimental plan then detailing the subsequent experiments.

6.2 Experimental plan

The proposed experimentation was split into two main stages. Firstly, a visual emotive assessment of both the 2D pattern design and the 3D texture design derived from the initial pattern designs. Secondly, a visual and tactile preference examination of the seven toolpath strategy variations exploring how this may affect the experience of these objects. An overview of the experimental process is shown in Figure 60.

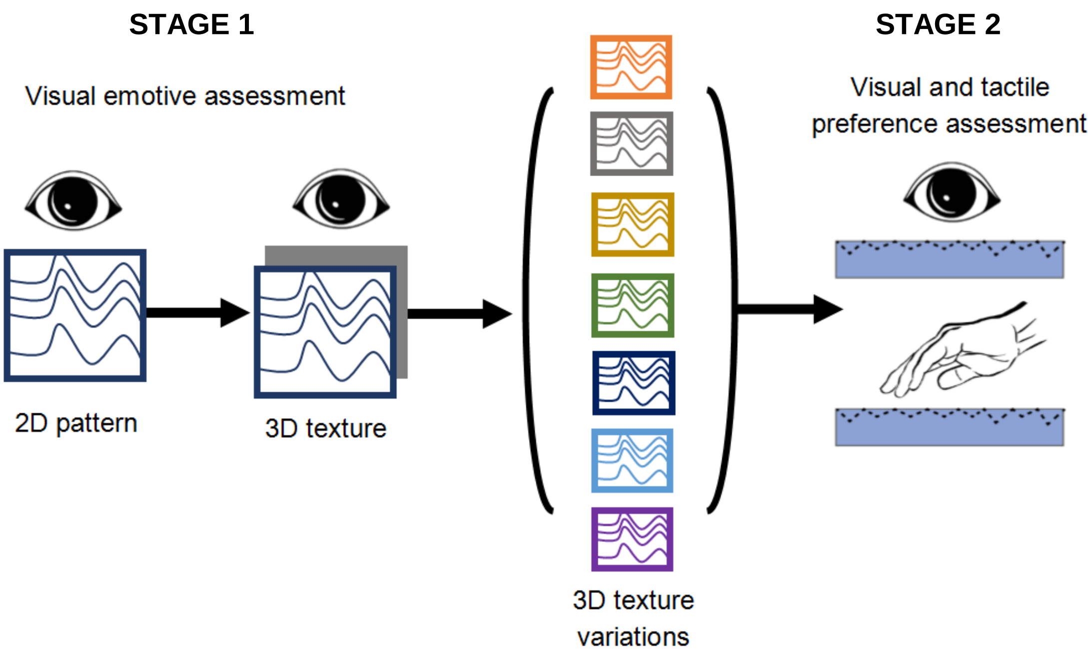


Figure 60 – Overview of experimental stages; visual emotive assessment of 2D patterns and 3D textures (left), followed by visual and tactile preference assessment of textures (right)

6.2.1 Stage one experimentation

The first stage of the experimentation was very much grounded in the approaches of experimental aesthetics researchers, many of which were explored previously in Chapter 3. Critically, the difference (if any) between the emotive experience of the 2D design compared with the 3D texture needs to be established. The designs were developed with respect to the evidence pertaining to the connection humans make between form, structure, and semantic meaning. Washburn and Crowe (1987) demonstrated that pattern was a tool for conveying various kinds of knowledge and meaning. From the analysis that has been presented, several discrete elements within patterns and within the stylistic ornamentation of pieces of design and architecture have been shown to convey powerful semantic ideas and relate to experiences of emotion.

The first stage compared two-dimensional form with three-dimensional physicality. Plutchik's (1980) model of emotions continued to be the basis by which emotive categories were analysed and again ordinal scales were the tool by which the data was recorded allowing for the broad measurement of subjective experience intensity. Plutchik's categories had successfully been used in the study detailed in chapter 4, however that study only explored dimensions of the core emotions and not the more complex feelings that are understood as combinations of two primary emotions. With respect to this, the emotive categories were changed to include the more complex emotions, details of which are presented later. Additionally, the seven texture variations, one of each set was given a ***datum*** status. The datum of each was the texture with the toolpath strategy orientated at ***90***°, meaning that the cutting direction was parallel to the vertical side of the plate – representative of an orthodox cutting approach.

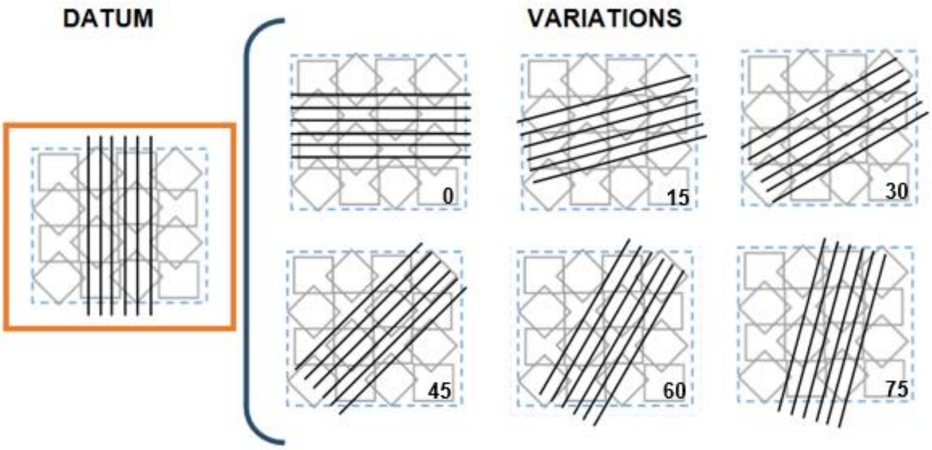


Figure 61 - Toolpath variations superimposed on stuctural abstraction of Surprise pattern

6.2.2 Stage two experimentation

The second phase of experimentation is grounded within the philosophy and approaches of Kansei engineering and HCD whereby experiential preferences are established based on reviewing design variations (see Chapter 1). The stage was split into two key tests, one visual and one tactile. Based on the comparison tests that are widely used in optometry, these tests used the datum plates mentioned in the previous paragraph against the 'comparison plates' (the remaining six plates) as a means of establishing if the differences in toolpath strategy related to any preferences in the visual or tactile domains. If some preferences can clearly be established, this has implications for machining protocol and manufacturing ontologies more generally.

6.3 First stage experimentation

6.3.1 Experimental setup

The experiment recruited 62 participants aged between 20-35, 33 male and 29 females, all from a design and engineering background and educated to university level. This sample was selected for convenience and it should be noted that a fully calculated study power analysis was not performed and is thus a limitation in the protocol. The first stage experiment was split into two key phases – the first to assess the patterns, the second to assess the textures. The critical goal was to establish to what extent pattern and texture can express or represent emotion concepts and how closely these two aesthetic experiences are linked. A set of 16 key emotive terms covering a range of semantic descriptors of emotion were extracted from the model to be used within the context of the experiment. The 'Wheel of Emotions' is split into multiple sections that emphasise how discrete emotional experiences are linked, and how combinations of emotions can create distinct complex feelings. The model was appealing as it provided a simple differentiation between emotive states but also alludes to their subjective intensiveness. For example, the emotion *joy* is placed in diametric opposition to *sadness* – its experiential opposite. Additionally, an emotion such as *rage* within the Wheel is viewed as a more intense emotion than *anger.* While there may be some semantic debate, the usefulness of the model is clear when it comes to assessing perceived emotional intensity and differentiating classes of emotional experience. Additionally, as the distinct dyads also describe complex emotions such as *love* (seen as a combination of joy and trust), there was scope to investigate if these more complex feelings could be represented within the patterns and texture designs.

It was felt that it would be impractical in terms of time to attempt to analyse all the emotive terminology that is within the Wheel. Accordingly, 16 terms from within the model were selected. 8 of these terms came from the core ring of the model, what are called the *primary* emotions. These primary emotions, it is argued, can be combined to create a more complex emotional experience, or feeling; the intersection of all the primary emotions and their adjacent emotions creates a set of 8 additional emotions that are combinations of the primary eight. The question of range did come up here – why just 16 emotions? This was in part practical and in part theoretically justified. While many models of emotion classification have many more than 16 (e.g., Ekman, 1992), others have fewer and are more focused (see James, 1884). Additionally, we wanted the options to be diverse but not confusing semantically as understandings between peoples and cultures of emotions can vary quite significantly (Mandal & Ambady, 2004). Hence, from a practical point of view 16 were chosen encompassing a reasonable range of positive, negative and mixed emotions that would also lend itself to straightforward experimental analytics. Given we sought to explore not just primary but more complex emotions also, the set of 16 emotive terms used within the experiment was as follows – Table 10 below provides the emotive term and a working definition. Half of the terms are the same as used in the previous study, half are different, comprising the combinatorial complex emotions.

Table 10 – Updated details of emotion terminology from Plutchik's (1980) 'Wheel of Emotions' model with working definitions, valence and intensity

Emotive term	**Description**	**Valence and intensity**
Aggressiveness	Hostile, antagonistic and forceful	Negative valence / combinatorial complex emotion
Anger	Displeasure or hostility	Negative valence / primary emotion, medium intensity
Anticipation	Excitement or preparation for future event	Mixed valence / primary emotion, medium intensity
Awe	Wonderment and amazement	Positive valence / combinatorial complex emotion
Contempt	Scorn and disrespect	Negative valence / combinatorial complex emotion
Disapproval	Dislike or reject	Negative valence / combinatorial complex emotion
Disgust	Revulsion and aversion	Negative valence / primary emotion, medium intensity
Fear	Terror or fright associated with danger	Negative valence / primary emotion, medium intensity
Joy	Pleasure or happiness	Positive valence / primary emotion, medium intensity
Love	Deep affection, liking and attachment	Positive valence / combinatorial complex emotion

Optimism	Hopefulness and confidence	Positive valence / combinatorial complex emotion
Remorse	Guilt or regret for a past event	Negative valence / combinatorial complex emotion
Sadness	Unhappiness, dejection or sorrow	Negative valence / primary emotion, medium intensity
Submission	Yielding or capitulation	Negative valence / combinatorial complex emotion
Surprise	Shock or amazement	Negative valence / primary emotion, medium intensity
Trust	Confidence, belief or faith	Positive valence / primary emotion, medium intensity

Before the experiment, each participant was given an information sheet detailing the tasks, a worksheet and requested to sign a consent form in compliance with University of Strathclyde's ethical guidelines. The worksheets contained the emotion terminology, the 16 terms, in randomized lists with a 0-5 ordinal scale next to each term. A sample worksheet is provided in Appendix 11.7. When judging each pattern and each texture, a different list order was presented. This was done as a measure to keep the participant thinking about each term and the meaning of each emotion, alternatively responses may have become somewhat automatic. The general setup of the experiment is illustrated in Figure 62 below where the two phases of stage one is detailed.

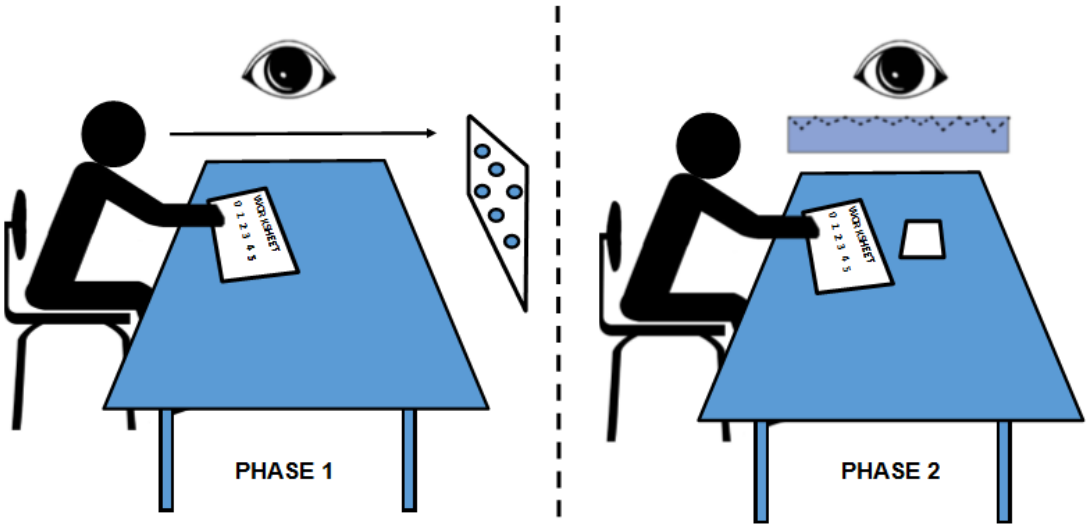


Figure 62 – Two phases of the first stage of experiments; Visual examination of 2D designs via computer screen (left) and visual examination of textures (right)

Each participant was presented with the four designs in turn within a controlled environment. For the first stage of the experiment – examination of the two-dimensional designs - the patterns were shown via a large computer screen with high-definition resolution in a randomized order. Any design intentions surrounding the designs were strictly removed, the pattern designs were only referred to as 'pattern 1', 'pattern 2' and so on allowing potential biases to be minimised. For the textured surfaces, the participants were shown the physical samples, again in a randomized order one at a time and directed not to touch or interact with them directly. They were permitted to examine them by coming closer to the plate and viewing it from different perspectives. The textures were presented in the same orientation as the two-dimensional designs, but the participants were encouraged to view the samples from multiple angles and explore the physicality of the parts. Each participant was given no more than two minutes in order to complete each assessment. Most people, though, were able to do it quickly, completing the exercise for each pattern and texture in around 30 or 40 seconds meaning the whole experiment could be completed in less than 10 minutes. The following section will provide the results from the first phase of experimentation, a detailed discussion of which will commence in chapter 7.

6.3.2 Two-dimensional patterns – results from visual assessment

Starting with the two-dimensional designs. The presented patterns were designed in order to represent emotive ideas, visual form as embodying semantic meaning. We have seen how this idea has notable coherence across experimental aesthetics and theories of art more generally. This work proposed to explore if this could be extended to pattern with respect to the many scholarly efforts to establish how pattern plays a role in kinds of cultural expression and knowledge. The patterns will be discussed in turn and in the same order they were presented to the participants, with principal reflection orientated around how the emotive assessments reflect those modelled by Plutchik (1980).

Pattern 1 – positive valence, 'Trust'

This pattern was conceived to be a representation of *trust*, or more broadly, positive feelings of happiness or connection following an analysis conducted previously. The design made notable use of the structural motif of overlapping rings which, it was postulated, capture some semantic representation of the feeling that Plutchik (1980) designates as a principal emotion. Upon analysis, it was noted that demarcating the male results from the female results showed no significant differences in the overall responses, the raw data of which can be viewed in Appendix 11.7. With respect to this, the results were taken together and analysed accordingly. Figure 63 displays the mean results of the emotive judgements.

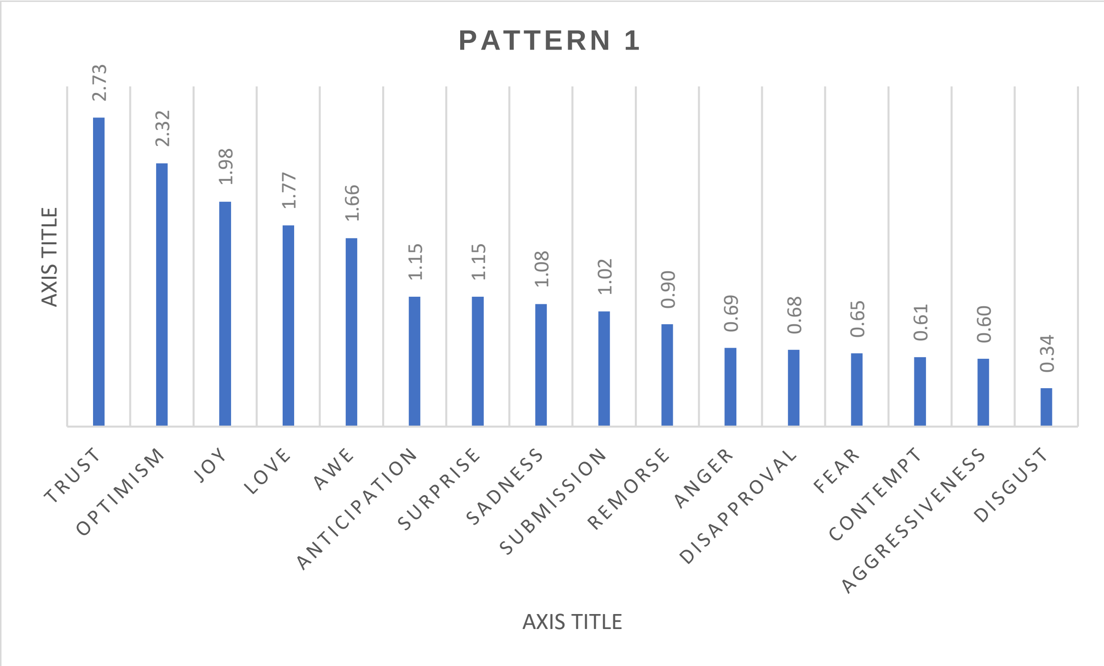


Figure 63 – Mean results for pattern 1 (Trust)

It is clear that the design has been successful as an abstract representation of *trust* with the emotion receiving the highest overall rating (2.72) in terms of a perceived visual representation. Additionally, the emotions of *optimism, joy* and *love* received high rankings, suggesting that the pattern may have the potential to relay more complex emotions and feelings. The negative emotions received contrastingly low ratings from participants, suggesting that while there was the subjective possibility that these emotions were present in some regard, the general effect was towards a 'positive' interpretation. With respect to Plutchik's (1980) model, the emotions span a range of perceived intensities with notable coherence around positive valence when compared with negative valence. Trust, optimism, joy and love have very high average ratings compared with their emotional opposites such as aggressiveness and disgust.

Pattern 2 – mixed valence, 'Surprise'

The design for this pattern was conceived as bringing together the author's previous studies and work from the Gestalt visual theorists, notably Rudolph Arnheim. The design aimed to capture a kind of visual energy and a temporality that may be experienced when surprised or during a period of excitement. Again, no significant differences between the male and female results were established, meaning they could be analysed together. The overall mean results are seen in Figure 64 below.

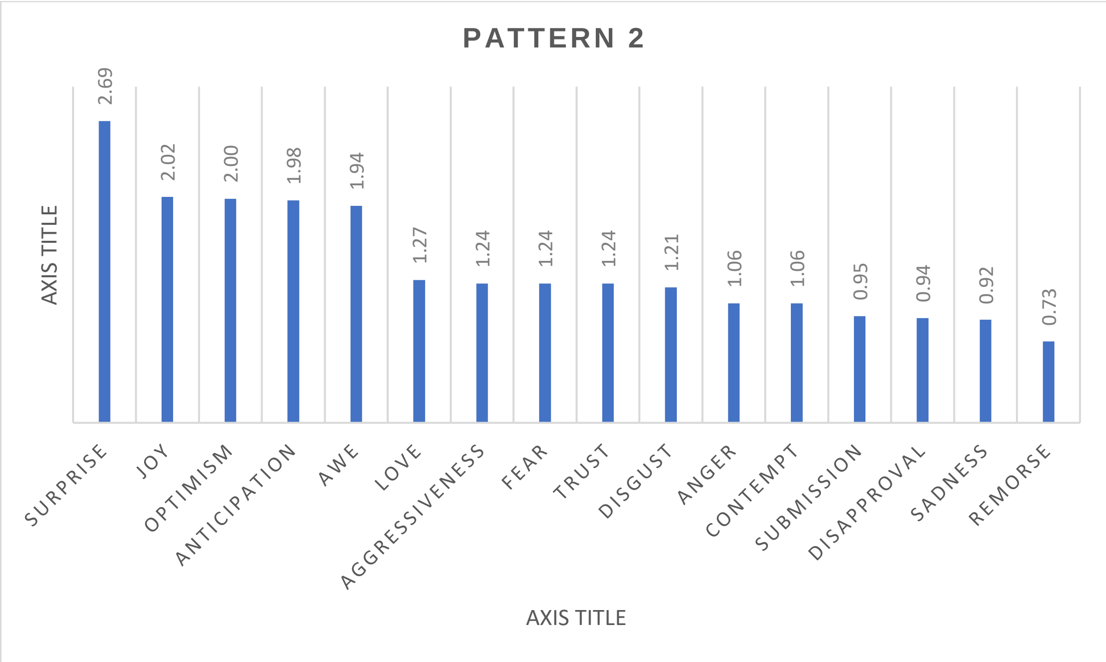


Figure 64 – Mean results for pattern 2 (Surprise)

Like pattern 1, pattern 2 has essentially achieved its envisioned design goal of embodying the emotion of *surprise* with this emotion receiving the highest intensity rating (2.69). Comparatively, emotions such as *sadness* and *remorse* received low scores suggesting a coherent semantic distinction. Furthermore, the ambiguity between a positive valence and a negative one that may be present in definitions of surprise, it appears, is more difficult to achieve in a visual context as there is a clear skewing towards a more positive interpretation of the forms. *Joy* and *optimism* received notable high scores suggesting that these feelings are more directly related to understandings of surprise as a feeling.

Pattern 3 – positive valence, 'Joy'

This pattern was conceived along similar lines to pattern 1, drawing from the previous studies by the authors (Urquhart & Wodehouse 2017, 2018) and other evidence drawing on curvature preferences to present a representation of *joy*. Unlike pattern 2, this pattern was conceived to be a clearer representation of the emotion and positive emotions more broadly. The results shown in Figure 65 demonstrate that while a positive interpretation has been achieved, the participant cohered around a more complex emotion, *love*. No significant differences between the male and female results were established, meaning that the results were again analysed together.

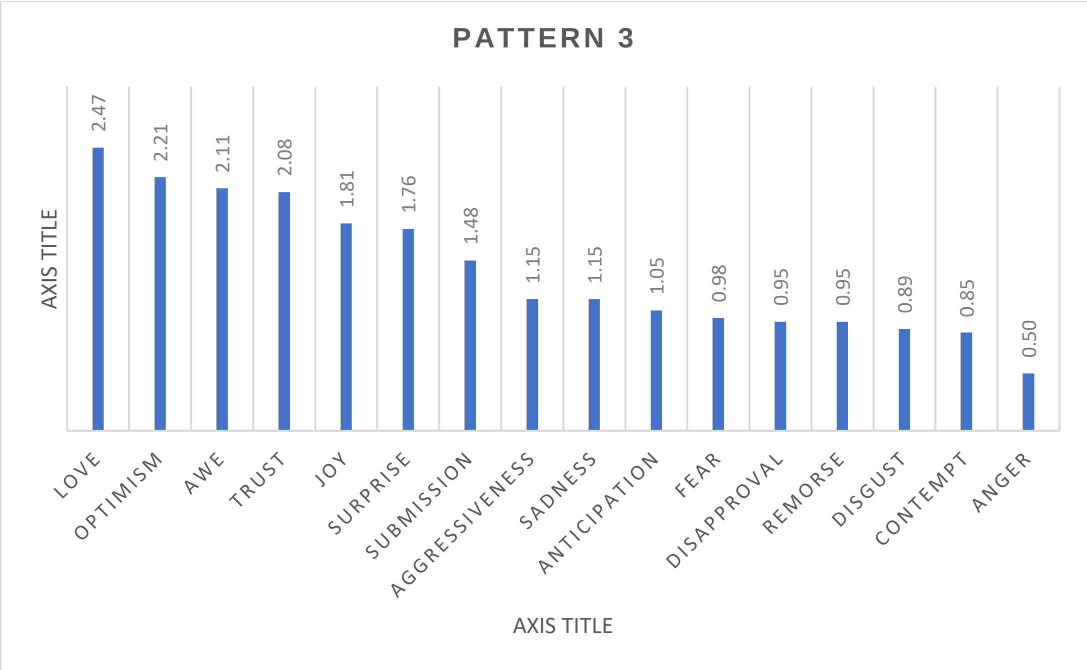


Figure 65 – Mean results for pattern 3 (Joy)

Love is an extremely complex emotion, characterised by Plutchik (1980) as a feeling drawn from not only *joy* and *trust* but feelings of serenity, acceptance and ecstasy too. *Love* received a rating of 2.46, closely followed by *optimism* at 2.20 and *awe* measuring 2.11. In contrast, emotions such as *anger* and *contempt* received relatively low scores indicating a semantic coherence within the design tending towards a positive valence.

Pattern 4 – negative valence, 'Fear'

The final pattern was designed to represent a subjectively negative emotion, for the purposes of the task *fear* was selected as a useful starting point though the broader goal was to represent a negative valence. The principal guidance for the design was the use of angularity to counter the curvature preference. As with pattern 3, pattern 4 did achieve the negative response predicted, however, the consensus showed that the pattern was more representative of *anger* and *aggressiveness*. No statistically significant differences between the male and female results were established so again the results were analysed together. The mean results are presented in Figure 66 below.

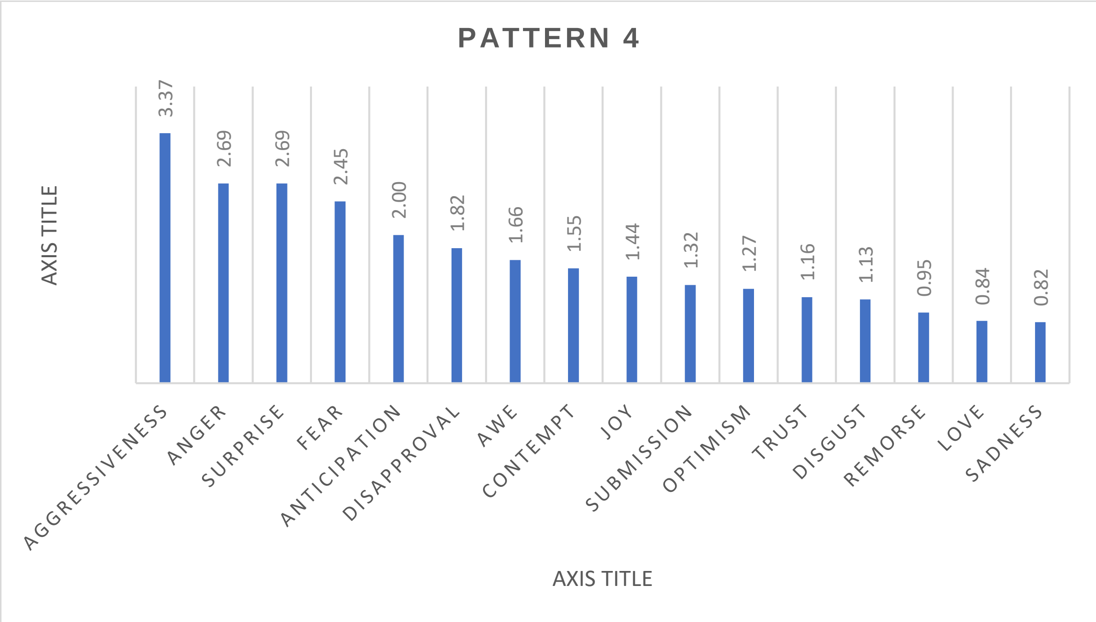


Figure 66 – Mean results for pattern 4 (Fear)

Interestingly, this pattern saw high scores for *aggressiveness* and *anger* – 3.37 and 2.69 respectively – but notably received a high score for *surprise*, also measured at 2.29. This introduces some complexity into the interpretation of the results as *surprise* was unambiguously cast within a framework of positive valence. It may be that the uncertainties that have already been discussed regarding surprise as an experience are manifest here in the subjective interpretation of this pattern. More of this will be discussed in the sections to follow.

6.3.3 Relation to physical textures - results from visual assessment with comparison to initial findings

These results represented a confirmation that a visual aesthetic can subjectively represent emotion. The question we can now address is whether these results can translate to a physical texture. We will take the textures in turn and for the aid of the analysis, the presented graphs will show both the pattern results and the texture results together. For clarity, each texture is shown against its equivalent pattern design. The textures were presented in a randomised order to the participants and the same order will be followed for the subsequent analysis.

Texture 1 – positive valence, 'Joy'

Despite many people reporting after the experiment that the form experience of the physical object was different in some respects, there was notable coherence across many of the measured emotions. Considering the equivalent designs for *Joy*, there is a similar pattern of results for both the raw pattern and the texture (Figure 67).

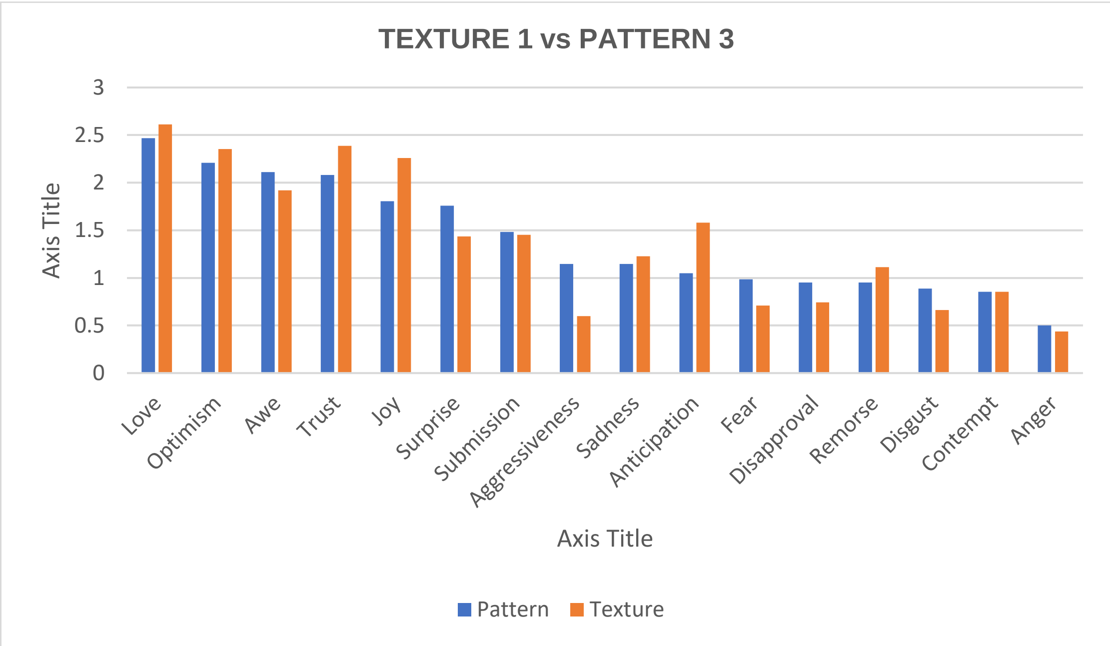


Figure 67 – Mean results for texture 1 compared with pattern 3 (Joy)

A statistical analysis of the male and female results was carried out revealing no significant statistical difference. Accordingly, the results were taken together to generate overall averages. When comparing the two sets of results, the overall intensity of the emotive responses to the physical textures was higher. However, on statistical evaluation, there is no significant difference between the 2D and 3D results – if there is a significant difference, it may take more participants to firmly reveal this. Some emotions did seem to elicit a much stronger response nonetheless; recorded levels of *joy*, *trust* and *anticipation* were significantly higher (2.25, 2.38 and 1.58 averages respectively) suggesting that a physical manifestation of the pattern provokes a stronger sense of semantic meaning. The dynamics of the process of machining may also play a role in this, a question that will be explored in the next chapter.

Texture 2 – mixed valence, 'Surprise'

As discussed earlier, *surprise* was quite a complex emotion to attempt to represent through pattern as it was argued there are implicit temporal elements to its experience. The design did however prove to be successful and distinctly aligned more towards the positive interpretation indicating that the valence of this emotion is culturally understood as such. The differences between the male and female results were not measured as statistically significant so again they were analysed together.

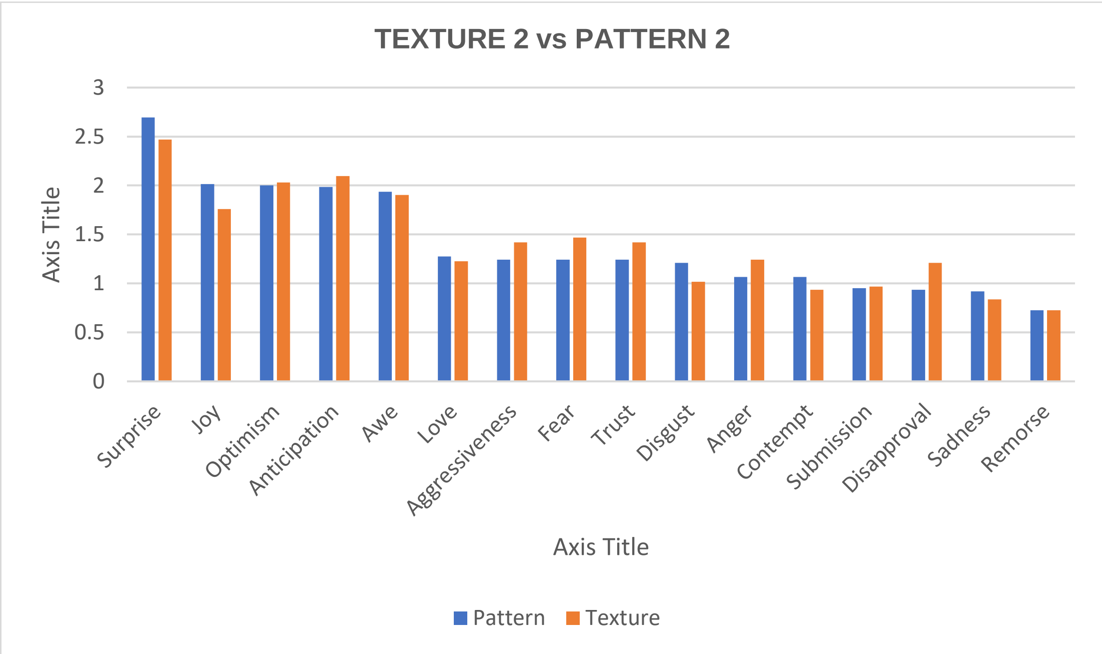


Figure 68 – Mean results for texture 2 compared with pattern 2 (Surprise)

Considering the comparison between the pattern and the texture (Figure 68), there is notable coherence between the two results with many of the texture results recorded as marginally higher than the patterns (notably not on the measurement of surprise itself). Statistically, a significant difference between the results was not measured meaning that the semantic qualities of the 2D design successfully translated to the physical domain. If there is a significant difference between the experiences, this may only be established with further testing. The results also seemed to be more mixed with respect to the textures where many of the negative emotions such as disapproval, fear and anger received relatively high scores when compared to the 2D designs. This will be discussed further in chapter 7.

Texture 3 – negative valence, 'Fear'

The pattern that texture 3 was based on was designed to be semantically associated with negative emotions, *fear*, in particular. In the previous section it was shown that while fear was a dominant emotion in the measurements overall, other emotions – *aggressiveness*, *anger* and *surprise* – were more strongly related. Figure 69 below illustrates the difference between the two sets of results. There was no statistically significant difference measured between the separate male and female results, accordingly, they were analysed together. When comparing the difference between the pattern and the texture, no significant difference was revealed suggesting that there is a coherence of interpretation between the 2D design and the 3D texture.

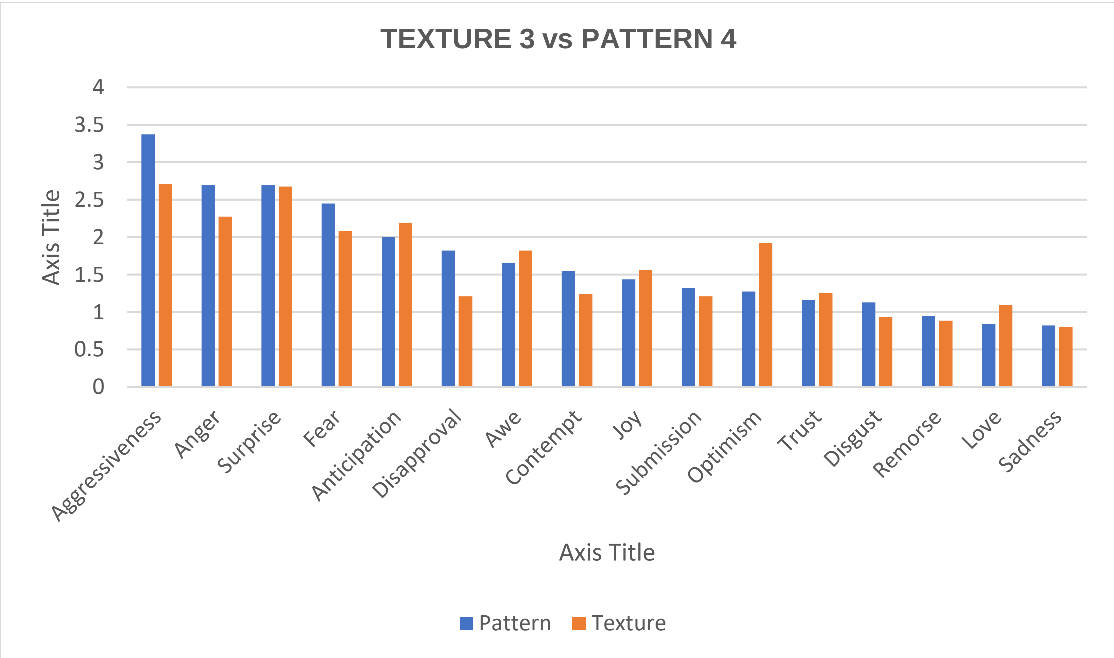


Figure 69 – Mean results for texture 3 compared with pattern 4 (Fear)

There are some notable deviations, however. The results for the texture have less overall variation when compared to the pattern; the results are flatter. This could possibly mean that the texture design is more dynamic in what emotions it can convey to people. With respect to machining fundamentals, the created surface is essentially freeform and lacks the visual angularity of the 2D configuration, this may result in a weakening of the negative responses. Notably, the measurements for *optimism* (1.91) and *disapproval* (1.20) are respectively much higher and much lower than their pattern equivalents. Additionally, the measurements for *surprise* roughly equal that of *aggressiveness* (2.67 - 2.69 range) calling into question the earlier argument that surprise was culturally understood with an implicit positive valence. Its connection to unambiguously negative emotions suggests otherwise.

Texture 4 – positive valence, 'Trust'

The trust pattern was built around a structural foundation of overlapping rings which were consistently shown to aesthetically relate to a semantic understanding of the emotion. When comparing the results, there is a coherence between the recorded emotive interpretations (Figure 70). No statistically significant difference between the two sets of results (M/F) was established, suggesting that they are interpreted similarly by the participants.

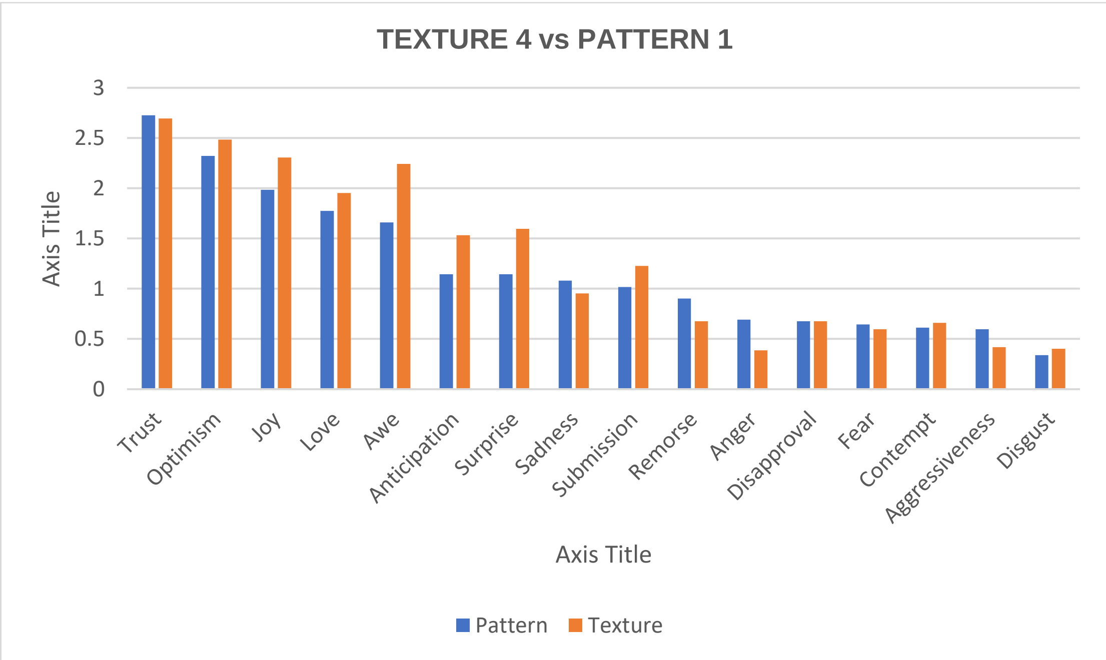


Figure 70 - Mean results for texture 4 compared with pattern 1 (Trust)

The highest recorded scores for both the pattern and the texture is *trust*, suggesting that the aesthetic of both in some way relates to a trust experience. There were some notable differences (which may have been drawn out more statistically given more participants); *awe*, *anticipation* and *surprise* received far higher scores (2.24, 1.53, and

1.59 respective averages) for the texture design than the pattern. This suggests that the physicality of the texture may enhance the symbolic visual representation of these emotions, a point that will be discussed further in the following chapter.

6.4 Second stage experimentation

6.4.1 Experimental setup

The second stage of experimentation was more closely aligned with the study of user-experience as drawn from the philosophies and approaches of Kansei engineering and HCD thinking. Critically, this stage could establish links between design and aesthetic theory with manufacturing protocol, in this case, toolpath strategy.

Visual and tactile preferences were the focus of this experimental stage where the six design variations were each compared against a datum. Each set of six comparison plates were presented to the participants in a randomized order to minimise automatic responses. Each participant was presented with a worksheet that contained three response options for each test, for the visual preference phase*; 'visually prefer', 'visually don't prefer', 'no visual preference'*. Each of these responses could be suffixed with 'when compared to the datum plate' to establish the direction of the preferences. This was made sufficiently clear by both the researcher and the provided information sheets. For the tactile preference test that followed, the terminology was aligned around tactile comfort; '*more comfortable', 'less comfortable', 'no preference'* (which again could be suffixed with 'when compared to the datum plate'). The plates were presented one by one in a randomized order and arranged next to the datum plate for visual comparison. All the plates included, each participant was required to assess 28 plates in total in both the visual and tactile domains equalling and total of 56 preference comparisons. Tactile comparison involved a short, guided interaction with the two plates, first the datum then the comparison using the participants index and middle fingers. The participants were permitted to hold the plates steady with their other hand during the interaction. While a maximum of two minutes was allotted to each task, most people were able to decide on their preferences in 10 or 20 seconds, making the experiment very quick overall. The sections to follow will provide the results from the second phase of experimentation with more detailed discussion commencing in chapter 7 considering the implications of the work for both theory and practice.

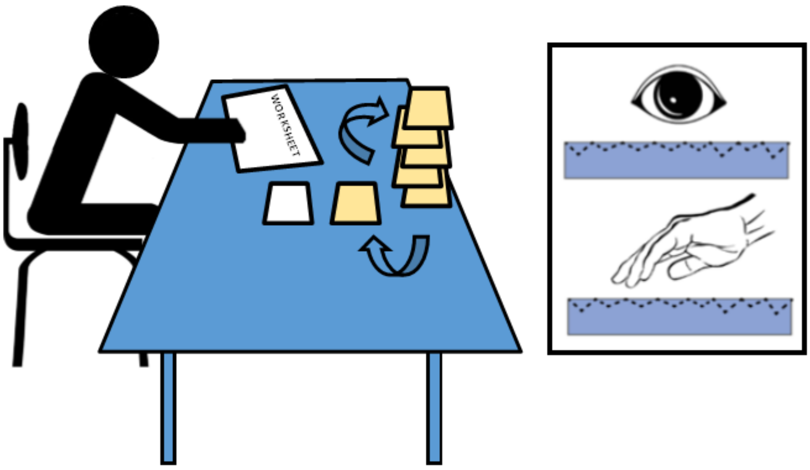


Figure 71 – Second stage of experimentation; guided visual and tactile preference assessments of the 28 textured plates. Each participant was given a 'datum plate' in order to assess against 6 'comparison plates'

6.4.2 Machining strategies for visual preferences

This test was split between visual and tactile preferences with the visual assessment being carried out first. As Figure 71 illustrates, each participant was presented with a datum plate for each texture design that was machined at a standard 90° raster angle relative to the workpiece. Rastering angle is a fundamental parameter in many machining operations, often used for finishing procedures which can make a tangible difference to the resultant appearance and surface texture of the part. While the angle can be edited, it is usually defaulted to be parallel with the cutting face, limiting the range of aesthetic exploration possible within the confines of the prosses. Thus, the plates with the varying raster angles were presented alongside as comparison plates, the randomized orders of which can be seen below in Table 11.

Table 11 – Order of comparison plates by raster angle

PATTERN DESIGN	ORDER OF COMPARISON PLATES
Surprise	**30˚, 45˚, 60˚, 0˚, 75˚, 15**
Joy	**60˚, 0˚, 75˚, 45˚, 15˚, 30˚**
Fear	**30˚, 15˚, 60˚, 75˚, 0˚, 45˚**
Trust	**60˚, 45˚, 30˚, 75˚, 15˚, 0˚**

As there was no statistically significant difference between the male and female preference results, these were taken together and examined accordingly. Looking at the visual preferences first, the results are as follows where Table 12 shows the comparison plate preference results against the distinct designs and toolpaths with the datum plate preference results. These results exclude 'no preference' choices, the colour coding indicating the relative differences in the values (green-high, red-low, clear-mid).

Table 12 – Participant preferences for visual comparison of plates

	Comparison plate preference results ('visually prefer')					
	0 °	**15 °**	**30 °**	**45 °**	**60 °**	**75 °**
Surprise	38	23	33	19	13	8
Joy	21	23	14	24	13	6
Fear	9	28	18	22	9	23
Trust	20	8	19	26	37	36
	Datum plate preference results ('visually don't prefer')					
	0 °	**15 °**	**30 °**	**45 °**	**60 °**	**75 °**
Surprise	13	22	16	26	33	47
Joy	32	30	35	31	39	50
Fear	43	27	38	31	47	33
Trust	27	48	37	24	16	18

On analysis, there is a significant difference between the comparison plate preferences and the datum preferences indicating that most people are drawn to some making approaches over others. The two graphs presented below are essentially inversions of each other but allow us to understand the data more effectively and identify trends where possible (Figure 72 and Figure 73). The graphs include the results for all four designs and are colour coded for the benefit of the reader.

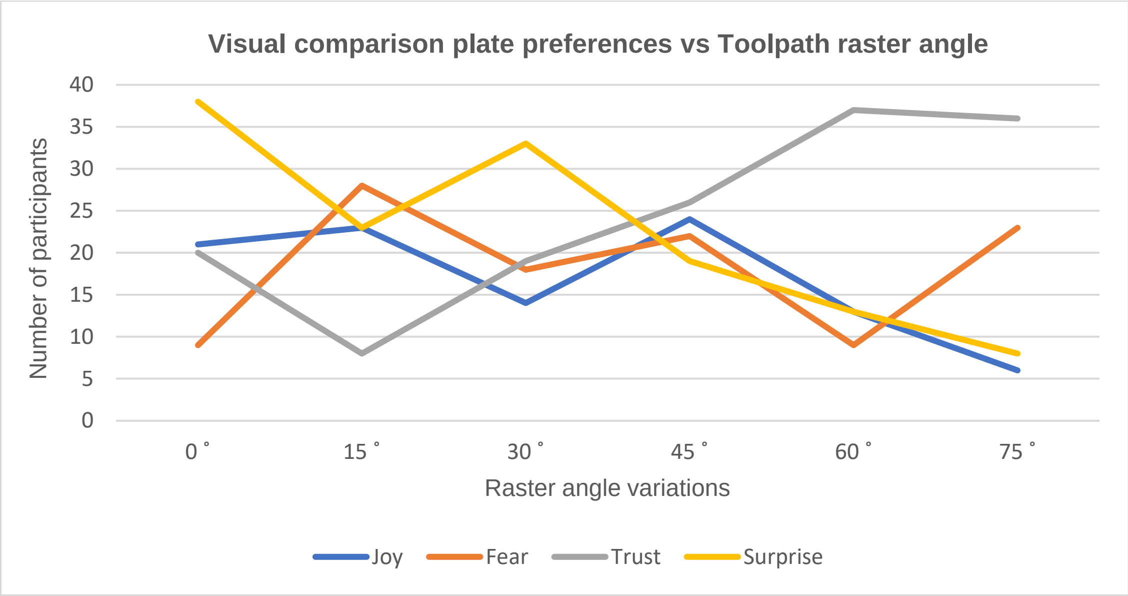


Figure 72 - Visual preference trends for comparison plates

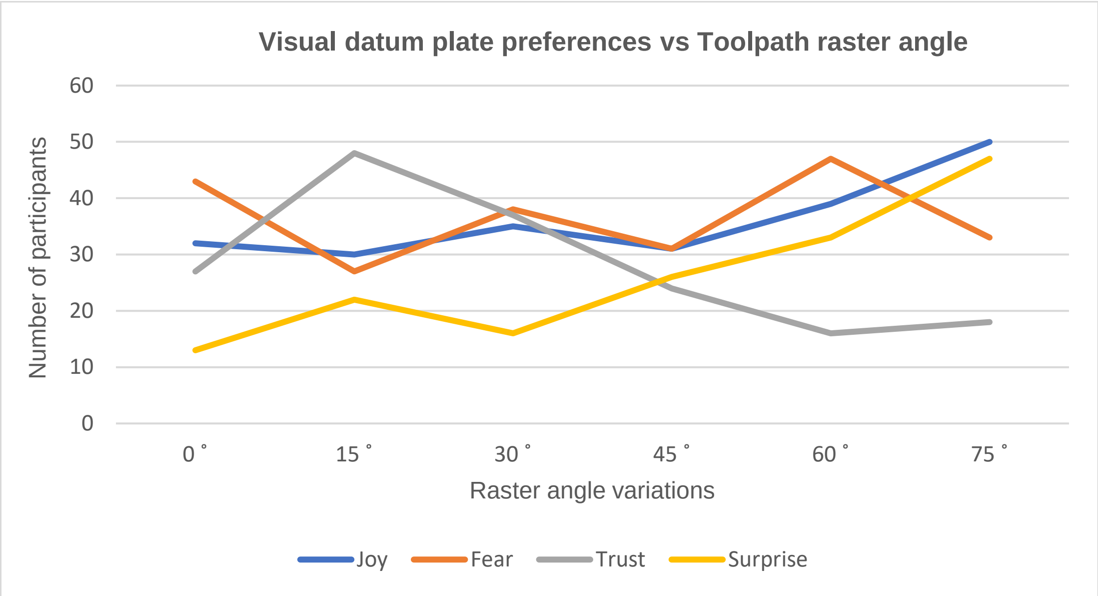


Figure 73 – Visual preference trends for datum plates

The conclusions of these findings will be discussed briefly in the sections to follow but will be more thoroughly examined in the next chapter where the implications of all the results in terms of theory and practice will be discussed. As the toolpath variations have been explored against a set of four different pattern-based texture designs, the structural basis of these designs must be closely considered in any analysis. Figure 74 shows the structural foundations of each of the designs. As shown, two of the designs rely on a cubic foundation, *Surprise* and *Fear*, but *Joy* and *Trust* rely on curvilinear foundations. The ways in which the toolpath interacts with this structure has an influence on the overall aesthetic, the subsequent Figure 75 revisits this.

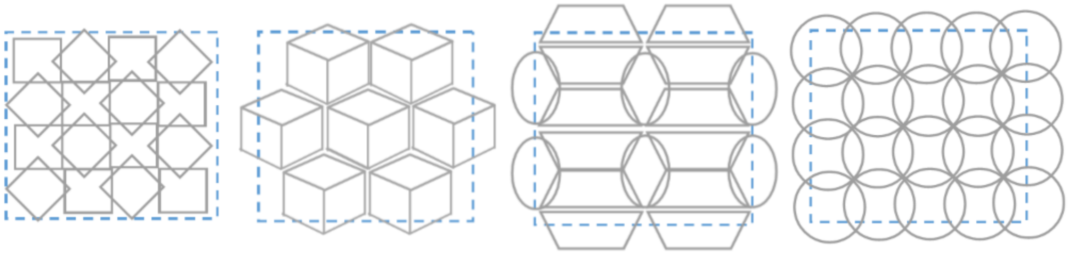


Figure 74 – Structural abstractions of pattern designs, Surprise, Fear, Joy, Trust (left to right)

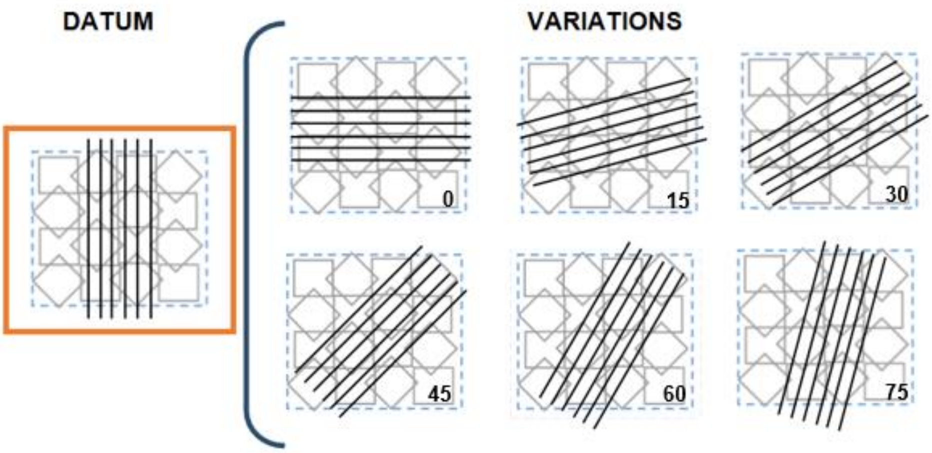


Figure 75 – Toolpath variations superimposed on stuctural abstraction of Surprise pattern. This strategy was repeated across the other deigns though the presented order was randomised

Each pattern-based texture can be looked at in turn. Looking at Figure 73 and focusing on the results for *Surprise* reveals that preferences are more aligned towards the datum as the raster angle moves away from 0° where the highest visual preferences are seen for the comparison plates. The lowest visual preference is seen for the 75° plate. The trend is not strictly linear but the trend towards preference for the datum is clear where the relative graph lines would intersect on their respective upwards and downwards trends. One notable deviation are the results for 15° and 30° which show a sharp decline and then a sharp increase in preference respectively. It is not clear why this is the case, but it is most likely due to subtle differences in surface quality (fewer defects) leading to a subconscious judgement as the general surface quality of both was very good.

A similar relationship is seen for *Joy* though it is not quite as pronounced and is subject to more variation against the different toolpath strategies. Generally, the datum plate was visually preferred but there were notable results for 0°, 15° and 45° variations that recorded nearly half of the participants preferring. 30° recorded an unusually high number of 'no preference' results leaving that relationship inconclusive. As the toolpath moves towards 75°, recorded preferences fall steeply, and the datum plate records its highest preference ratings. Why there is such a sharp drop in visual preference after a 45° raster angle is not entirely clear. The surface finish between the parts was consistent overall so is more probably connected to how the toolpath pattern interacts with the texture design. 45° and 15° respectively recorded 24/62 and 23/62 participant preferences. There is a possibility that the visible qualities of the making process provide better visual energy, in turn, enhancing the impact of the aesthetic symbolism that is evidenced by the increased levels of perceived emotive intensity noted for *love*, *joy* and *optimism*.

Fear was built upon a cubic structural basis and the design was driven by a dynamic angularity. Within these results, there are several points of interest. Overall, the participants were drawn to the datum approach more than any other in terms of visual preference. The results for the 15° variation noted a tiny majority of one and the 75° variation recorded a just below half indicating a preference. In terms of preference trends, any relationships remain elusive and may only be established with further study. It appears that most participants aligned to a linear cutting approach as it visually compliments the cubic structure of the design. Examples such as the 60° variation, which recorded a notably low preference distribution, could be explained by a relatively poor surface quality, although this cannot account for all such examples.

On analysis of the visual preference results for trust shows a somewhat linear trend line with visual preference increasing as the raster angle becomes more extreme. Some of these results will have to be discussed against surface finish inadequacies, but this cannot account for the observed trends in this case. Visual preference at the 15° variation remains low, possibly owing to chatter-based machining errors, but increases steadily with the 60° and 75° variations recording majority preferences of 37/62 and 36/62 respectively. The subtle visual dynamics of the toolpath against the texture design may make these off-set rastering angles more pleasing visually – something that will be discussed in the following chapter.

6.4.3 Machining strategies for tactile preferences

As the experiment was repeated in the same way but reframed to analyse tactile interaction, the data can be presented in a similar format. Again, the raw data from which these results derive can be seen fully in Appendix 11.7 and the 'no preference' choices are not included. Table 13 below provides the data for both the comparison plate preferences against the datum plates.

Table 13 - Participant preferences for tactile comparison of plates

	Comparison plate preference results ('more comfortable')					
	0 °	**15 °**	**30 °**	**45 °**	**60 °**	**75 °**
Surprise	13	12	7	3	12	6
Joy	7	15	11	4	3	3
Fear	6	11	8	11	5	18
Trust	10	9	7	10	16	12
	Datum plate preference results ('less comfortable')					
	0 °	**15 °**	**30 °**	**45 °**	**60 °**	**75 °**
Surprise	28	23	46	43	28	41
Joy	37	39	41	45	45	49
Fear	41	33	47	38	46	24
Trust	32	45	45	39	26	24

Two graphs can again be generated from this data that can help in the identification of trends. The graphs are presented as follows and represent inversions of one another. The graphs at Figure 76 and Figure 77 do not contain the 'no preference' data as this will be discussed separately.

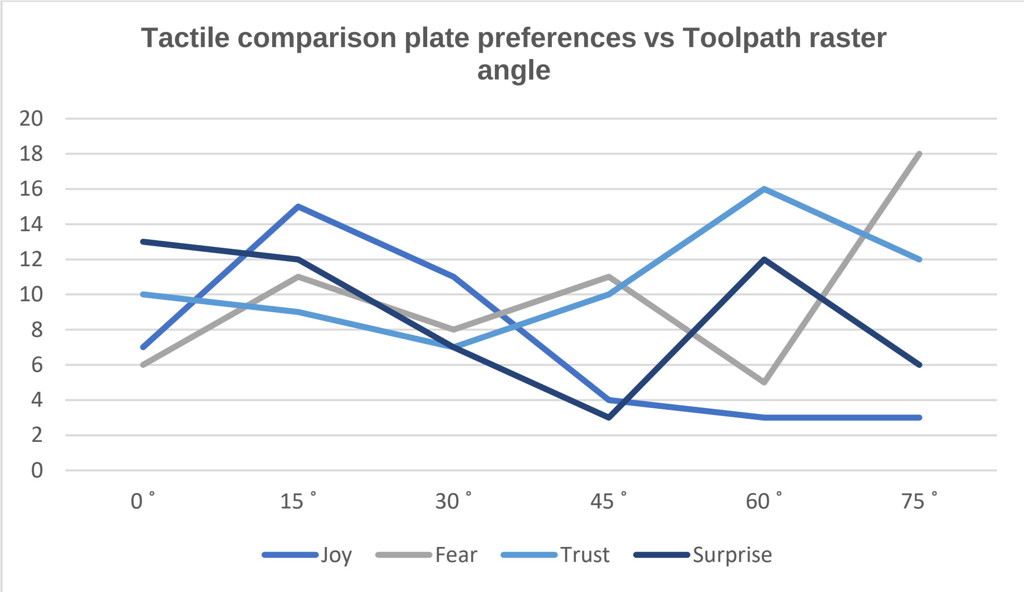


Figure 76 - Tactile preference trends for comparison plates

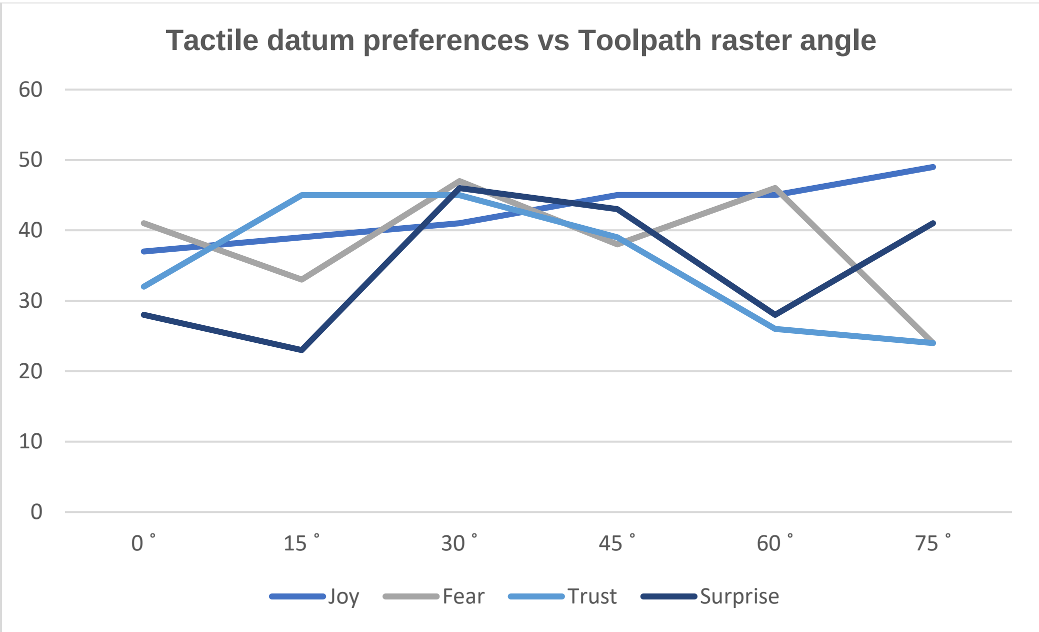
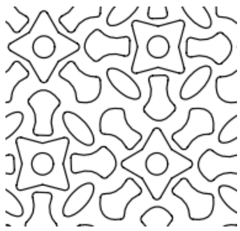
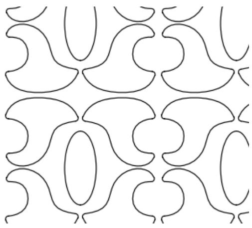
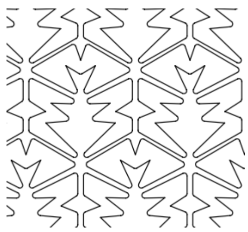
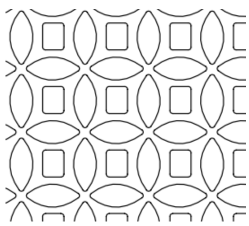


Figure 77 – Tactile preference trends for datum plates

The variations in tactile preference present a bigger challenge to unpack given firstly the subtleties of the tactile changes and secondly the visual references that the participants also had had. The extent of the subtleties may account for the lower rate of preference variation that is seen across the two graphs. Upon analysis, a statistically significant difference between the datum and comparison results was indicated, suggesting that most of the participants did prefer one kind of tactile interaction over another. However, the ‘no preference’ responses were significantly higher than that of the visual preference examination indicating that tactile differences as a results of machining strategies of this scale are less detectable than visual differences. The ‘no preference’ results are shown in Table 14 below.

Table 14 – No preference results

Design		Number of recorded ‘no preference’ results vs total responses
Surprise		**73 / 372**
Joy		**83 / 372**
Fear		**97 / 372**
Trust		**110 / 372**

While these results are clearly skewed towards a preference for the datum or a ‘no preference’ response, the most extreme toolpath preferences are seen at the lower and higher ends of the raster angle spectrum. *Surprise* shows the highest preference ratings for 0°, 15° and 60°. *Joy* shows a similar relationship with the highest preferences given for 15° and 30° with the preferences dropping sharply with the other variations. A relatively large number of participants (18) recorded a preference for *fear* at 75° and *trust* at 60° (16). Considering Table 13, the concentration of positive datum preferences is focused upon the central area from 15°-60°. As these preferences significantly decrease around this area (indicated by red), this provides evidence that some proportion of people prefer the tactile experience of cutting angles that deviate slightly from a toolpath parallel to the workpiece edge. Interestingly, this result is echoed somewhat in the visual responses suggesting there may be an alignment between the visual and tactile preference choices although this is probably a weak relationship. Aesthetic uniformity may be another factor that influenced the responses. The *trust* pattern was created to be very uniform and structured, but *surprise* and *joy* less so. A tactile sense of uniformity may affect the 'no preference' responses; if the pattern has a more uniform construction, tactile differences are less detectable.

6.5 Summary

This section described the core experimental phase of the work. The central philosophical exploration of this stage was the bridging between the technical and material basis of manufacturing and the abstract experiential qualities of emotional interaction with designed objects. More specifically, the tactile and visual preferences were the focus allowing both a physical (non-ocular) interaction and a non-physical (ocular) experiential mode to be examined. The experiment was setup in a simple format that could be easily replicated with a basic principle of preference comparisons underlying the approach.

The work concluded that variances in process parameters had measurable impact on user preferences in terms of the visual and tactile domains. As this aspect of the work is of a subjective disposition and reliant on the interpretation of participants, any conclusions drawn are open to question and scrutiny. The accumulation of more data may produce clearer relationships but what can be concluded is that there are consistently a proportion of people who have aesthetic and tactile preferences with respect to toolpath. If the datum approaches represent a kind of 'normality' or an orthodox technical approach and the comparison plates represent unorthodox approaches, it is clear that an orthodox approach is not always favoured with significant numbers of participants having preferences for an experiential space exterior to a kind of designated material-manufacture 'normality'. This opens the door for a reframing of manufacturing ontology of which we can use machining as an initial exploratory example. The next section will flesh out the implication of these results by introducing a new ontological model of form-emergence for AMT by which AMT approaches can be framed from the perspective of human-centred design, factoring in the complex dynamic of making and its connection to user-experience.

7. A new ontology of modern manufacturing

The birth of an object is the deforming of the objects around it. An object appears like a crack in the real.

- Timothy Morton

This chapter will develop the final contribution of the work: a new ontology of modern advanced manufacturing. To recap, *ontology* in this context is the foundational means by which a manufacturing process is understood within the world – its status within known reality. The ontology uses the central metaphor of *line* to expand upon the principle of *ductus* and bridge the gap between a technical and positivistic perspective of making and the actual experience of the made. Using the ontological model to frame the discussion; firstly, the central principle of ductus will be examined further – how it relates to the work with respect to line, pattern and the other conceptual ground covered. But crucially how it is indelibly tied to both the processes of making and the intentions of the designer. Following this, we explore the reframing of form-emergence that the logic of ductus introduces and consider closely how the studies of line and pattern both contribute to understanding the perception of form and help to frame the development of the new ontology. Through the case study of CNC machining and the explorations of pattern, the coherence between the modelled ontological approach and what can be observed through practical experimental efforts is made plain.

After the critical theoretical background of the ontological model is laid bare, the implications of such a contribution is discussed. Critically, the model, shown visually in full in Figure 78 challenges the dominant designer-agent thesis by *flattening* the ontology of emergence. Philosophically this is complex, but the discussions presented within this chapter look to consider the concept of the ‘will’ (i.e. the will of the designer against the emergence of the made) and how it can be reframed to create a new generalisable ontology.

7.1 Introducing the ontological model

The model is intended to be a new conceptual basis by which to view manufacturing, for this reason it could be used by manufacturing engineers, designers, or artists alike. In essence, it provides an alternative framework in which to consider the processes of production and making by highlighting the links between manufacturing decisions and perception. Additionally, it is explicitly intended to inform the future development of CAM systems and process control systems more generally by highlighting the importance of perception and how it is intimately related to the processes of making. While there is always a ductus (telos, trace or narrative) to a making process, this ontology subverts the standard hylomorphic conceptions of manufacturing ductus by highlighting how when material is shaped by a tool, the material is also working against the tool in a process of exchange, and it is within this dynamic that the perceptual qualities of form (tactility, aesthetics etc.) derive. The experimental work presented in this thesis used CNC machining as a core example of how an understanding of process ductus may be utilised to achieve interesting perceptual outcomes, but the ontology is intended to be generalisable across all processes that have some architecture of digital control implicit in their operation – this question will be explored later in this section by looking at a number of other examples. We can also see how taking a process-centric view can lead to the identification of patterns within the process itself where pattern functions as an important meta-concept for design generally. The following section will examine the ontological model that was developed from the theoretical and experimental stages of this thesis.

Firstly, the dynamics of form, emotion and semantics were considered and cast as an integral part of what has been labelled 'form-emergence' or a kind of ontogenesis (following Simondon, 2005; 2009) where form is not imposed but grows from a multifaceted process. This form emergence is not a fixed state of material physicality but interacts with the subjective feelings that constitute the user experience of an artefact. This transference of information from form to subjective feeling to form is messy and non-linear and is illustrated as such, echoing the transience of emotional states and semantic meaning that was illustrated in the Line model (Chapter 3). Wiberg (2014) has argued that 'wholeness' originating in a subjective experience of material meaning is connected to the appraisal of material through aspects of texture and detailing. This results in notions of authenticity and aesthetic quality entering the overall judgement of an object (artefact materiality). Thus, the modelled ontology shows an interaction between form emergence, artefact aesthetic and artefact materiality. This goes beyond the standard design methodologies and beyond standard conceptions of design for manufacturing. While links between these factors are casually drawn between these elements, they are rarely addressed at the level of ontologies of making and there is an assumed linearity of creation starting with the designer. Pugh's (1990) conception of design for example posits a linear process in which questions of making or manufacturing are only addressed after conceptualisation. By subverting this to make the process the basis of creation, it challenges the assumptions that are made in traditional design processes and opens potential new avenues of aesthetics and material experience. Aesthetics and materiality are indelibly linked to emergence as informed by process ductus and subsequently influence the subjective experience of the artefact on the levels of emotion, semantics and real or perceived affordances.

Secondly, the foundation of the ontology was defined as process and process ductus mediated by computational methods of process analysis such as CAM simulation. This aspect of the ontology allows for its differentiation against 'traditional' methods of making. While the ontological framework is trying to integrate concepts from theoretical making, the distinction is vital given the exploratory studies this work has carried out and the existing ontological models of advanced manufacturing technology this work both challenges and expands upon. The model also considers the interaction between ductus and materials and between ductus and the intentions of the designer. These elements, as we have seen, are vital to the overall process of making and the resultant experience of an artefact; form can indeed be configured to convey abstract concepts of emotion.

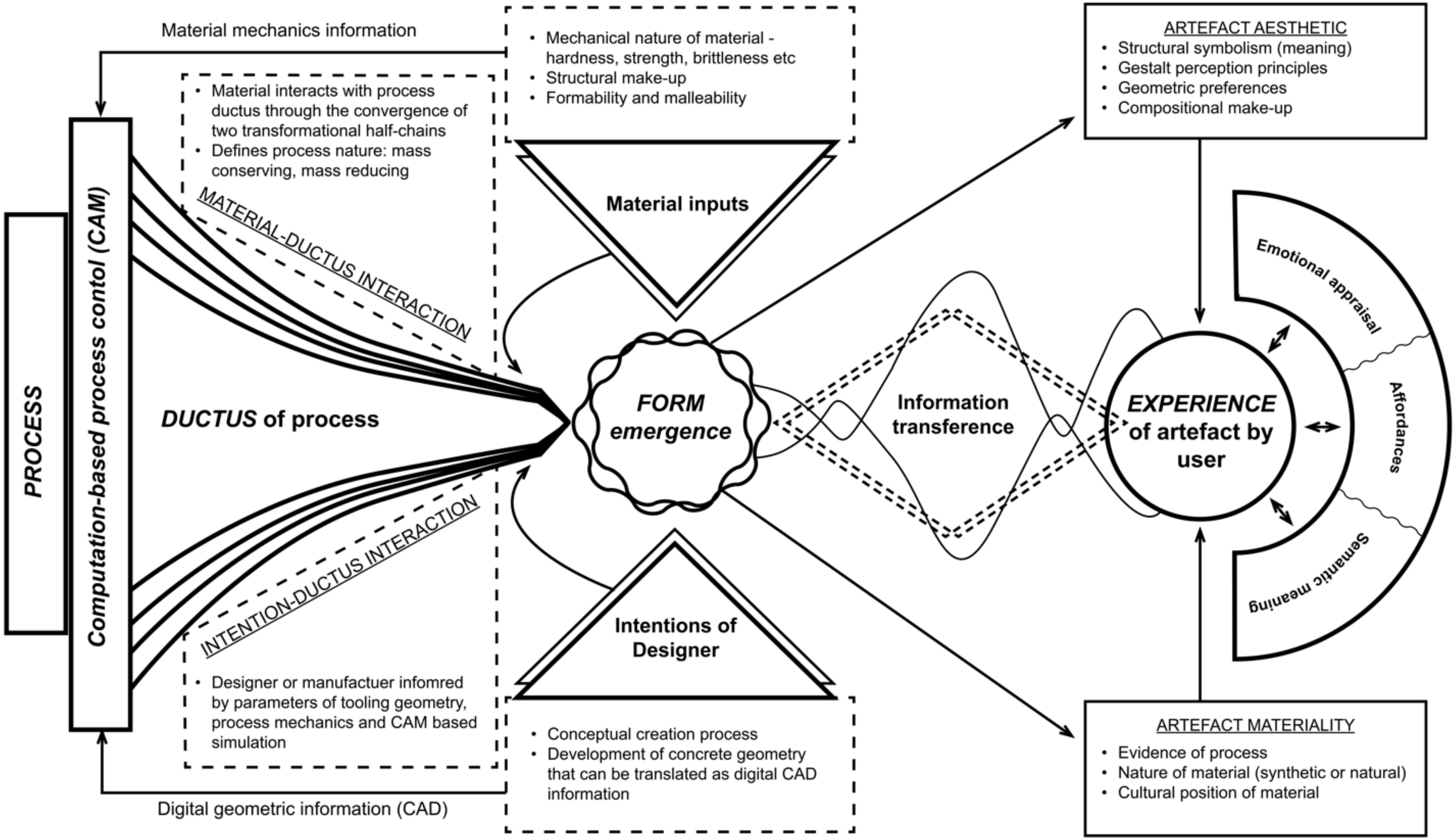


Figure 78 – Proposed generalisable ontology of emergence for AMT including process ductus, Form emergence and user experience of artefact

Material inputs will always have sets of mechanical parameters that may be more flexible or more constrained but the interaction between this and the process in part defines the nature of the transformation – mass reducing, conserving or joining. It is also an interaction based on convergence. This element is critical as it re-establishes the importance of material forces and the primary role they play in how process *ductus* is understood.

Ductus is however modelled as the strongest and most fundamental aspect of the advanced manufacturing ontology. The different strands representing the different parameters of a making process – in machining this could be the size of a cutting tool, feed rates or tool path strategy. All these elements directly influence form emergence and material experience by extension.

7.1.1 Ductus of machining

The principle of *ductus* has been discussed at some length over the course of this project with the intention of reframing it as a basis by which to explore processes of making and form-emergence. If we establish ductus as a kind of imprint or trace left by a process, in what ways can this be applied to a general discussion of AMT and the aesthetics of objects produced through such methods? The answer is complex, and we must draw upon much of our previous discussions as well as the aesthetics and emotion studies undertaken.

Within the context of craft, ductus may be easier to establish absolutely, whereby each individual maker will impart an individuality upon the object. Advanced modern processes are different in one critical sense; the processes are mediated by computer systems. CAD and CAM used in conjunction, allows a manufacturer to make digital representations physical. Though these digital systems are an extension of human intentionality and the manufacturing machines extensions of tools. Ductus can thus be identified (within the context of AMT) at the intersection between concept and process, articulated by a computer system that provides control over the parameters of making. Form emergence is accordingly bounded by material inputs, conceptual design intentions and the making parameters. Simondon (2005; 2009), in his critique of hylomorphic models of making discussed how not only do tools work against material, the material works against the tool. This can be extended to this discussion around machining and to the wider discussion around process ductus making up a critical element in a new ontology for advanced manufacturing. As the machining tool meets the material, guided by a digitally bounded process ductus (CAM software), the material also meets the tool as a kind of oppositional force or what Simondon described as a convergence of 'transformational half-chains' (p.41). In Ingold's (2012, p.433) discussion of this, he describes form emergence as the consequence of a 'field of forces' where the emergence is described a kind of 'transitory equilibration'.

The CAM programme acts as a mediator between the material and the process, allowing the digital forms to be 'ready' for the process - compatible with the technical constraints of the manufacturing system – but also allowing the process (the machine setup) to be 'ready' for a material input. Deleuze and Guattari (2013, p.451) describe form emergence as a process of 'perpetually variable, continuous modulation'. In the context of machining, this modulation lies in the interaction between the cutting tool and the material mediated by a CAM system. This is illustrated by the diagram below where form emergence is not ontologised as a point-to-point transition from CAD information to CAM system to process to material, but as a multi-directional transference between material, geometric information, and process parameters. The interaction between these properties defines the process ductus. Ultimately it is the material and the process ductus that underlie the form emergence or as Ingold (2013, p.434) has stated; 'iron flows, and the smith has to follow' - the dynamics of material and energy influencing form emergence as any intentionality of a designer agent.

In the presented studies, the ductus element explored was that of toolpath, a critical element in the end aesthetic of machined parts. Machining leaves traces in the form of lines and other kinds of markings on the workpiece, sometimes these are very detectable but are usually removed through post-process polishing or finishing operations. These marks and lines, it has been argued imbue a kind of temporality onto the artefact in the same way that the act of drawing leaves a dynamic and temporal trace providing insight into the historic motion of the drawer (Berger, 1990). The marks provide a direct insight into the motions of making conducted by the machines. These motions also contribute to a form emergence and within the context of AMT are strictly controlled within a framework of Cartesian coordinates. The next relevant question is whether this bounded computer system can in any way be ontologically equivalent to the direct work of the human hand. Despite some forceful argumentation from thinkers such as Ingold and Pallasma, the picture is not exactly clear – at what point does the integration of industrial automation cause a loss of materiality? These studies go some way to demonstrate that even within a bounded computational system where a process is mediated by digital simulation, different vistas of material experience can be created. For this reason, it can be considered as a building block in a new ontology of advanced manufacturing. Figure 79 shows this dynamic at work – a process of form-emergence mediated by a system of technical control of process (CAM).

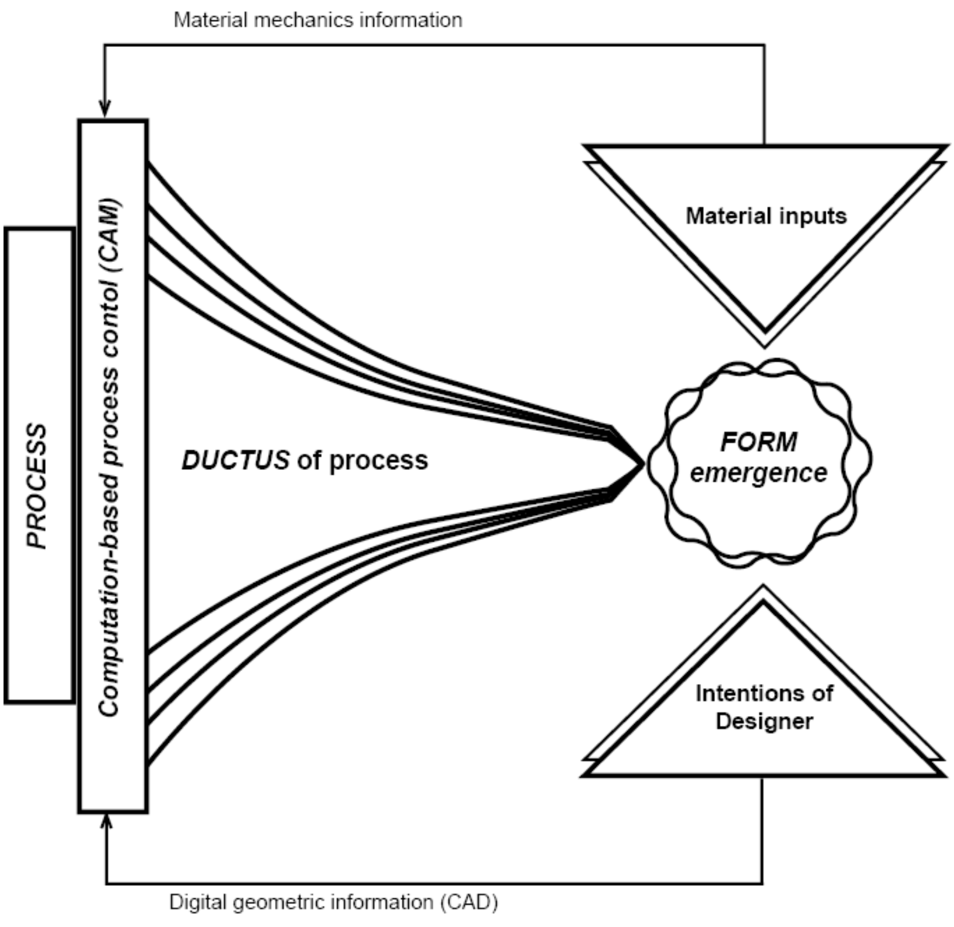


Figure 79 – Ontological basis of form emergence in the context of AMT founded upon process and process ductus with material and intentional inputs also mapped

7.1.2 Ductus and emergence; HCD and Kansei engineering

How can these conceptions of process ductus be integrated into wider design theory? And what implications can this have for HCD thinking and Kansei engineering? So far, we have seen how the control of process that is afforded by CAM technology can be reframed within a new ontology for manufacturing. The critical component in the new ontology is how process ductus influences form emergence and interacts with other factors such as emotion and semantics. There are several critical ways in which this ontological reframing can influence HCD thinking. Looking back to Interaction Design theory that was discussed in section 1.6, there is much to be said. The 'dimensions' the Moggeridge introduced to delineate the relationships between the physical dimensions of a product (its physical form) and other qualities of product use (meaning, time and behaviour). Interaction Design is philosophically and practically important for HCD as it allows for the tuning of products to be better understood functionally and more pleasurable to use, following Jordan's (2000) framing. Introducing the ductus concept or a more process-focused framing of making benefits this philosophical position by configuring a form-emergence within a system of material-process interactions that can be on some level controlled using technology such as CAM software. Human-centred approaches favour design outcomes that are highly attuned to specific user groups or specific needs (Giacomin, 2014). By establishing a process ductus, aspects of form, aesthetics and tactility can be addressed in a more controlled and direct way. This new ontological model could be an HCD approach to improve visual guidance for users – enhancing what Norman (2004) called a 'real' or 'detectable' affordance and what Moggeridge (2007) described in the dimensions of 'visual representation' and 'behaviour'. This is only in the context of CNC machining, but the concept is easily extendable to other processes where different material aspects and different dimensions of user experience can be drawn out.

As a related mode of design thinking, Kansei engineering can also be enhanced by the introduction of a conceptual process ductus. Kansei design thinking posits, in a similar way to HCD, that products and services can be edited or reconfigured to achieve more positive experiences for users (Schütte et al., 2004). Critically, the Kansei methods are reliant on the integration semantic theory with practices within product engineering. The exploratory studies that were presented over the course of this project demonstrate a plausible approach by which properties of manufacturing processes can be integrated within the framework of Kansei design thinking. Specifically, Kansei engineering develops attuned psychological and physiological experiences based on focused user testing (Lévy, 2013). Ontologically, the methods are framed from a perspective of psychological responses to form, aesthetics, and function but not from responses to specific material properties or properties associated with process ductus. Introducing process and ductus into this perspective advances the scope of Kansei methods allowing the intrinsic aspects of process to be utilised for attuned psychological and ergonomic design. The interesting studies from Niedderer (2012) demonstrate that manufacturing processes can be configured to deliver enhanced emotional responses and engagements and enhanced function. Accordingly, the resultant product or object experiences are richer as a result of these ductus-focused making perspectives.

Principally, these questions were explored with reference to firstly line and then, by extension, pattern. Line was used as a means of establishing a context in which to consider form. As discussed, 'form' is a tricky concept – at once seemingly abstract and concrete but ultimately entwined with the lived experience of emotion and semantics (see Dewey, 1934). But the line model that was introduced in chapter 3 allowed us to pin down some forms of representation of which the central embodying tool was the use of repeating motifs and symmetry. Even a lack of detectable pattern or symmetry counter-intuitively, recognises it. Once pattern was detected as the principal tool in operation, it was explored further. Both pattern as an explicit decorative or functional design element and pattern as a kind of meta-concept within design (its presence literally everywhere, from wood grain to the organisation of glass windows on a skyscraper). In this sense, line and pattern become ways in which we can explore ductus further and, in many ways, CNC machining is an ideal example with respect to these concepts. As shown in section 5.3, modern advanced machining processes utilise simulation software to visualize the planned operation before it is performed in the physical world. Interestingly enough, these tools path simulations are mapped using *line* itself. The cutting operation, as imagined within this digital space, explicitly uses the metaphor or the line or path to communicate the process. What's more is that the paths themselves follow patterned trajectories – their paths are bounded around particular geometric relationalities; the resultant paths additionally create patterns through unintentional emergences from the interactions between the paths. The picture that emerges is that of a kind of layered patterning; form as built from line into shapes and structural elements is mediated through the pattern meta-concept, and the process of making itself is *dependent upon a kind of patterning*. In the experimentation presented in this work, this process is brought to the fore. Pattern is explored on four levels:

1) *The abstract-conceptual level;* pattern as a meta-concept and foundational tool within design
2) *The symbolic-aesthetic level*; pattern explored explicitly as an artefact of decoration or ornament
3) *The structural level*: pattern translated from a two-dimensional representation into a three-dimensional one necessitating a structural architecture with repeating shapes bounded within a system of symmetry
4) *The process-emergence level;* the patterning implicit within processes of making and formation of artefacts, the ductus of the making process

The relationalities between these levels is the central narrative of what has been discussed and explored. With respect to advanced machining, instead of viewing it from a rigid ontology of hylomorphic inputs and outputs, its ductus and resultant form-emergence can be viewed as a nexus of interrelated patterns, both physical and abstract.

7.1.3 Dynamics of 2D and 3D form – experience and emotion

The interplay between these levels described above is perhaps one of the most interesting factors for further discussion. During the studies on pattern aesthetics, the patterns and associated textures most dominantly structured around curves were strongly associated with feelings of *love, joy* and *trust*. This was also seen in the analysis of line where structured curved linear elements were viewed as having a positive valence. Although, the results also present a complex picture of aesthetics and emotion. While the epistemic basis of emotion is a topic beyond the scope of this work, phenomenological conclusions can be drawn. John Dewey, in his philosophical study of the aesthetic experience spoke of emotional transience and a shift between emotional states which is instructive:

'We are given to thinking of emotions as things as simple and compact as are words by which we name them. Joy, sorrow, hope, fear, anger, curiosity, are treated as if each in itself were a sort of entity that enters full-made… In fact, emotions are qualities… of a complex experience that moves and changes.' (Dewey, 1934, p.41)

The developed line model substantiates this perspective but also tries to concretise the experience in some way. Like the literal paths we walk, the structures contain both a literal static architecture but also movement and change are implicit in their presence. Isolated geometry and lines were explored for the emotive connections they draw – lines representing a kind of structural exploration space and modes of detecting solid forms or boundaries, a 'pinning down' of form. The findings presented illustrate the complexities of emotional interpretation, where broad classes of experience can be created but it is harder to detect specific discrete experiences. Some measurements of the patterns and textures showed a flatness of interpretation, but others were less ambiguous. This can be linked to the varieties of object experience and the varieties of semiotic processes by which meaning is created within the context of object interaction. Considering Krippendorff's (2006) model of meaning emergence (Figure 8), the meanings come from an interplay between actions, the senses, and the external world. When people view the patterns and interact with the textures, this process of meaning emergence is at work informed by natural inclinations towards Gestalt factors, cultural symbolism, and processes of action. Wikstrom, (1996) has described how these factors create an overall gestalt impression that describes, expresses, signifies, and identifies the semantic functions of products. A study from Demirbilek and Sener (2003) emphasise this perspective by demonstrating that the semantic signifiers of 'cuteness' can be repurposed for use in product elements and product styling. The exercise of arranging discrete geometry to create emotive patterns shows that simple abstract indicators will be furnished by observers with emotive meaning. One pattern for example was symbolic of *love* for many observers indicating that even highly complex human emotions and ideas can be 'embodied' within the non-human object.

In developing a new ontology for advanced manufacturing, the emotive-semantic associations of form must be considered. Following the studies comparing 2D and 3D geometry and the discussions around styling and semantics that culminated in the Line model (Chapter 3), a component of the model can be established. This component represents the exchange between form, material, semantic signifiers, and emotional experience. If we take a 'form emergence' phenomena, that is facilitated by machine engagements and processes of making, as an initial starting point, an element of a new ontology can be examined. The critical dynamic is one of exchange whereby the experiences associated with form engagement or interaction (emotion, semantic interpretation and so on) are both informed by and an influence on the form itself (Figure 80). The process is bidirectional where the qualities of experience change the nature of an object's formal qualities; the way illusion can reveal symbolic values in form and symbolic values can stir emotion. All of this is fundamental to a process of form emergence that Ingold (2009) has stated is contingent upon flows of material and energy but is also bounded in an ontology contingent upon flows of emotional experiences, semantic meanings and identified affordances. It should also be noted that what we might call the 'architecture' of experiences or the conditions which produce and inform it, exist *prior* to the form itself and exist in a space somewhat detached from the process of form emergence (as shown). They are, nevertheless, the foundation of the experience of the user – existing in a kind of superposition, not intrinsically a part of an artefact but also not entirely removed from it. For example, the experience of an object appearing 'cute' depends on a pre-existent nexus of cultural and psychosocial arrangements that the made object is both dependent on and outside of.

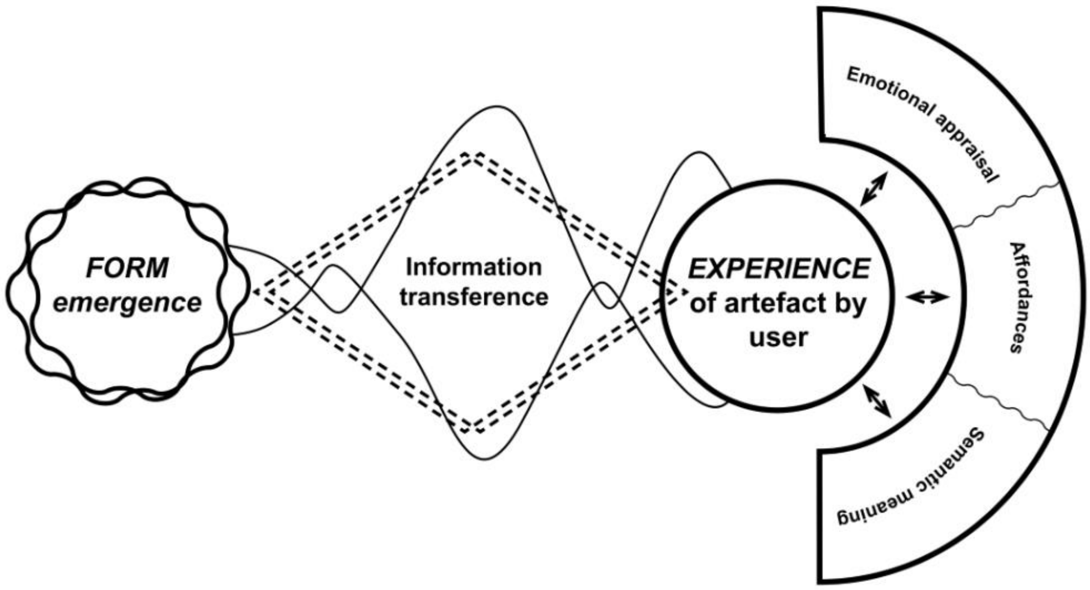


Figure 80 – Ontological basis of form emergence with respect to the subjective domain of user experience including emotions, affordances, and semantic meaning of artefact

7.1.4 2D and 3D form – making and the perceptual process

Pattern has been addressed as the central meta-concept in design with this work exploring it on abstract, aesthetic, structural and operational levels. Pattern and pattern-based texture were investigated as powerful tools for aesthetic, cultural and semantic expression. This opened up further questions and subsequently we can ask to what extent pattern and texture can transmit psychological knowledge, knowledge of emotions and discrete semantic concepts associated with emotions? The results presented in Chapter 6 go some way to answer these questions. Going back to the initial methodology formulated in Chapter 2, the philosophical approach is a unification of weak-positivism and weak-interpretivism bounded by a realist position allowing for both objective and subjective aspects of knowledge to be established. The mixed-method approach involved the subjective interpretation of forms by participants which was then assessed quantitatively, establishing some subjective responses as more dominant than others. This subjective conceptual dominance allows us to draw inferences around semantics, symbology and aesthetic preferences in pattern and texture helping us further examine an ontology of emergence seen in advanced machining processes. It is the move from two-dimensions into three-dimensions that allows us to examine both form from an abstract perspective and then form as it emerges in the material world.

The separate patterns were designed with reference to aesthetic theory and work in experimental aesthetics to represent distinct emotion concepts. On review of the raw, 2D designs, it was found that pattern could be used to represent emotions as intended following Foster's (1984) model of feature recognition in composition. While there were some small deviations, the positive versus negative valence was always consistent adding further validation to the previous findings of other perception and aesthetics scholars. These results were then mirrored in the results for the texture designs. No statistically significant difference between the results was found indicating that both configurations of the designs could coherently represent emotive values. Some values were seen to increase in perceived intensity while others decreased, suggesting that the move to a physical space created subtle differences in aesthetic experience. Theories and experimental work in perception are vital for understanding these findings. As we are reviewing the difference between a physicalised version of a 2D design, the body of literature exploring change detection is relevant. The Weber-Fencher laws of Just-Noticeable Differences (see Dehaene, 2003 for an overview) hypothesised that perceived change and actual change between stimuli follow proportional rules.

Accordingly, if a big change has occurred the effectiveness of our senses to detect it will be strong. The later stages of this work have explicitly focused on the relationship between marginal changes and visual-tactile preferences. While proportional trends were not directly observed, some weak trends suggest stronger preference effects for toolpath raster angles that were significantly different from the datum and vice versa. Additionally, the structural design of the patterns themselves may have played a role with preferences determined by the dominant compositional elements within the patterns and textures. This is seen directly in the results for the trust, joy and fear texture preferences – the structural elements against the visible toolpath may be an influence. Another effect, though only measured marginally, was the increase in perceived intensity of many of the emotive concepts in the physical space, implying a greater level of apparent dominance for certain visual elements (following Reed Kostellow's (Hannah, 2008) theory of compositional dominance).

Gestalt psychologists instruct that the orientation, proximity, and sense of symmetry play a role in visual processing of form. The subtle changes that come from a 3D translation may have implications for the sense of meaning conveyed by the shapes – this effect may be small but could be borne out with further study. Modern Gestalt theory has described a 'sense of happening' that may inform an aesthetic encounter (Pinna, 2010). The sense of happening that is drawn from a 2D rendition may be different to a 3D one; there are elevated levels of dynamics in the forms, more directional changes, more psychological forces to use Arnheim's terminology. Arnheim (1997, p.254) has indeed stated that 'thinking calls for images, and images contain thought' implying that changes and transitions in form, change the kind of thought required to understand or interpret them. This can be extended to design and the interpretation of product artefacts. Modern work related to Gestalt theory has discussed a perception of history by which things can be seen through the lens of how they have been changed. Chen and Scholl (2016) have articulated that even static objects can induce feelings of 'illusory motion' based on an imagined change history, an explicit temporality in the perceptual understanding. Additional work has related perceived material properties with a basic visual-cue-based heuristic (Paulun et al., 2017). The same principle can fundamentally be applied to the ideas presented here – an enhanced materiality through visible toolpath creates a causal history in which the matter has been intruded upon by process in some visible way. Or does it provide insight into the properties of the material itself? 'Temporal form' was discussed previously through the work of Vallgårda (2013) with others considering the possibilities of smart shape-changing interfaces that are reliant on a sense of temporality (Alexander et al., 2018). Enhancing the material space, making it a shifting fabric of lines and geometric interactions draws out a sense of history; a tangible history of process relating to a wider ontology of emergence. As an inversion of this, additive manufacturing offers another interesting example. Additive manufacturing, like machining is guided by patterns and lines that leave a trace of its process of form emergence. Unlike machining, it adds material not subtracting it, allowing for a different array of aesthetic and textural options.

Affordances have been established as a useful concept, though what can be said for the affordances present in these textured surfaces? The study of tactile preferences and visual preferences establish a basis by which user interaction can be enhanced thus supplementing an affordance dynamic with experientially attuned design elements in particular domains. Texture and pattern can act as guides for functional interaction – like the haptic feedback of computing technology, a textured space with symbolic value can instruct or guide the user. An interesting example of this already implemented is the Media Lab TRANSFORM interface developed by MIT which provides both visual and tactile interactions for users – a smart interface that is simultaneously proactive and reactive with respect to the user[20]. This work has explored aesthetic and tactile preferences and not function explicitly, but it is not hard to see how a carefully designed toolpath strategy might enhance design affordances, guiding users towards key functions within a product space. Figure 81 shows a hypothetical toolpath strategy that uses tooling marks to *guide* the use of the proposed product. The imagined product is a simple interface with a few key function points. The simple toolpath strategy visually emphasises the important points of function, acting as a guide for potential users.

[20] https://www.media.mit.edu/projects/transform/overview/

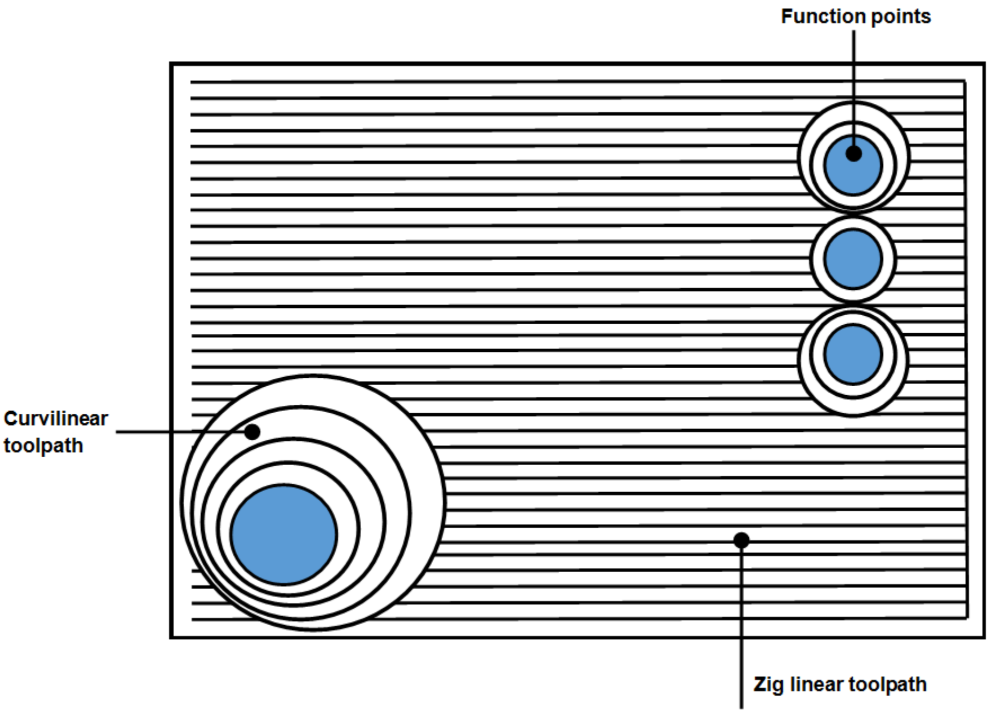


Figure 81 – Hypothesised toolpath that visually emphasises function points through strategy variation, the curvilinear path contrasts the linear path leading to an interesting visual effect

The figure above can be viewed as a simple exercise in trying to visually highlight areas of function within a structure. This can be expanded to consider more complex instances. Exploring the pattern and line theme further, Figure 82 below, illustrates how machining tool path could be used to create intricate networks of interlacing lines that have the appearance of a pattern themselves. Like the example above, the weaving of these lines could bring out points of value on the structure.

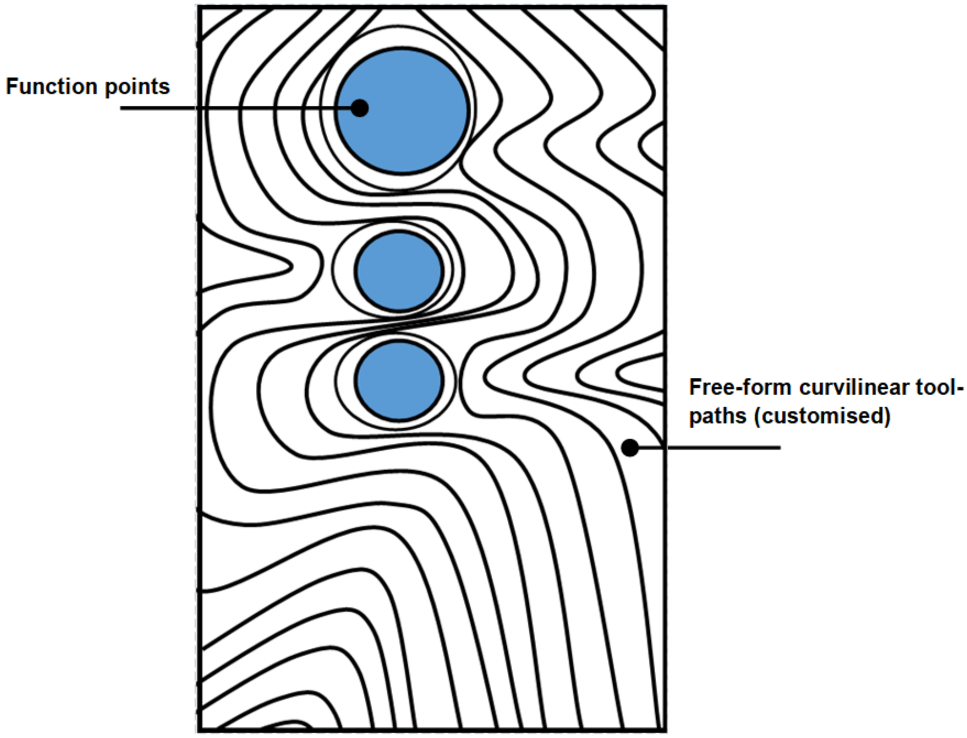


Figure 82 - Hypothesised toolpath that visually emphasises function points through a free-form curvilinear toolpath similar to the representations of 'joy' explored earlier

The toolpaths may also operate on the symbolic level whereby the curving geometries are configured as a representation of an idea or to embody a particular emotion. As we have seen, the line not only represents a kind of movement or energy transference, it can represent specific emotions. As shown in the hypothetical example, part of the structure may have a more positive structural valence and another a more negative.

While the first two examples considered pattern at the level of process (i.e., the ductus embodied in the traces left by the machining toolpaths), pattern at the level of aesthetics and symbolism can also be considered. Imagine a pattern-based texture of the type shown below (Figure 83). An advanced process like CNC machining would provide control of the form in both the horizontal (mapping of structural cross-sections) and vertical directions (textility and depth of structure). In the example below we can consider a pattern that 'moves' from a larger angular formation (negative valence) to a smaller curved formation (positive valence) that appears to 'focus in' on a point of value. As noted, the point of value – possibly a point of functionality or an aesthetic feature – could be enhanced by this visual element but also by a textural quality where the feature is either embossed or debossed relative to the rest of the structure.

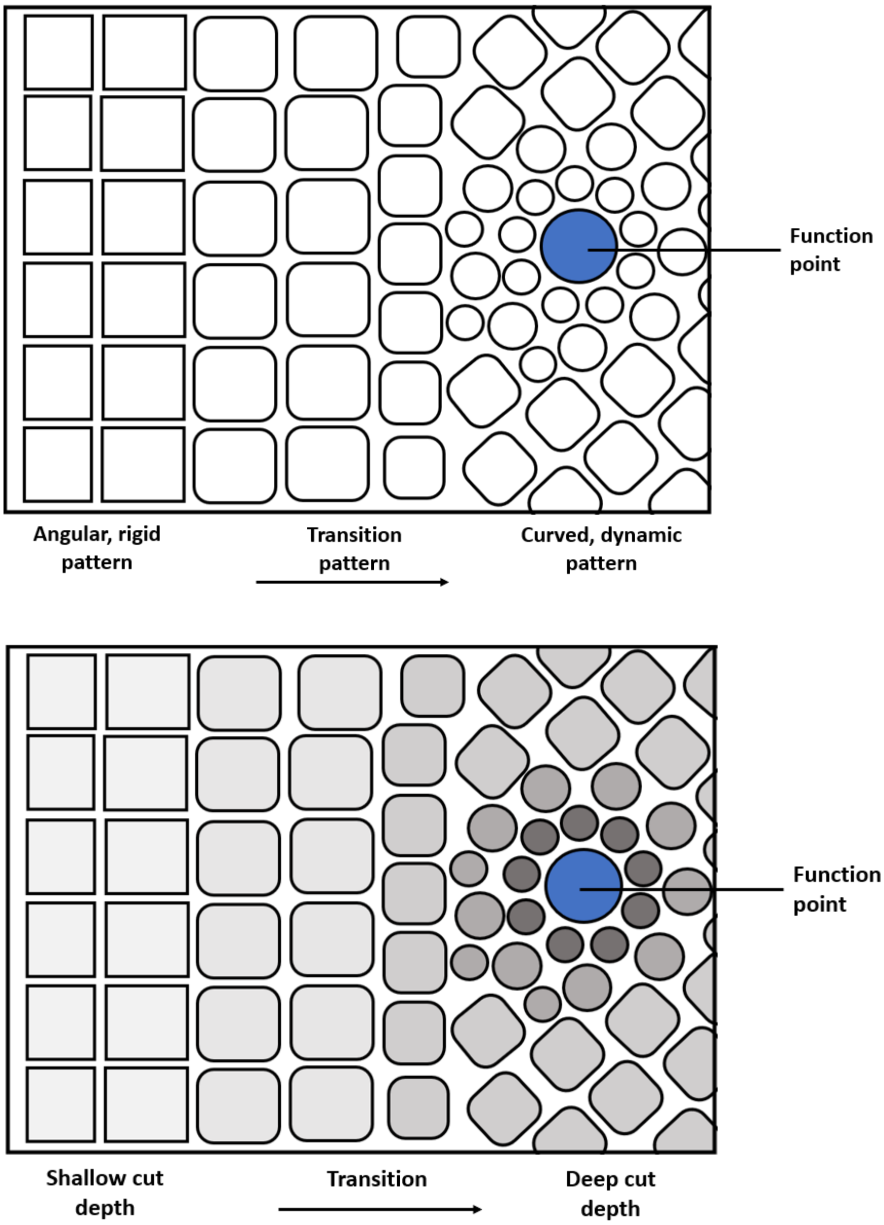


Figure 83 - Hypothetical embossing vs debossing visual geometric effect

But this also revisits up one of the fundamental concerns of this work; form as experienced in the visual dimension and how the manufacturing process interfaces with this. In Figure 84 below, two examples are shown in which a structural pattern and a process pattern are highlighted. In the bottom image a toolpath pattern that does not map onto the directional formation of the structural elements is shown – this causes visual interference. The earlier studies demonstrated that forms of visual interference can actually make aesthetic qualities seem more *interesting* to the onlooker. By contrast, on the top a toolpath pattern is shown that conforms to the directional formation of the features. This conformity presents something that has less visual interference and perhaps more emotive *neutrality*. Either of these could be desirable in particular design contexts. The two patterns give very different aesthetic appearances that could be used in different design contexts. The Gestalt theorists discussed earlier proposed a holistic view of aesthetics – this example shows the relevance of their thinking. Bringing gestalt holism into the aesthetic thinking behind toolpath strategy could clearly open new avenues of aesthetic and tactile experience.

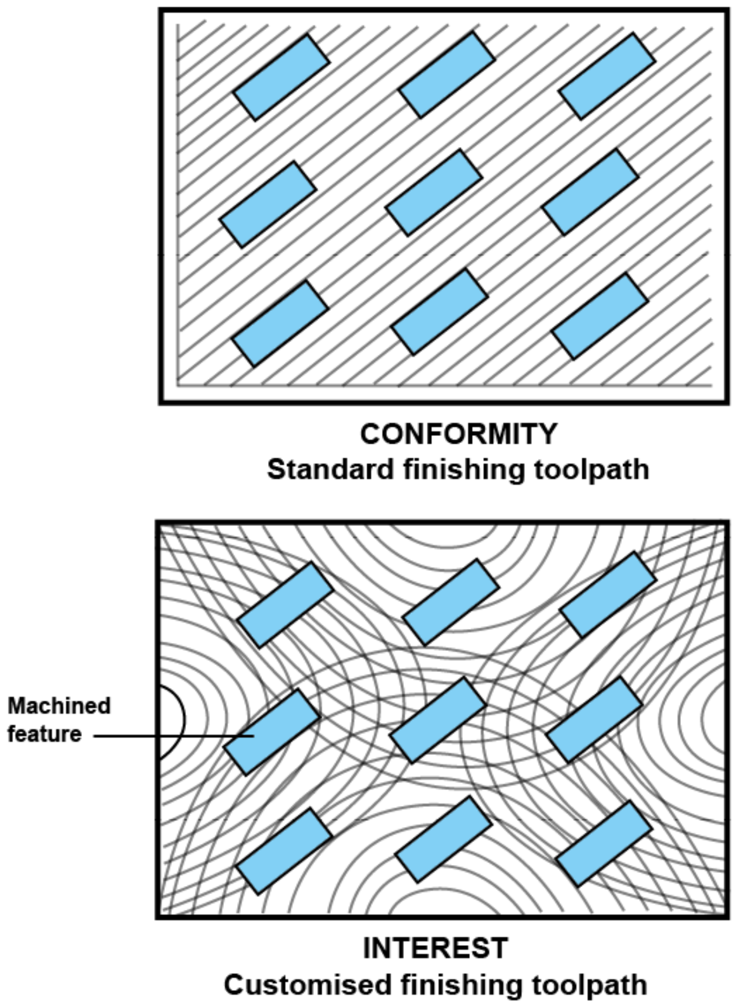


Figure 84 - Hypothetical conformity vs interest toolpath concept visulizations

Given the modern dominance of CAM systems that *generate* toolpaths based on assumed efficiencies means that this proposed kind of *crafted* toolpath is less feasible. In the past, toolpaths were programmed step by step and while this is still possible in theory, in practice the prescribed toolpath strategies established within various software are more often used. This technological and cultural shift has meant this kind of crafted numerically controlled toolpath is rarer. As proposed, a cultural reframing that considers elements of the process as something to be crafted, what Ingold (2009) has referred to as a 'textility' of making, could have clear benefits for design aesthetics, interaction and affordance markers and signifiers. Indeed, work from Inella and Rodgers (2018) has argued that the processes of modern engineering practice should be much more engaged in the cultures of art, suggesting the developers of these technical systems should have art 'context tools' to develop emotional and critical sensitivities.

7.1.5 Tactile properties of machined metal: texture and materiality

Due to its widespread use in machining, this work studied the effects of the machining process on metal, specifically Aluminium. Many materials are machined including wood, manmade boards, and polymers though metal accounts for most of machined material due to the widespread aerospace and automotive applications. Over the course of this work, it was established that tactile preferences either deferred to a datum orthodoxy or were not meaningfully detectable. It seems that the recorded non-datum preferences within the visual domain far outweighed the non-datum preferences for the tactile domain. There are a few plausible reasons for this; first, people care less about tactile features, second, the manufacturing process did not create large enough tactile properties, third, the datum preferences represent real preferences and not reversion to a norm or orthodox state. Given the work of numerous research efforts establishing the importance of material experiences (see Ashby and Johnson, 2002 for a good summary), the first option is unlikely. This leaves the second and third options which are both possible but could only be established with any certainty with further study. The second option seems more plausible given that if detection of a stimuli is possible, the results may have a larger range of recorded preferences, as with the visual dimension. Regardless, even if the effect is small or there is a large bias towards the datum, this indicates the presence of preferential tactile experiences with relation to machining strategy. The 90° datum essentially represents an efficient orthodox approach, parallel to the edge of the workpiece. Participants may feel naturally drawn to a motion that is up and down, following the structure of the work material, feeling deviations from this path to be strange – we have already explored how the line can act as a map, a delineated route.

Past work on texture and material preferences has indicated that some tactile sensation can have emotional implications by being associated with experiences of warmth or coldness - sensoaesthetics (Miodownik, 2007). This could be a point for further investigation with the textures. While it has been established that they convey emotive concepts, it is unclear whether the tactile sensations themselves can relay such concepts – previous work such as Karana et al. (2009) would suggest such. What is interesting however is considering if objective surface smoothness is guiding the preferences. Despite the datum and 'no preference' choices being dominant, the highest tactile preference scores were recorded on plates with relatively few defects implying that a good surface quality with respect to the geometric elements is important with respect to machined components but does not necessarily represent the most vital experiential factor. Looking at the relationship between the tactile and visual preferences, there is a very weak correlation in the trends for all the texture designs. This implies that the experiences are connected, possibly influencing each other. Yanagisawa and Takatsuji (2015) considered how visual expectations can influence tactile perception finding that exposure to certain material qualities (e.g. visual glossiness) can influence tactile experience of a different material. While the material in our tests remained consistent, this real effect with respect to the visual exposure to textures in the first part of the tests may influence the subsequent material experience. Given the constraints of the experiment and the available data, it is not possible to know with certainty.

With respect to the new ontology that is being developed, the accumulated results tell us that the tactile domain does produce real preferences, but these are only weakly tied to the visual preferences. It is likely that a larger size of stepover, or a larger machine tool would have created more noticeable tactile differences in the parts whereby the conclusions of these results may be clearer. This would have enhanced the relationship between the process ductus and the form emergence. The measured effects suggest that the tactile domain is a factor in the overarching material experience of machined metal thus providing a foundation to further develop an ontology of process, though first we must examine the notion of ductus with respect to aesthetics more closely.

7.1.6 CAM and the perceptual experiences of artefacts

The evidence presented in this work suggests that the free modification of targeted process parameters can achieve specific experience factors. With respect to the patterning and texturing features explored in the last section, such features could for instance be used on housings of consumer products. Apple Mac laptops and Linn hi-fi systems utilise CNC metal machining in the construction of their products. A kind of patterning and texturing could be used to enhance the aesthetics of these artefacts and 'guide' users in some ways by drawing them visually and emotively towards points of interest that may perform function or enhance product identity.

This raises the question of creating a generalisable tool; how can these concepts of perception and experience and new concepts like 'ductus' be integrated within current production practices to achieve novel outcomes? To do this, the function and architecture of CAM systems can be re-examined. Previously in section 5.3 the background and foundational culture of CAM was explored, outlining how standard CAM systems and systems of process control more generally have in-built biases towards particular kinds of manufacturing outcomes – efficient and free of 'imperfections' (Taylorist). This bias to what Pallasma (2005/2012) called the 'flatness' in modern production has led the architecture of CAM systems to limit the exploration capacity of processes and removes what can be broadly described as user-experience concepts. The diagram below shows the as-is status of CAM systems where the process has an in-built linearity with the cultural assumptions of hylomorphism. The designer wants to create something; accordingly, the processes are tailored to achieve this exact goal (Figure 85).

It should also be noted however that the tacit knowledge[21] of machinists is also a component in the successful creation of a part. CNC milling technicians who may have worked for many years to develop skills in using machining equipment have a unique

[21] 'Tacit knowledge' was defined by Polanyi (1958) as knowledge that is not or cannot be formally codified, or as Polanyi asserted 'we can know more than we can tell'.

type of knowledge, similar to what Vinck (2009) has described as 'everyday engineering' whereby a range of problem solving abilities are honed but not necessarily systematised, formalised or encoded into the process control systems. The result is an as-is CAM architecture that is incomplete as it does not capture this kind of tacit knowledge. In essence, an abstraction serves particular useful functions but is limited by the attenuation of craftman-like knowledge.

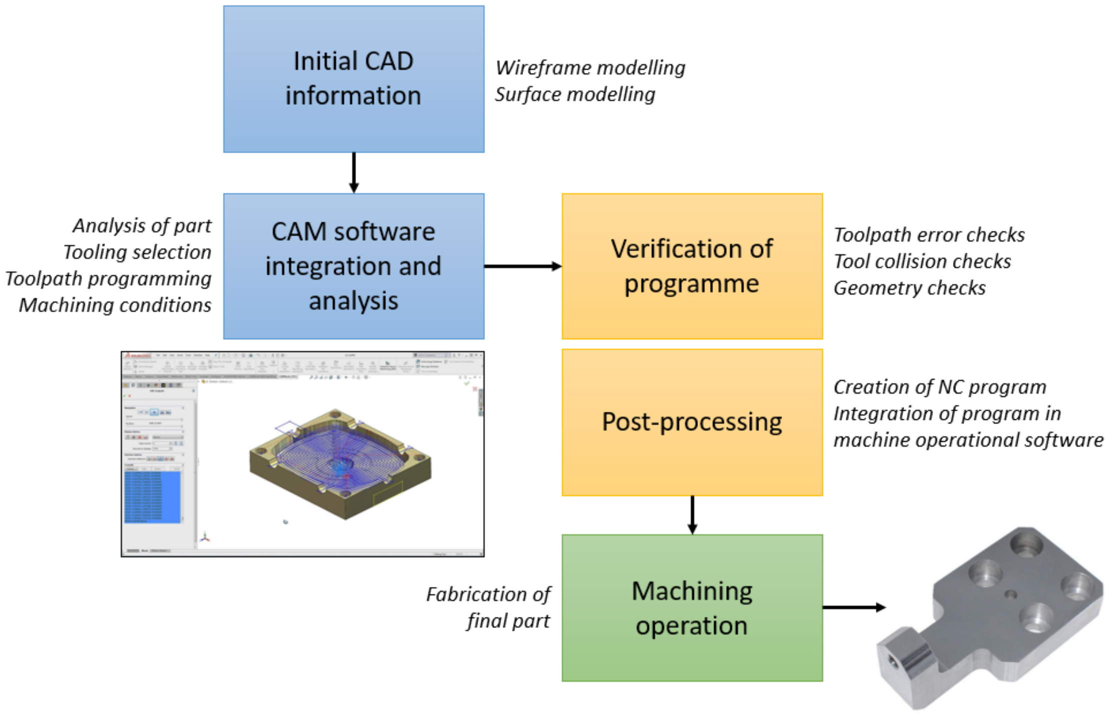


Figure 85 - As-is CAM architecture

This presupposes that the in-process dynamics cannot offer anything in themselves of value outside the bounds of perfected object fabrication. As we have seen however, the intrinsic qualities of a process can introduce new and interesting properties into fabricated objects at both the level of form and perception. EdgeCAM for instance has a sophisticated rendering engine and allows the user to 'see' how the part would look utilising a defined set of parameters (similar systems for additive manufacturing such as Fusion 360 use this approach). As the process is simulated, interesting effects appear in the render as the simulation creates patterns. The problem is that these interesting possibilities are not highlighted by the software at all. Furthermore, CAM software does not offer any insight into UX or human factors; properties of perception and experience are not considered in reference to a simulated process. With respect to this observed shortcoming, a new CAM architecture is proposed and mapped out in the diagram below (Figure 86).

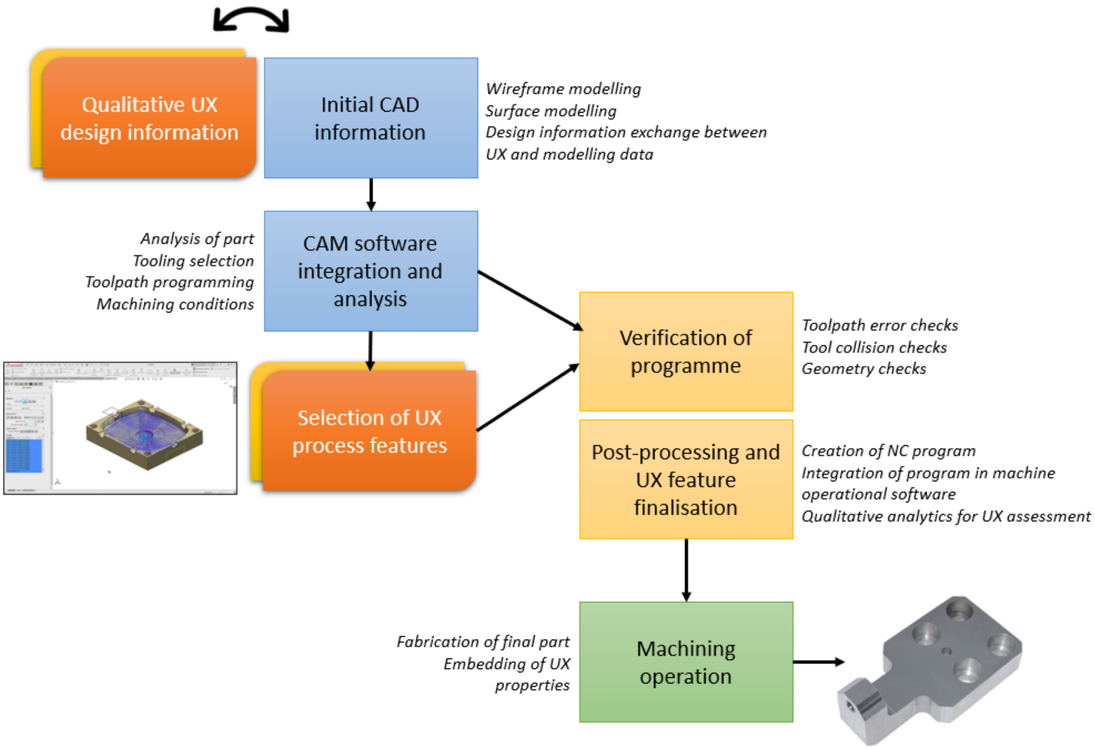


Figure 86 - To-be CAM architecture integrating human-factors and UX concepts

The new hypothetical architecture integrates human factors options into a CAM software system and also unorthodox possibilities relating to the ductus of process. This could include perceptual information such as emotions, semantic meaning, and affordances. Work from other design researchers has developed models that follow a similar logic whereby the intrinsic links between the procedures of manufacturing engineering and the more abstract domains of aesthetics and social functions are elucidated (see Childs, 2013). Furthermore, Sikhwal and Childs (2021) have explored the concept of 'mass individualization' proposing that product development could utilise sets of integrated modules unified by an open hardware platform. In a similar vein, this hypothetical architecture would facilitate more user involvement in the selection of discrete form properties, in turn creating a wider array of distinct product forms. For example, a CAM simulation mapping the fabrication of a part through additive manufacturing could offer the user options with respect to the visual interest factors of the build. Additionally, a build could be tailored for comfort utilising texturing options. Handheld objects such as gaming controllers could be attuned for specific experiential outcomes within the CAM system, drawing on the dynamics of process ductus. This essentially reframes the CAM philosophies seen earlier as not just processes of material transformation control, but processes linked to potential perceptual experiences.

7.2 Towards a new ontology of advanced manufacturing

7.2.1 Challenging hylomorphic manufacturing ontologies

Chapter 5 explored various taxonomies of advanced manufacturing technology, these being ways of defining the fundamental characteristics of processes and the foundation by which they are understood to exist and operate within the world (their ontological status). It was argued that while many of these are useful ways of conceptualizing manufacturing, it misses crucial aspects of material experience and its articulation with form emergence. Stating that a process is mass conserving and uses thermal energy in the process tells us nothing about the nature of the material change or how the process is guided by interaction between machines and materials – this is missing from these ontological framings. Tim Ingold, whose thinking has influenced many of the arguments within this work has frequently posited that modern conceptions of making, design and, by extension, advanced production are directed by Aristotelian hylomorphic assumptions (Ingold 2008, 2009). Hylomorphism puts the designer-agent at the pinnacle of a top-down ontology of emergence (see Peramatzis, 2018). This framing of making has now entered the ontologies of advanced production methods whereby the digitally controlled machine-actor imposes a *will* (albeit a will mediated through a digitised system) onto a lump of matter, perhaps sitting within a large, automated machine. The literature and culture around these processes reflects this belief in an apparently relentless search for improved machine 'efficiencies' or improved aesthetics (surface finishes, defect reduction and the like). Some of this culture can be attributed to visual subjectivity and the cementing of linear perspective and proportion within the Western mind from the aesthetic models of ancient Greece and the 14^{th} century European Renaissance through the Enlightenment. Some thinkers such as Grafton Tanner (2020) and Vincent Mosco (2005) have argued that the Enlightenment notions of the 'sublime' have now fused with the experiences of utilising digital devices; disproportionate value is now placed on systems or experiences that are mediated through and delivered by computers. This so-called 'digital-sublime' can extend into the critique of the hylomorphism implicit within advanced numerically controlled processes. While CAM and CNC systems offer kinds of control and power over making processes, they strongly orient the designer/engineer within a digital world; a world that relates to the real one but is also separate from it. In the world of the digital-sublime, the potential for transgression exists but it is often discouraged by the appearance of 'ERROR' messages; at once expanding the power of the designer but limiting her within a system of rules that only correlates to a set of agreed upon technical requirements whose origins or justifications may be unclear. This intrinsically separates the maker from the process of making (process ductus in this framing). In the case of machining, which this work has focused on as an exploratory case study, if certain categories of imperfections are so common, can they be reframed as a 'natural' or inevitable part of the process? Ceramic craft consistently shows the presence of form imperfections like non-uniform surfaces and cracked glazes. But this is viewed as fundamental to the process and a necessary consequence of the material interacting with the making procedures (see Tanizaki's 1933 work *In Praise of Shadows* which details the Japanese concept of 'Mono no aware' – the awareness of impermanence – for an early exploration of seeing value and meaning in repairing broken pieces of ceramic). Indeed, this enhanced materiality has led many to argue that the experience of object use and interaction was richer.

7.2.2 Reframing of the 'will'

Many efforts have been made by other thinkers to reframe or challenge the traditional ontologies inherited from ancient Greek, Christian or Enlightenment traditions in the West. With respect to design, interesting contributions have been put forward by Flusser mentioned earlier, and more recently by Ingold both of which have been explored already. Though there still exists a space in which the contributions of these thinkers (and others) have missed. The question broadly stated is as follows; what is the primacy of human *will* within the design and making process? Ultimately this amounts to a challenge to human agency and status and relates more specifically to the elusive metaphysical concept known as the '*will*', explored most prominently in recent times by German philosopher Arthur Schopenhauer in his 1818/2000 opus *The World* *as Will and Representation*. Without delving too deeply, Schopenhauer thought that the highly developed Kantian distinction and separation of noumena (objects existing as distinct entities in the world, outside perception) and phenomena (sensory perceptual experiences), developed in the *Critique of Pure Reason* (1781/2008) as irreconcilable. In Schopenhauer's critique of this, the world-in-itself exists only in reference to a real world, knowledge of which is inaccessible or mysterious (an extension of Plato's thinking in his cave allegory). This is what Schopenhauer calls the world as 'representation' where any and all inputs are experienced as phenomena and not the more direct noumena, thus knowledge of the world-in-itself remains elusive. The *will* is identified with a mysterious inner essence that drives everything, a kind of energy that is blind and purposeless, yet enmeshed within the Kantian metaphysics of noumena and phenomena. In this framing, the *will* is objectified as the world of representation hence the mysterious *will* is present in all human experience – we are both subservient to it but unable to pin it down as an objective 'feature' of the world.

Schopenhauer thought that the *will* was essentially the root of all forms of experience including pleasure and suffering, and before this discussion becomes too 'mystical' we can now relate this back to the central discourse around design, making and advanced processes. Importantly, Schopenhauer thought that engagement with aesthetics was a means of transcending or overcoming the *will*, offering a kind of temporary relief where the *will* is completely subsumed by its representation. Forms of craft and music were cited by Schopenhauer favourably and by extension, we can argue that the processes of making may offer the kind of 'transcendence' he refers to. Though how can this relate to the advanced processes we have discussed so far? Throughout, this work has argued that the designer-agent model of form-emergence is problematic – to use the language of Schopenhauer, this ontology of emergence is a *slave to the will.* To relate this back to Aristotelian thought, the concept of the 'four causes' (see Falcon, 2022 for an overview) may also prove insightful. The four causes, in the hylomorphic imagining, are the formal cause (design), agent/efficient cause (maker), material cause (matter) and final/end cause (purpose). Here Aristotle makes the argument that the creation of say, a table, is essentially *teleological*; it has a defined, preordained purpose mediated by human agency and the manipulation of inert matter.

In essence, the *will* is then indelibly linked to the processes of form-emergence – in the presented ontological model this is recognised as the input 'designer intentions'. But the *will* can potentially be transcended. Instead of thinking in terms of transcending things vertically, the idea of flattening or equalling is perhaps a better approach. Graham Harman's (2002; 2018) philosophical developments in Object-Oriented-Ontology (OOO) is at this point instructive. OOO posits that the ontological relations between a human subject and an object, traditionally thought of as higher in status than that of object-object relations, can be flattened or made equivalent. This flat ontology presents space to move away strongly from hylomorphism, the Kantian noumena-phenomena bilateral and even the ominous *will*. In advanced numerically controlled processes, the relationality between the human subject and the object being created or emerging becomes disconnected. As such the *process-material,* or *object-object* interaction becomes paramount, becoming equal in ontological status to the intentions or will of the human actor. This is part of what the presented ontology is illustrating. The principle of ductus is essentially the interface between the subject-object/designer-agent element and the object-object/process-material element. Furthermore, the interobjectivity that Morton has described translates human intentionality into an 'object' that can interact with other objects. This mesh of object interactions results in the birth of new objects: paradoxically both distinct from and part of the processes that created them, what Morton has called the mysteriousness or 'magic' and the heart of things as their essential qualities become 'withdrawn'. To quote Morton (2013):

'For [object-oriented ontology], the physical shape of an object, its form, is a form-as and a form-by: in other words, it is interobjective and thus aesthetic. A glass is shaped the way the breath and hands of a glass blower, a tube and a blob of molten glass interacted. Its shape is the record, the trace of what happened' (p.212)

Process-ductus is thus both a description of object interactions as artefacts emerge, and a *trace* or footprint left by these interactions. Furthermore, causality itself becomes a property of the aesthetic realm, a trace of emergence.

Linking this back to the earlier discussions in chapter 2 and 3 where the relations between design and experience were examined, we can now see that properties such as line and pattern can be viewed as tools that are relational to this novel ontological reframing. More specifically, pattern and line seem to have a *will* unto themselves, what Ingold (2008; 2009) and Arnheim (1954) recognised as a kind of intrinsic quality of energy transference. This is of course a form of non-human *will* and one that potentially relieves the striving for procedural/process perfection that has become the dominant goal of advanced industrial manufacturing. There remains a form of design intent in the selection of appropriate patterns for a particular context, but this is in some ways attenuated by the natural experience of form. As we have seen, form has intrinsic experiential facets that are not dictated by the will of the designer, the forms seem to will the experiential responses themselves.

What this ontological flattening achieves is a reframing of 'advanced' processes to something akin to *craft* whereby designer-agent intentionality is stripped of its status and the elements of process and material are elevated (following Simondon's 'transformational half-chains' process of individuation). The new ductus-based ontology seeks to reframe human *will*, flattening the ontology of making and reinstating value in non-anthropocentric emergence and the related 'imperfections' that themselves link to rich emotive experiences and the embodiment of distinct semantic concepts, as demonstrated through the presented experimental work. Related ideas in 'process philosophy' explore how *change* is the fundamental basis of reality (see Whitehead, 1979). Particularly, Thomas Nail's (2019) work has impacted the 'new materialism' mentioned earlier and articulates closely with OOO by suggesting that patterns of movement or 'fields of motion' – a folding and junctioning of motion (Figure 87), that could nicely map onto the toolpath of a machining drill bit - is the foundation of all form emergence. (This formulation is something similar to Ingold's flows and transference of energy). This pattern of interactions between matter is represented on multiple levels in the case of CNC machining and again elevates the central ductus concept to one *ontologically equivalent to the intentions of the designer*.

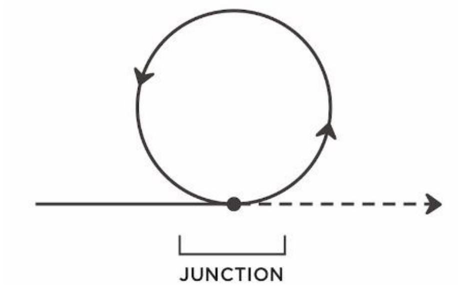


Figure 87 - Field of motion diagram following Thomas Nail[22]

7.3 Summary and further questions

This ontological model for advanced manufacturing technology was developed subsequent to the exploratory studies of CNC machining described in the previous chapters. These studies revealed how small manipulations in process parameters can strongly influence form emergence and user experience. An ontology was developed and modelled based on these conclusions and reflection upon the efforts of previous scholars. The model aimed to be dynamic and complex, while coherently presenting the conclusions of the work. With respect to this, the model can be applied in a number of critical ways:

1) *This ontological model allows scholars, designers or manufacturing engineers to consider making or manufacturing from a different perspective; one that integrates material inputs, process parameters, designer intentions and qualities of an end experience of artefact interaction*
2) *The perspective of a scholar interested in making ontologies may be informed by reference to the model in particular its focus on advanced modern processes which was identified as a substantial gap in research knowledge. The perspective of designers is challenged by allowing them to view form emergence in new ways as opposed to something coming from 'within them' – this exteriority opens new avenues of creativity and expression where the creator acts as a 'partner' to a process ductus. The manufacturing engineer is challenged in a similar way but also is exposed to the perspective that perceptual experience and semantic meaning is explicitly linked to process – something which the contemporary philosophy embedded in CAM neglects*

[22] Source: RyanHSanborn via Wikimedia Commons: [Fold and junction diagram]

3) *The model challenges the dominant designer-agent manufacturing ontology (hylomorphism) by decentralising the intentions of the designer-agent and maximising the influence of process parameters and chains of interrelated feedback (Simondon's 'transformational half-chains'). This ontological flattening can also relate to an object-oriented perspective where the relations between processes and materials are reframed as equivalent to those of designer intentionality*
4) *Challenges to 'will'-oriented models by flattening the ontology of form emergence, creating a kind of equivalence between the intentions of the designer, the nature of the making process and the experience of use – all are part of one central narrative or 'ductus'. Pattern for example emerges at multiple levels, operational with respect to the designers' intentions and the nature of the making process*
5) *Introduces the concept of 'ductus' into advanced manufacturing, changing the conceptual boundaries by which processes can be thought about, leading to a possibility of enhanced artefact materiality and more attuned user preferences*
6) *Allows the conceptual foundation of CAM systems to be re-evaluated presenting new potential system architectures integrating perceptual qualities into the simulations and visualizations of CAM software*

These are four ways in which this model could be applied and influence thinking in design and manufacturing engineering. There are however some questions that arise from the model. Firstly, the concept of ductus may have limited applicability within some contexts in affecting experiential facets of artefacts. What follows is a question of how generalisable the ontology is. Secondly, are the parameters that can be controlled within CAM truly reflective of a process ductus? In some cases, such as CNC machining, the ductus or trace of process is obvious and easy to control in the context of CAM simulation. But other simulation engines for different processes may not be so straightforwardly relatable, questioning the applicability of the model. This leads to further questions of what constitutes ductus and what are the conceptual and physical limits of it. Ductus does however offer a challenge to conventional modes of thinking about the production of objects. While some of these ideas have been explored within scholarly work considering craft, this work extends these ideas into the domain of advanced manufacturing and may offer new avenues for creativity and process innovation.

7.3.1 Practicalities and applications

While this model may seem abstract, we can consider several practical applications of such thinking and examine their feasibility. As has been demonstrated, changes in process parameters consistently influence experiential responses to fabricated artefacts. This in turn interfaces with other behavioural responses like semantic interpretation and affordances. Given evidence of this, we have considered how specific patterns operating at the level of process, aesthetics and structure underlined by an overarching abstract notion of pattern as the central design meta-concept, can be applied to benefit designers. This is articulated mostly in section 7.1.4 with the key points as follows:

1) *The process of making/manufacturing itself is based on a form of patterning and this patterning can be changed and manipulated in various ways to create discrete visual and tactile outcomes that have little influence on the pattern operating at the structural level*
2) *Pattern can be utilised as a visual and tactile tool, mediated in CNC machining by a horizontal control over the structural cross-section and a vertical control over the textility and depth of the structure*
3) *Process pattern can interact with the structural pattern in various ways. In CNC machining the trace of the toolpath (process ductus) can 'conform' to the structural elements or 'interfere' with it, creating quite different visual aesthetics following the principles of Gestalt holism*
4) *All the explorations of pattern at the structural and process level can be configured around semantics and emotion; the main structural elements may be configured to create a positive or negative emotive valence as can the process pattern in the way it interacts with the main structure*

7.4 Expert interviews

The practicalities and applications listed in the last section develop an architecture allowing us to penetrate the problem even further. As a means of exploring these points expert interviews have been conducted. These interviews, conducted with two professionals working within commercial advanced manufacturing services and research at the National Manufacturing Institute Scotland (NMIS) who have a great deal of knowledge concerning advanced production methods with expertise in machining and additive manufacturing:

- **Participant one** is a chartered engineer with degrees in astrophysics and aeronautical engineering. Having previously worked at the University of Sheffield's Advanced Manufacturing Research Centre she currently works as a manufacturing engineer at NMIS where she specialises in advanced machining technologies including toolpath programming and experimental milling strategies for both research and industry contracts.
- **Participant two** is a manufacturing engineer at NMIS with degrees in product design and advanced manufacturing. He has previously worked for the University of Dundee specialising in advanced additive manufacturing techniques and cultivates an interest in topology optimization and automation.

The interview was conducted in a semi-structured fashion with the conversation developed around a set of eight questions. Initially a short presentation of the key elements of this doctoral work were distilled to the participant to provide some background to the questions and foreground the conversation. The interview structure was designed to extract key information from the participants, summarised as follows:

- *Background and experience with advanced manufacturing technology*
- *Approaches taken to manufacturing problems i.e., the 'cultural' approach taken when thinking through a manufacturing task*
- *Understanding of the presented concepts and how they may be applied within a practical context*
- *Criticisms of the presented concepts and insights into possible improvements*

The following sections will show extracts from these conversations and provide useful insight into how the theoretical conclusions of the work are considered within a practical and commercial context. Both participants have provided explicit permission for the reproduction of the interview content, a full transcript of which can be found in Appendix section 11.10 and 11.11. While the interviews were conducted separately, the presentation of the answers will be amalgamated for the purposes of brevity and readability. Participants 1 and 2 are referred to as 'P1' and 'P2' respectively and the comments from the interviewer referenced with 'LU' and italics.

7.4.1 Key interview excerpts

Question 1: Describe your experience with manufacturing technology; how is a manufacturing problem initially thought through?

P1: I get a part and I need to put it into CAM, program the tool paths, and then output the CNC program, but it doesn't stop there. What I need to do then is go up to the machine and machine the parts and build the tools, um, get the parts out the door… I need to understand which tooling we have available, that could help me to understand what tool paths to use when I'm selecting the part.

P2: We go through a concept generation stage where we consider a few different ones. And I guess this is where I'm saying that we do design for manufacturer for each of these [designs], but, with regards to CAD and or even a sketch, we actually worked backwards first before going forward. So, we strip it back and look at the available design space; what material is this? What are some standards, et cetera?

Question 2: Do qualitative experiential factors form a basis in your thinking about using advanced manufacturing technology?

P1: When you have to go into nitty-gritty of the difference between climbing cutting and conventional cutting. That's a qualitative thing. So you kind of decide, would it look better if you climb cut compared to conventional cut and actually with metal cutting, especially to climb cut. So you start with thicker chip and end up with thinner. With composite cutting it's the opposite. So that's one thing that we have to think about more, a finer detail to make the experience better.

…also when we are looking at cutting materials, you have to think about the relationship between the feeds and speeds… But actually, what we do work with is understanding the dynamic stability of the tools, and that helps you to understand how much the tool, vibrates.

P2: One is the customers when you're proposing a set design, you need their buy in. But if it's going to be a component or product that either people interact with or can see...

LU: So you think that it depends on the kind of context of use, I suppose. And if it's concealed and not seen then it's less relevant to think about?

Yeah. If it was something that people were going to interact with a great deal, and I would say there'd be a great emphasis placed on aesthetic perceived safety, tactile interaction.

I guess the nearest comparable thing for a standard manufacturing process would be your kind of high-density polymers that are used for injection molding, where people use high density polymers and coat them in metallic finishes, and it has that kind of weight to the look; it looks metallic but is a polymer...

Question 3: Given your experience and/or knowledge of CNC machining, do you feel this exploration of the process is useful? Does it expand the framework of how the process is currently thought about?

P1: Yeah, absolutely, you know, you talk about the visual experience and some people actually say that the patterns are nicer, visually nicer than that is something that is not just for, aesthetics, you know, it's not just the visual experience. Sometimes you need a better visual experience as well for surface quality, I mean the quality of the part itself.

P2: Yeah, I mean, absolutely. It's just probably quite a 'left-field' application on my first evaluation ...but commercial products like golf putters, the machine finish has a huge bearing. And I guess there's two aspects to it. One is the aesthetics; golfers like to show off their equipment... and another would be perceived performance. And obviously it's all psychological and driven by marketing, but a lot of manufacturers will lead you to believe that a certain type of finish, whether that is the actual milling pattern using offset fly cutters actually gives a performance enhancement to clubs. But in all reality, it's pure, purely marketing it's psychological!

LU: But nonetheless, a real effect?

I mean, absolutely. And yeah, that's just one example, but if you could start to talk about more precious personal products, maybe say something like watches. And I think this would have a huge bearing on the perceived value of these products.

Question 4: Do you think other advanced processes such as additive manufacturing could also benefit from this kind of conceptual expansion?

P1: Yeah, I think actually is more suitable for additive processes in a way, because the patterns that you have created, I think you've got less limitations when you're doing it in additive.

So you have to have a plate, you can have more exotic patterns, that's the process. So you could actually go through more emotions. So additive is more suited to this, but then again, sometimes with additive you sometimes get the same surface finish. And what you want from yours is to get different finishes. So you might end up needing to do some post-processing on those additive surfaces, but if you're satisfied with the surface, it's just about the patterns. So your just comparing the patterns rather than the finish or the angles – there's a compromise.

LU: Yeah, exactly. And then do you think there's a kind of related point and do you think there's a kind of link or a kind of process link to this in some ways between, say something like machining and something like additive, which both, say like FDM, additive manufacturing process, like, and comparing it to machining. They both use these sort of nozzle type shapes, like structures that sort of go around, they kind of use maps of lines to sort of create their structures and they sort of use these sort of pattern functions. So in my example, they're sort of a pattern upon a pattern. And so, there's like a pattern of the making process and then a pattern that's created in the form. But do you think there's a link between additive and machining? Or do you think it's a bit more sort of complicated and that. Because the way I see it, machining is almost an inversion of additive, so machining comes in and subtracts material, but you know, it subtracts material incrementally in a way. It will map out the process and then sort of go and complete it, um, and sort of similarly, and inversely like additive will you know, it'll map out the process and build up material. The way I see it, there's almost kind of inverse symmetry to the process.

P2: Additive manufacturing will create isotropic properties both at a crystallized level, as well as a larger level in terms of the actual patterns created as it is built in a linear process. And therefore, trying to come away from anisotropic and trying to work towards isotropic properties... a Swedish company have tried to do this and they have a process called 'islands' ...it's like a way from just going from one state to the other layer that may break it down in to little cubes. And these are what they refer to as islands... it's to challenge the heating and cooling. And it does actually end up with quite an aesthetically satisfying look to it, and which is interesting.

And the other thing is recently there's a software company, I'm trying to remember the exact terminology; 'play pocket' yeh. So when we typically build things, we would take the Zed axis and slice that into equal layers and equal uniform layers. And that would be planar building. Recently, they started to look at non-planar... where you can build on curved surfaces, but not only can it do that perpendicular to said curved surfaces or angled surfaces.

What it also achieves is you can actually build an overhangs without the need for support structure underneath. So if you think about something like a T like this, you need to have support structure under this part and under this part here, otherwise it has nothing to hold it. They start to build out a 45° angle, that allows that to consolidate together that support structure. These new build angles that are non-planar actually have very interesting and final forms to them and structure. And there's been a lot of interest, especially from the furniture manufacturing world and, a Dutch company have been using it to manufacture chairs...they've chosen to, again, a non-planar route because the flowing aesthetic which aligns to their design needs and aesthetic output

LU: Yeah. That's interesting, actually. Yeah. I mean, that's, that's sort of like indicates that there is there's a sort of, kind of hidden realm, I suppose, in the, in thinking about the process and a different way, whereby you unlock like a new, um, yeah. A new area of aesthetics that hadn't previously been explored.

Question 5: Do you believe better control and understanding of key parameters relating to experiential facets of a manufactured part would be useful to industry clients? Do you think the users of products could benefit from being aware of the manufacturing processes in this way?

P1: Personally, I would like to know. But you know, not everyone cares. I always look at things wonder how they were made. I, I do think about things like that but not everyone necessarily does.

LU: I suppose part of the reason I was exploring that was because … in the past, you'd have small products that you would use on a daily basis. And each one would have all these traces of how it was made in various ways. So would have this unique mark of the of the maker… and that sort of thing has kind of almost gone from the world. I guess what I'm trying to try to do to some extent is try to bring back some of that thinking into our more advanced manufacturing. So could that sort of crafty kind of older world type way of thinking about making things inform how we make things using modern, advanced techniques.

I love that thought process and I think that would be useful in STEM activities. So a good way to promote engineering to the younger audience so they become more aware of understanding how the things are made… People could definitely benefit from it…it's just how do you start the ball rolling?

P2: I would say from a consumer point of view, yes. For an engineering point of view, no. The drivers aren't there for that. It's too much to do with applied resource efficiency to be a concern about for the consumer, but yes absolutely. So again, they can have products that we highlight. Putters, watches, these sorts of things, absolutely. And, I think for machining, I think for the world of meta-information to do with how something was manufactured is something that's perhaps an app you could have… a QR code or a welcome box or something that comes with your watch…where you can scan all code, go to their website and you might be able to see how that particular watch or how that watch company manufactures things. And I think we're moving towards more of an appreciation for, I guess, digital craft. Would you call it?

LU: Yeah, exactly. This, this sort of bringing the skill and knowledge and that sort of subjective artisanal quality that you see in handmade objects.

Question 6: Do you think the ideas presented here have limitations? i.e. could these approaches impede machining practice in any ways?

P1: I don't think it will change the culture side of things. People usually just get stuff and then they get told the types of machining processes that they need to follow. And they will follow them as long as they've got the capabilities in their machines.

LU: So culturally in general, a machinist would be happy to perform this, this kind of crazy operation, if they were given the plans

...obviously you've got these old-school people will probably will, maybe think, oh, 'this is not going to make a difference'. If you have the scallop height here, you have that surface finish there, they'll be like, but they're drawing will state they have to have it that way.

P2: I guess probably a clear split between engineering and consumer products. And I think from an engineering perspective, the industry wouldn't be interested in this unless you're approaching that really high end. So, starting to think about like say hyper cars, things like that are really performance driven, but still have some aesthetics linked to them. And they're more interested in buy-to-fly ratio, so, and minimal amounts of material as well as its resource efficiency.

LU: Yeah. I would say that there was sort of two cultures whereby there's this kind of culture of now, as you said, this culture of efficiency and making sure your process is done in the most effective way possible. And also there's this other culture of the sort of things I'm talking about where you make sacrifices at that functional end to achieve more interesting things out of the experiential end. And so there is this trade-off sure, but I guess what I'm trying to do with this work is sort of challenge that assumption that the most efficient or most optimized method is just by default the best... and say you can actually get interesting insights and positive and value from doing things differently that are unlike the orthodox in technical terms.

Question 7: Do you think the integration of these methods of thinking about advanced production could be integrated into technical control systems such as CAM?

P1: It could be done! Obviously, I use NX [CAM software produced by Siemens] and even just introduced a new function, which is trochoidal. So traditionally trochoidal, it was like full circle, going round, cutting incrementally. Whereas they figured out, it's coming back and cutting slowly, but it's not actually cutting anything. So they've changed that tool path. So, it was literally just doing a moon shape cut directly. And doing another bit. So, they've changed it. The settings that you can see; scallop height, or how many step overs, so they could have one that says if you want it to be more if you want the mood to be a certain way, you click there, it will just automatically know what that the scallop height would be at that point. So I think it can be done… it's just will

P2: Evolutionary algorithms and generic algorithms have had huge and lasting effects of design for additive and advanced toolpaths. In the field of robotics, they have studied lots of different animals and humans' movement, not necessarily just analyse somebody walking up and down but analysing people dancing… this is then taken into how these robots move… If you relate this back to CAM, how robotic arms work and move, they've found more efficient ways to manoeuvre these, especially when they're working together in systems… the shortest distance between two points isn't necessarily a straight line.

LU: But what it doesn't show you is how the CAM strategies might link to perceptual properties such as… emotional response or tactile response and that kind of thing. I personally think that would be useful as an option, or to be added to the CAM architecture as a kind of conceptual expansion… would you agree with that?

Yeah, absolutely. If we need to highlight a pocket feature in CAM software, you get options for the machining strategies. What would be interesting is not only where it tells you recommended feeds and speeds and the resultant cutting time, but actually to then be able to hover over a surface and pops up an image of what does this cutting pattern produce. And I think that could be influential in the decision-making process primarily for consumer-based products. But especially when you're talking about high-end or high value engineering along the lines of super cars, these kinds of applications, it would make a big difference in what they choose to do.

Question 8: Do you think industry and engineering specialists could feasibly apply this kind of new thinking to manufacturing problems?

P1: As I said, that's another thing you have to have a good enough argument to say that these things will bring out these emotions, you know? But I think it could be done especially in industries selling things like laptops and things where [the products are used] all the time. They want to have certain types of features from them…

I think it is very interesting. I think it's a very interesting concept. If it can be done, it'd great to get [specialists] on board as well. You just have to go to the right people, you know, research departments and all these places, start off with people like us [NMIS] who engage with companies.

P2: In short: yeh. Though, I think you'd need to evidence or demonstrate why it is useful.

7.5 Critical insights from interviews

Table 15 distils the key insights gained from the interview excerpts transcribed in the previous section. Generally, the discussions regarding the work were positive with both participants highlighting interest in the benefits a conceptual expansion in CAM could bring.

Table 15 - Summary of critical insights from expert interviews

QUESTION	KEY INSIGHTS
Q1 - Describe your experience with manufacturing technology; how is a manufacturing problem initially thought through?	• Manufacturing problem is approached systematically through logistical analytics considering available tooling and machine availability • CAM is utilised to explore the problem and the available options in terms of manufacturing strategies • Optimisation tools are also used to explore optimal design configurations before commencing with manufacture

Q2 - Do qualitative experiential factors form a basis in your thinking about using advanced manufacturing technology?	• Different strategies are used in order to improve part quality in terms of surface finish but often these factors are mediated by cost and lead times of the company • Context of use is important – can the consumer see the particular element of the product and will considering qualitative factors in the fabrication influence the final user experience? Componentry that is not directly interacted will not be considered typically • Developments in additive technology highlight desire for qualitative options e.g., options to create 'metallic' finished to make parts seem stronger
Q3 - Given your experience and/or knowledge of CNC machining, do you feel this exploration of the process is useful? Does it expand the framework of how the process is currently thought about?	• The exploration of different cutting angles to achieve different surface outcomes was very interesting and may indicate that the 'best' surface finishes are not always the most desirable for the user or client • Perceived performance may be influenced by these approaches, a prominent example may be golf putters which utilise machining strategies to improve the perceived performance quality of the products
Q4 - Do you think other advanced processes such as additive manufacturing could also benefit from this kind of conceptual expansion?	• There are limitations with both, but additive is arguably better suited to a conceptual expansion of this kind due to the wider flexibility in the process • Machining and additive processes like FDM are inversions of each other – one subtracts, the other adds material • Some companies are exploring the use of non-conventional additive approaches to achieve interesting aesthetics for furniture design

Q5 - Do you believe better control and understanding of key parameters relating to experiential facets of a manufactured part would be useful to industry clients? Do you think the users of products could benefit from being aware of the manufacturing processes in this way?	• Not everyone would be interested or compelled to know but many people would be • Highlighting how mass-produced items are made may be useful for getting more people interested in engineering and STEM subjects • From a consumer point of view, yes but from a strict engineering point of view, the drivers are not there • Some product sectors cited such as putters, watches, laptops, could benefit
Q6 - Do you think the ideas presented here have limitations? i.e. could these approaches impede machining practice in any ways?	• Some 'old-school' machinists may not be open to trying different approaches but if there is a clear rationale and the benefits can be demonstrated, the culture could be adjusted • Highlights the clear split between strict engineering and consumer product culture whereby resource efficiency is paramount in the former
Q7 - Do you think the integration of these methods of thinking about advanced production could be integrated into technical control systems such as CAM?	• It could be done and is feasible, it is just a question of implementation and will to carry out such a project • Unconventional approaches have been used in robotic automation innovation which could be echoed within reconfiguration of CAM software architecture • Designers could have greater control over manufacturing processes by not defaulting to the most efficient procedure • High-end products could have customisability options allows customers to tailor particular manufacturing procedures around a specific mood or emotional desire • Could be influential in the decision-making processes for consumers to be able to tailor manufacturing procedures

Q8 - Do you think industry and engineering specialists could feasibly apply this kind of new thinking to manufacturing problems?	• The concepts are very interesting and potentially very useful for wider design and engineering practice • There would be challenges in implementation and the usefulness of such a conceptual expansion would probably need to be meaningfully demonstrated

Generally, both participants thought the theoretical and practical material explored throughout this thesis could have tangible benefit for industrial practice. While they could both connect more with the practical elements of the work, they were also enthusiastic about the theoretical elements explored through the discussions. Particularly in the world of CAM and questions of product customisation could be hugely benefited from a greater integration of UX concepts into the technical apparatus of process control.

8. Conclusions

Design has always involved shaping or embellishing everyday things, to provide us with a reminder of the world beyond utility. It is ultimately concerned with the emotional character of objects.

- Deyan Sudjic

The above quote from Sudjic relates to the overarching aims presented within this work. A project that seeks to examine the relations between the maker and the made, between the material and the process. This final chapter will elaborate on the core contributions of this work by firstly describing the critical knowledge contributions (KCs) and then unpacking those through revisiting the key findings from each stage. Lastly, the possibilities of future work will be considered by offering realistic paths in which future researchers could tread and speculation about how such work may influence engineering and design practice at large. Philosophically this work has been mixed and has at times even flirted with speculative realism. But ultimately this thesis is designed to make the conceptual leaps that have so far not materialised within design thinking and open up space in which engineering and design practitioners in the future can experiment further. In some ways the traditional linear path from theory to practice has been reversed. The practical explorations that advanced manufacturing processes offer mean that the theoretical ground examining the implications of what they reveal can be challenging to describe but perhaps as interesting and captivating as the processes themselves.

8.1 Knowledge contributions

At this point it is wise to revisit the aims of this project set forth at the beginning. The knowledge contributions that will subsequently be described can map onto the central aim of the project as introduced in the Introduction:

To develop a novel ontology of form emergence integrating notions of materiality and making with protocols for advanced modern manufacturing practices to expand the *conceptual and operative schemas in which modern manufacturing is deployed within the context of product development and the built environment.* When considering and assessing the knowledge contributions (KCs), it is useful to split these into a *primary* contribution and *secondary* contributions.

The primary contribution of this work is as follows:

> **KC1:** *Development of a ductus-based ontological model for advanced manufacturing. The model was developed firstly from a critical evaluation of the available literature regarding form-theory, making and manufacturing. Secondly from the analysis of line and pattern and a theoretical level. And thirdly from the practical experimentation attempting to explore the relation between these concepts and processes of form-emergence. The core elements of the model are hence derived both theoretically and empirically, bridging a conceptual gap.*

The secondary contributions of the work are as follows:

> **KC2:** *The experimental phase demonstrated how changes to process strategy may influence the experience of the resultant object, bringing the processes of form-emergence in AMT in closer unity with the experiential facets of object interaction*
>
> **KC3:** *A practical and experimental exploration of the use of 'patterning' at multiple levels in an advanced manufacturing process. Pattern was shown to be a powerful tool at a structural level and at the process-emergence level. The studies exploring line and pattern aesthetics were conceptually developed for the final study exploring the embodiment of pattern in textures through a CNC machining process. As the technical aspects of the machining process were unpacked, it was shown that the process itself can in some respect be ontologised as a patterning system*
>
> **KC4:** *A conceptual exploration of form-theory. Form was explored from the point of view of aesthetics and structure but also from the perspective of creation and emergence with a focused critique of designer-agent hylomorphism as mediated by current advanced technical production methods*

KC5: *Development of the line model of form and emotion. Derived from a critical evaluation of experimental aesthetics literature and literature focused on design-emotion and design semantics. In addition, the model was also built from a theoretical exercise in breaking down designed artefacts (products, buildings etc.) into discrete linear elements*

KC6: *Novel explorations and expositions of line and pattern as design tools that can both influence people and transmit abstract information by triggering distinct emotive responses and relaying semantic ideas. This contribution was derived from the three studies focused explicitly on line and pattern*

KC7: *An exposition of pattern as a fundamental 'meta-concept' within design and form-emergence*

Lastly, as mentioned previously, several publications were developed in association with the practical and theoretical aspects of the work, a complete list of which can be found within the Contents pages – **see Journal paper contributions toward** thesis **and Conference paper contributions toward** thesis **headings.**

8.2 Have the objectives been met?

In the Introduction to this thesis, a number of objectives were set out in which the key aims of the work are addressed. Below is a summary of these objectives in which we can examine whether the objective has been met and provide a summary of how it has been approached.

Table 16 – Completion status of objectives

Objective description	Has it been met?	Summary
1) Critical review of literature with historical analysis	YES	• Comprehensive review of literature conducted focusing on form theory, form perception, design emotion, design semantics, pattern, advanced manufacturing and

		manufacturing and making ontologies • Development of Line model (published) which integrates information from this literature overview and grounds the future discussions within the thesis
2) Experimental analysis of aesthetics and perception	YES, WITH RESERVATIONS	• Pattern and line identified as a medium in which to explore aesthetics and perception • Three studies (published) showed that particular shape arrangements have strong associations was particular emotions • This objective may have had a stronger outcome if the experimental work had been more systematic in its design – while the results are reliable, the confidence of the conclusions could be stronger
3) Qualitative design work based on experiment findings	YES	• Development of bespoke pattern designs based on experimental findings
4) Exploration of manufacturing protocol through simulation and practical making	YES	• Exploration of CNC machining parameters through EdgeCAM simulation efforts – identification of parallel lace

		raster strategy as a viable focus • Fabrication of pattern-based surface texture designs through CNC machining processes
5) Analysis of aesthetic and tactile properties of made artefacts linking manufacturing protocol with perceptual experiences	YES, WITH RESERVATIONS	• Two interconnected studies conducted to examine the perceptual properties of the pattern (2D) versus the texture (3D) designs – the rationale for this could have been more clearly set out but nonetheless, it confirmed that the transition maintained the core perceptual effects of the forms • Examination of visual and tactile preferences showed significant trends away from 'default' manufacturing approaches though the reasons for these trends were difficult to conclusively identify
6) Development of theoretical conclusions based on experimental work and literature analysis	YES	• Experimental results combined with new theoretical understanding ontological model for advanced manufacturing (published)

7) Validation of findings and conclusions through series of expert interviews	YES	• Expert interviews with two experienced manufacturing engineers • Both interviewees engaged strongly with the work and felt its theoretical conclusions could be practically applied within an industry context

8.3 The new ontology: applications and limitations (KC1, 2)

The presented ontology is framed around the concept of ductus, itself a very old concept that relates to the nature of existence and being. Ductus, in this sense, introduces a *telos* to a production method – but a telos that may be viewed as partly outside of human intentionality. This reframing challenges the dominant hylomorphic/matter manipulation picture of manufacturing that is presented within the literature. That said, only a limited number of articles concerning the theoretical or ontological basis for modern manufacturing were discovered meaning there was identified scope to introduce a deeper understanding of concepts such as aesthetic experience and materiality into this discourse. Similarly, ontologies of making do not enter generic discussions within design either, representing two significant gaps this work has attempted to fill. It is possible to say that new modes of making and form construction are beginning to challenge the hylomorphic view. This has been particularly well documented in architectural design through the work of Zaha Hadid or Thomas Heatherwick where computational methods have been used to generate organic forms. Many of these designs are much more exploratory and are not bounded by the principles of Modernism or the Enlightenment-era Neoclassicism which preceded it. In design, these movements are still developing, and more work is needed to integrate aesthetic theory and theories of material culture with modern manufacturing protocol. Notable contributions to materials and design culture have come from Elvin Karana, Mike Ashby, Kara Johnson, Chris Lefteri and Mark Miodownik but other interesting conceptual evolutions are still possible to further challenging the entrenched anthropocentrism of the hylomorphic, linear model of emergence.

The applications of the ontological model are thus:

1) *Allows for the creation of an artefact to be viewed from a new perspective – not simply as an execution of design intentions but a process mediated by a ductus*
2) *Provides new conceptual space for the creative exploration of form and aesthetics – instead of deriving the experiential factors of form from a preformed idea of what the experience should be this process can be inverted by looking to the process itself for new modes of expression and creativity*
3) *Provides a new way of thinking about designed objects – not just in terms of a conservative functionality but also in terms of emergence and end experience of users*

The model also has limitations:

- Thinking about design or engineering in such abstract terms may not be particularly practical therefore there is a limitation in terms of translating the theoretical ground covered into practice. Ideally, the work would map onto the conceptual reframing of a tool such as CAM, offering new insights for designers or engineers at the practical level
- There are factors the ontology does not address such as the concept of 'design knowledge' itself. While this could relate to the different levels of patterning that were discussed, how this articulates with the model was not explored in depth
- While the model presents insight that might be useful for considering artefacts that may interact with people (e.g., household products), it does not consider the category of things made not for direct human interaction or use (e.g., turbine blades). A development of the ontology would also be required to fully consider the status of these objects within this framing

8.4 Exploring pattern and line: levels of operation (KC2, 3, 4)

Pattern and line have been important concepts within the development of this work. From their identification as potential objects of focus, we have explored them extensively both from an abstract-conceptual perspective and a physical-practical perspective. The critical contributions relate to how line and pattern are used within design and how they can transmit perceptual information, sometimes in surprising ways. During the experiment phases of the work, it was demonstrated how line and pattern could be powerful conceptual frameworks for which to explore design. Line for example could be viewed as a structural feature that could relay specific symbolic ideas. From this initial examination of line, pattern became another concept that was identified. By considering a range of work in experimental aesthetics, an analysis of historic trends in aesthetic expression (emotive and semantic) and a practical study exploring how people express emotive concepts aesthetically, concepts such as symmetry, narrative and repetition of motifs came to the fore opening the way for the analysis of pattern as a central 'meta-concept' for design.

The study of pattern presented in this work revealed that not only do people 'see' specific themes within existing patterns i.e., the patterns are semantically loaded, pattern can also be created that generate similar results. In essence, pattern is both descriptive and prescriptive. Descriptive in the sense of its representational power and prescriptive in its power to command particular feelings and even draw the eye in specific directions.

This initial analysis was expanded to reflect on how pattern is manifest at multiple levels of design and processes of making. In summary, pattern was recognised as a tool that was operational at multiple levels – abstract, aesthetic, structural and form-emergence levels - and indeed as a foundational meta-concept. This was discussed fully in section 7.1.2 and is revisited as follows:

1) *The abstract-conceptual level;* pattern as a meta-concept and foundational tool within design
2) *The symbolic-aesthetic level*; pattern explored explicitly as an artefact of decoration or ornament
3) *The structural level:* pattern translated from a two-dimensional representation into a three-dimensional one necessitating a structural architecture with repeating shapes bounded within a system of symmetry
4) *The form-emergence level;* the patterning implicit within processes of making and formation of artefacts, the ductus of the making process

Limitations of the studies of line and pattern include:

- The examinations of line did not examine fully the overarching aesthetic contexts. While some studies have shown that context and orientation can make a large difference to perceptual reporting, these studies only considered the lines in isolation
- While line can clearly convey ideas and concepts, it is not clear how effective it is at this compared with other methods of embodied symbolism
- Similarly, pattern presents this same problem. Pattern, as an arrangement of lines and shapes, can convey ideas and concepts but it is unclear how this compares to other modes of symbolic representation (e.g., anthropomorphic representation)
- The pattern studies only examined a small portion of possible patterns, making its generalisability questionable, however, other evidence from experimental aesthetics indicates that some of the relationships revealed may be generalisable on some level

8.5 Line model: applications and limitations (KC5, 6, 7)

How can this work advance contemporary design practice, be it product, architectural or technological? While the line model, in its current iteration, is theoretical and draws upon a variety of sources to advance the arguments, it can provide some tangible insights. Firstly, there is a significance for design practitioners wanting to create more emotionally resonant products. The work of Jordan (2000) has set out the relevance for a deeper level of human factors understanding in industrial design including aesthetic pleasure and the pleasure derived from using a product. As Jordan (p.7) states; 'products are not merely tools: they can be seen as living objects with which people have relationships'. This transition from products seen as tools or ornaments to something embodying experiential value is highly significant and can extend to architecture, the built environment, and methods for understanding artefact production. Factors of emotional experience are becoming vital components in modern design practice, as Norman (2004) has also noted. The model, while not dealing with use factors directly, can be used as a guide for experiential factors relating to aesthetics, particularly emotion. Within a particular context, a product or architectural structure could be designed with insights from our relationships of emotional experience and form elements. A recent study has in fact suggested that emotionally pleasurable forms can be meaningfully categorized within defined semantic and experiential boundaries (Chang & Wu, 2007) and another found that form can even convey types of personalities (Desmet et al., 2008). These are complex relationships humans can have with designed objects and more understanding in this area could lead to increased well-being for individuals and perhaps the wider society. Through our novel form abstraction method, our work seeks to show the value in a deeper knowledge of emotional experience, categories of emotional experiences, historical change in form expression and semantic theory. The key benefits of the work and the model in its current iteration to general design practice are summarised below:

1) *Allows designers critical visual direction when designing products, spaces, or buildings for a category of emotional experience*
2) *The historical breakdown of form development provides examples of how form has been emotionally expressed since the 18th century*
3) *Provides designers with a deeper understanding of form-semantics when attempting to configure emotionally sensitive products, spaces, or buildings*
4) *Provides a heuristic framework to inspire discussion on form and emotion*

The model also has some identifiable limitations. These are mostly derived from the fact that the model is theoretical and subjective in nature and does not represent an empirically derived assessment:

- The model does not capture all design trends – it is focused on the Western traditions and misses the rich traditions from other parts of the world such as the Middle East, South America, or Africa
- The model is abstract and, by definition, subjective. While it may present a starting point, there is significant scope for expansion
- The model does not capture all the design 'information' contained in the periods it focuses on such as competing cultural ideas and the material conditions of the time

8.6 Summary of contributions: *advantages* and *disadvantages*

Taken together, the key contributions of the work can be considered against likely advantages and disadvantages. Table 17 below summaries these for each of the key contributions listed at the beginning of the chapter, section 8.1.

Table 17 - Summary of knowledge contributions

KC	Advantages	Disadvantages
KC1	• Reframing of ontology for advanced manufacturing allows designers or engineers to consider new modes of creative expression mediated through process qualities • Challenges dominant designer-agent hylomorphic thinking around design and production opening up space for new ways to consider how advanced processes may be controlled (e.g. software that may show the user how a process ductus may interact with perceptual qualities)	• Ontological reframing is abstract in nature and paths to applications may not be entirely clear • Ontology does not capture some dimensions of design and production such as a priori knowledge
KC2	• Brings the processes of form-emergence in AMT in closer unity with the experiential facets of object interaction • Presents new architecture in which CAM systems could be developed to integrate perceptual properties	• Not all processes or making methods lend themselves to this kind of study/analysis.
KC3	• Pattern was revealed as a powerful design tool operational at multiple levels introducing the idea that patterning can be viewed as a central meta-concept for design • Patterning processes were revealed to be operational at the	• A study of this kind would not be relevant for artefacts that do not interact directly with humans • The studies are focused on experiential facets (visual and tactile sensations) and do not focus on

	level of process, tying together the ontological model and the practical explorations	aspects of functionality which may also influence experience factors
KC4	• Develops and advances work in form-theory leading to new conceptual frameworks in which to view form	• Form is the central focus and the relation between form and function is not fully explored
KC5	• Line model presents a new heuristic tool for designers hoping to better attune products for particular prescriptive emotive and semantic outcomes	• Model does not capture particular properties of aesthetics such as colour and scale
KC6	• Studies of line and pattern demonstrate how complex emotive and semantic concepts can be captured in abstract representations • Provides framework in which emotive patterns or emotive line structures can be developed	• Findings are subjective and qualitative in nature making them open to interpretation or future changes
KC7	• Identification of pattern as a meta-concept allowing for the development of new research avenues and new ways of thinking about design aesthetics and design history	• Patterning is a complex design task and the studies presented do not explore all the nuances and complexities of pattern as they relate to design practice (e.g. symmetry operations could be studied much more extensively)

8.7 Future work

It is hoped that this work will be both illuminating and challenging in equal measure; allowing the reader to think about design and manufacturing in new ways. This naturally leads to the final question that can be asked about the work; *where can future research take it?* Because this research has sought to cross over and bridge multiple themes and topics, it is hoped that future work may also follow similar methods. To address the question of future work, we can follow on from each of the topics contained in the work and consider how they can be further advanced with respect to the contributions identified.

8.7.1 Expansion or application of ontological model

The first to address is the core contribution, the new ontological model and the development of the ductus concept. While the model was built from a cross-discipline menu of scholarship that was in some sense validated by the precursor experimental stages, it unquestionably has gaps. Future work could examine the philosophical implications further and create even more sophisticated models. A better integration of *process philosophy* would be interesting for example.

Perhaps more importantly is the question of applications. Further research into how this new way of considering manufacturing processes may influence the processes themselves. For instance, developments in CAM software could facilitate this by highlighting the dynamics of process parameters more and drawing attention to how they may influence experiential factors such as aesthetics or tactility. Studies examining the effectiveness of such a strategy would be interesting and valuable and advance the goal of closing the gap between theory and practice.

8.7.2 Exploration of other manufacturing methods using framework

As a partial extension to this, further studies could focus on other advanced manufacturing processes to explore the generalisability of the approach. The focus of this work was CNC machining but other advanced processes such as rotary forging, hydroforming, or molding-based processes such as injection molding or die forging may also lend themselves to such an analysis. Expanding the scope of the studies presented here may reveal other avenues in which experiential factors of artefacts could be further explored. There are already interesting studies within the literature that seek to broach this question – Niederer (2012) for example has considered laser welding and the use of ultra-thin metals and Neri Oxman (2012) has developed new modes of form-emergence utilising additive manufacturing that articulate closely with the ideas presented within this thesis.

8.7.3 Further study of pattern, semantics, and emotion

This work took particular interest in pattern as a design tool operating at multiple levels. Future work could explore the use of pattern in design further – both its use as a decorative or symbolic element and its use as a means of structural planning could be interesting. Further study of how patterns have evolved aesthetically over time may provide insight for designers hoping to develop specific aesthetics and attuned emotive responses. While the studies presented in this work explore two-dimensional monochrome patterns and their three-dimensional translations, future studies could consider the influence of multicoloured patterns. Additionally, the translations into three-dimensional structures could also be examined further, exploring the effects of debossing, or embossing particular elements and the resultant experiential effects on emotive and semantic interpretation. The nature of form still holds many mysteries.

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11. Appendices

11.1 Participant worksheet – pattern study 1

Excerpt, all worksheets available on request

1

EMOTIVE VALUES	PERCEIVED INTENSITY (Low to high)					
Pensiveness	0	1	2	3	4	5
Disgust	0	1	2	3	4	5
Apprehension	0	1	2	3	4	5
Anger	0	1	2	3	4	5
Surprise	0	1	2	3	4	5
Joy	0	1	2	3	4	5
Serenity	0	1	2	3	4	5
Annoyance	0	1	2	3	4	5
Distraction	0	1	2	3	4	5
Acceptance	0	1	2	3	4	5
Fear	0	1	2	3	4	5
Sadness	0	1	2	3	4	5
Boredom	0	1	2	3	4	5
Anticipation	0	1	2	3	4	5
Interest	0	1	2	3	4	5
Trust	0	1	2	3	4	5

11.1.1 Pattern study 1 – results (raw data)

	FEMALE RESULTS	Pattern 1																
Emotive intensity	Acceptance	2	0	1	0	0	1	3	4	1	4	2	0	0	3	0	1	1.375
	Anger	0	3	0	1	4	3	0	1	0	3	0	2	4	0	5	1	1.6875
	Annoyance	0	3	5	3	0	2	0	2	1	2	2	2	5	0	5	4	2.25
	Anticipation	2	1	0	3	0	1	1	2	2	4	2	2	4	3	2	0	1.8125
	Apprehension	0	2	4	3	3	4	0	2	2	2	3	2	0	0	3	5	2.1875
	Boredom	0	0	0	0	1	1	0	3	1	1	0	0	0	0	0	2	0.5625
	Disgust	0	0	0	0	4	0	0	1	0	1	0	0	3	0	4	1	0.875
	Distraction	3	4	5	4	5	3	3	4	4	3	3	3	2	0	5	5	3.5
	Fear	0	3	1	0	2	2	0	1	1	2	0	2	4	0	0	3	1.3125
	Interest	5	2	5	3	1	2	4	4	4	4	3	5	1	4	0	1	3
	Joy	1	0	0	0	0	1	2	3	3	4	0	2	0	3	0	2	1.3125
	Pensiveness	1	1	5	0	5	3	4	5	3	3	2	1	0	2	0	4	2.4375
	Sadness	0	1	0	0	1	2	0	1	0	1	0	0	1	0	0	1	0.5
	Serenity	0	1	0	0	0	0	2	4	1	3	0	0	0	1	0	0	0.75
	Surprise	3	1	0	0	0	1	0	2	1	3	1	4	0	2	3	2	1.4375
	Trust	2	0	0	1	0	1	4	2	0	2	0	1	0	3	0	0	1

	MALE RESULTS	Pattern 1														
Emotive intensity	Acceptance	0	1	3	0	1	2	2	5	2	1	3	3	1	3	1.92857
	Anger	0	0	3	0	4	2	5	1	1	2	1	2	0	0	1.5
	Annoyance	0	3	4	0	1	3	4	0	3	3	1	1	3	0	1.85714
	Anticipation	0	3	2	2	2	3	3	1	1	3	2	3	2	2	2.07143
	Apprehension	0	3	4	1	4	3	3	4	3	2	2	1	2	1	2.35714
	Boredom	0	1	1	0	1	1	2	1	1	2	0	4	0	0	1
	Disgust	0	1	3	0	2	2	0	3	2	0	1	3	1	0	1.28571
	Distraction	3	3	5	2	4	3	4	1	5	2	2	5	4	0	3.07143
	Fear	0	2	2	0	1	3	2	0	2	0	0	2	3	0	1.21429
	Interest	3	3	3	3	4	3	1	5	2	2	4	3	4	2	3
	Joy	2	0	2	2	1	3	0	2	1	2	1	4	1	1	1.57143
	Pensiveness	1	4	1	2	4	1	2	4	1	5	4	2	3	1	2.5
	Sadness	0	0	2	0	3	2	4	0	3	0	0	3	1	0	1.28571
	Serenity	4	0	1	0	0	1	3	3	2	4	1	2	1	1	1.64286
	Surprise	1	0	3	0	3	3	1	0	2	4	3	3	4	2	2.07143
	Trust	0	0	2	0	3	1	2	4	3	0	3	0	1	3	1.57143

	FEMALE RESULTS	Pattern 2																
Emotive intensity	Acceptance	3	5	0	0	3	1	3	0	1	2	2	0	0	0	0	0	1.25
	Anger	1	0	5	1	1	0	4	1	1	0	0	5	0	4	1	2	1.625
	Annoyance	3	0	4	1	2	2	3	5	2	1	0	5	3	5	2	5	2.6875
	Annticipation	0	0	0	3	3	1	2	0	2	1	2	1	3	3	0	0	1.3125
	Apprehension	4	0	2	3	2	2	3	2	1	0	0	5	0	4	0	2	1.875
	Boredom	1	0	3	0	0	1	1	3	2	3	0	1	2	5	1	0	1.4375
	Disgust	1	0	5	3	1	0	2	5	1	1	0	2	0	4	0	2	1.6875
	Distraction	3	0	0	4	3	2	3	3	3	3	0	5	4	5	3	5	2.875
	Fear	0	0	1	1	1	0	3	1	1	0	0	5	0	0	2	0	0.9375
	Interest	1	5	0	1	4	1	3	1	3	2	2	0	0	0	1	1	1.5625
	Joy	1	2	0	0	1	1	2	0	2	1	3	0	0	0	0	0	0.8125
	Pensiveness	2	4	0	0	0	1	3	3	4	4	2	1	3	5	0	0	2
	Sadness	3	0	1	3	0	3	3	1	3	0	0	3	0	0	0	0	1.25
	Serenity	1	4	0	0	0	3	1	0	3	1	2	0	0	0	0	0	0.9375
	Surprise	1	0	0	0	3	1	3	3	2	1	1	1	0	0	1	0	1.0625
	Trust	2	3	0	0	1	0	2	1	1	2	2	0	0	0	0	0	0.875

	MALE RESULTS	Pattern 2														
Emotive intensity	*Acceptance*	2	1	0	1	4	1	0	3	3	2	3	0	0	0	1.42857
	Anger	0	0	1	0	1	4	3	2	1	2	0	5	2	0	1.5
	Annoyance	0	2	5	4	2	3	5	3	2	3	0	5	3	0	2.64286
	Annticipation	3	3	2	1	4	5	1	4	3	4	1	1	2	0	2.42857
	Apprehension	0	1	2	1	2	2	4	3	3	3	0	4	3	0	2
	Boredom	0	1	2	4	0	1	0	4	1	1	0	2	2	1	1.35714
	Disgust	0	1	3	2	0	2	5	1	2	1	0	5	1	0	1.64286
	Distraction	0	3	5	3	1	2	4	2	2	3	0	3	2	2	2.28571
	Fear	0	1	1	1	3	3	4	2	2	2	0	3	3	1	1.85714
	Interest	3	3	3	1	5	3	1	2	3	3	2	2	2	2	2.5
	Joy	0	0	2	1	4	1	0	1	2	2	2	1	0	1	1.21429
	Pensiveness	1	3	2	2	5	0	0	1	3	4	0	1	3	1	1.85714
	Sadness	0	0	0	3	1	1	3	2	1	1	0	3	3	0	1.28571
	Serenity	2	2	0	0	4	0	0	1	2	2	3	1	0	1	1.28571
	Surprise	1	2	3	3	3	4	0	3	2	3	1	3	0	0	2
	Trust	3	1	0	0	4	3	0	0	3	2	3	0	2	0	1.5

	FEMALE RESULTS	Pattern 3																
Emotive intensity	*Acceptance*	0	0	4	0	3	3	4	1	5	3	5	5	3	5	4	0	2.8125
	Anger	0	2	0	0	0	0	0	3	1	1	0	0	0	0	0	1	0.5
	Annoyance	0	3	0	0	3	0	1	2	0	2	0	0	0	0	0	5	1
	Anticipation	0	0	1	0	1	2	3	3	2	3	0	2	3	2	0	0	1.375
	Apprehension	0	0	0	0	2	0	2	3	1	2	0	0	0	2	0	4	1
	Boredom	0	0	0	1	2	0	1	4	1	1	0	0	0	1	0	1	0.75
	Disgust	0	2	0	0	0	0	1	3	0	1	0	0	0	0	0	4	0.6875
	Distraction	0	3	0	2	3	0	3	2	2	2	3	1	0	0	0	4	1.5625
	Fear	0	4	0	0	2	0	1	3	0	2	0	0	0	0	1	3	1
	Interest	3	0	4	3	2	3	4	3	4	4	5	5	4	5	5	1	3.4375
	Joy	1	0	5	0	2	3	1	1	2	4	3	4	0	3	3	0	2
	Pensiveness	2	1	4	4	3	1	4	3	1	3	2	0	4	4	2	5	2.6875
	Sadness	0	2	0	0	3	0	2	4	1	1	0	0	0	1	3	4	1.3125
	Serenity	1	1	5	0	3	3	2	1	4	3	3	3	0	3	4	0	2.25
	Surprise	0	0	0	2	2	1	3	2	1	4	1	5	3	2	0	1	1.6875
	Trust	2	0	0	0	4	4	2	2	4	4	3	3	1	1	2	0	2

	MALE RESULTS	Pattern 3														
Emotive intensity	*Acceptance*	0	5	4	2	4	2	3	0	3	2	2	1	4	3	2.5
	Anger	0	1	0	1	1	3	1	4	2	0	1	4	0	0	1.28571
	Annoyance	0	1	1	0	1	4	1	0	2	1	4	5	1	0	1.5
	Anticipation	0	1	2	0	1	3	3	3	3	2	1	3	0	3	1.78571
	Apprehension	0	1	1	2	1	3	2	4	3	2	3	5	1	0	2
	Boredom	0	1	2	0	2	2	3	5	2	0	3	2	0	0	1.57143
	Disgust	0	0	1	0	1	4	1	5	1	1	2	2	1	0	1.35714
	Distraction	1	1	4	1	2	3	2	0	2	1	3	4	1	0	1.78571
	Fear	0	1	0	1	1	4	1	4	3	0	1	4	0	0	1.42857
	Interest	2	2	3	2	4	3	3	5	4	4	1	2	4	3	3
	Joy	0	1	3	0	3	1	0	1	4	3	2	1	3	2	1.71429
	Pensiveness	2	1	2	2	2	2	3	4	2	3	3	2	2	1	2.21429
	Sadness	0	4	2	0	3	3	1	4	3	1	2	5	0	0	2
	Serenity	3	3	3	0	3	1	3	1	2	1	1	1	4	3	2.07143
	Surprise	0	2	2	1	2	3	0	4	4	1	1	3	1	1	1.78571
	Trust	0	2	5	0	4	1	2	0	5	0	1	3	3	3	2.07143

	FEMALE RESULTS	Pattern 4																
Emotive intensity	*Acceptance*	3	5	2	4	4	0	4	4	4	4	2	4	0	4	0	0	2.75
	Anger	2	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0.25
	Annoyance	2	0	1	0	0	0	1	0	1	2	0	1	0	0	0	4	0.75
	Anticipation	1	0	4	0	2	1	3	2	3	3	1	3	0	2	0	0	1.5625
	Apprehension	3	0	5	0	1	1	1	1	1	0	2	3	0	0	1	1	1.25
	Boredom	1	0	0	0	0	0	1	1	1	2	0	1	0	0	0	0	0.4375
	Disgust	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0.1875
	Distraction	3	3	4	4	2	3	3	2	4	3	0	1	0	4	2	3	2.5625
	Fear	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0.3125
	Interest	3	5	4	5	3	2	4	3	3	3	3	3	1	4	2	1	3.0625
	Joy	3	5	2	3	4	0	3	1	3	3	3	4	0	4	2	0	2.5
	Pensiveness	3	5	4	4	0	1	2	4	4	4	3	0	4	5	1	2	2.875
	Sadness	3	0	0	0	0	1	1	1	1	1	0	1	0	0	0	0	0.5625
	Serenity	3	4	1	3	2	0	4	3	4	4	3	4	0	4	1	0	2.5
	Surprise	1	0	3	5	4	1	3	0	3	1	1	2	0	2	3	2	1.9375
	Trust	4	3	2	0	2	2	3	4	4	4	2	4	0	0	0	1	2.1875

	MALE RESULTS	Pattern 4														
Emotive intensity	Acceptance	3	3	5	2	2	4	4	2	3	4	2	5	3	0	3
	Anger	0	0	0	0	1	1	1	1	1	1	0	2	2	0	0.71429
	Annoyance	0	0	0	2	0	3	0	2	1	1	0	3	1	0	0.92857
	Anticipation	3	0	0	2	1	2	0	1	3	1	2	2	0	0	1.21429
	Apprehension	0	1	2	2	1	2	0	2	3	2	0	1	1	0	1.21429
	Boredom	0	3	0	3	2	2	0	2	2	2	0	1	1	1	1.35714
	Disgust	0	1	0	0	0	0	0	2	1	0	0	1	1	0	0.42857
	Distraction	0	3	5	0	2	2	2	2	2	1	1	4	2	0	1.85714
	Fear	0	0	0	0	0	1	0	3	1	0	0	1	1	0	0.5
	Interest	3	1	5	2	4	2	2	3	3	4	2	2	2	2	2.64286
	Joy	1	1	5	0	2	2	2	0	3	2	2	4	3	0	1.92857
	Pensiveness	1	3	3	2	5	3	4	2	3	3	2	4	1	1	2.64286
	Sadness	0	0	0	1	2	3	0	4	1	0	0	4	1	0	1.14286
	Serenity	2	3	5	2	2	5	4	2	3	4	2	2	1	3	2.85714
	Surprise	2	0	2	1	3	1	0	0	3	1	3	3	1	0	1.42857
	Trust	2	2	5	1	1	2	4	3	3	3	2	3	3	0	2.42857

	FEMALE RESULTS	Pattern 5																
Emotive intensity	Acceptance	1	0	0	0	2	0	2	2	0	2	0	3	2	3	0	0	1.0625
	Anger	0	2	5	0	0	2	1	1	2	3	1	0	0	3	2	1	1.4375
	Annoyance	0	0	5	0	0	4	0	3	3	4	1	0	0	5	3	5	2.0625
	Anticipation	1	1	3	1	4	2	3	3	3	3	1	1	3	2	3	0	2.125
	Appehension	0	0	3	0	3	3	2	2	2	4	3	1	0	4	4	4	2.1875
	Boredom	0	1	5	2	0	4	2	1	0	1	1	0	0	1	0	1	1.1875
	Disgust	0	1	5	0	1	2	2	1	0	1	1	0	0	5	4	4	1.6875
	Distraction	3	4	5	0	3	1	3	3	4	4	1	2	4	4	5	3	3.0625
	Fear	0	0	2	0	1	3	2	1	3	1	1	0	0	2	0	4	1.25
	Interest	4	1	0	5	4	0	3	4	4	4	1	5	5	3	5	2	3.125
	Joy	1	0	0	0	2	0	1	1	1	2	0	3	3	2	0	0	1
	Pensiveness	0	3	0	5	3	2	4	4	5	4	1	1	3	4	5	5	3.0625
	Sadness	0	1	0	0	1	2	1	2	1	3	1	0	0	1	0	4	1.0625
	Serenity	1	0	0	0	2	0	1	2	0	2	0	0	0	0	1	0	0.5625
	Surprise	3	2	1	0	4	3	3	2	3	3	1	4	5	3	5	2	2.75
	Trust	0	0	0	0	1	0	1	3	1	2	1	1	3	0	2	0	0.9375

	MALE RESULTS	Pattern 5														
Emotive intensity	Acceptance	0	0	1	0	3	3	3	0	1	4	3	3	2	3	1.85714
	Anger	0	2	4	1	1	1	2	5	4	0	2	5	1	0	2
	Annoyance	0	3	5	1	3	1	2	0	5	1	2	5	4	0	2.28571
	Anticipation	0	2	1	1	4	3	1	0	3	4	2	2	3	2	2
	Appehension	0	3	3	1	2	3	2	1	5	3	1	2	4	0	2.14286
	Boredom	0	1	1	0	1	2	1	0	1	0	1	0	1	0	0.64286
	Disgust	0	3	3	1	0	2	2	4	1	0	1	2	3	0	1.57143
	Distraction	1	3	4	1	4	2	1	1	5	2	2	5	3	0	2.42857
	Fear	0	3	1	1	1	2	3	3	4	1	0	3	2	0	1.71429
	Interest	4	1	3	3	5	3	4	4	5	5	3	5	4	3	3.71429
	Joy	0	0	2	0	2	3	3	1	0	4	1	2	0	2	1.42857
	Pensiveness	0	3	1	3	5	3	4	2	1	5	1	0	2	3	2.35714
	Sadness	0	0	3	1	1	1	5	5	1	1	1	5	0	0	1.71429
	Serenity	2	0	1	0	3	1	2	0	0	3	2	0	0	3	1.21429
	Surprise	2	2	3	1	4	2	2	0	4	3	0	2	1	1	1.92857
	Trust	0	0	1	0	3	2	3	0	0	4	3	1	1	3	1.5

	FEMALE RESULTS	Pattern 6																
Emotive intensity	Acceptence	4	5	2	0	3	0	2	1	4	2	3	5	0	3	0	1	2.1875
	Anger	0	0	0	0	0	1	2	0	1	2	0	0	0	0	0	0	0.375
	Annoyance	0	0	0	4	0	1	3	1	2	1	0	0	4	0	0	0	1
	Anticipation	4	0	3	0	1	1	4	1	3	2	3	2	0	0	1	0	1.5625
	Apprehension	1	0	1	0	0	1	3	1	1	2	2	3	0	0	0	0	0.9375
	Boredom	3	0	2	0	0	0	2	0	1	0	0	1	3	0	0	0	0.75
	Disgust	0	0	1	0	0	1	3	1	1	1	0	0	0	0	0	0	0.5
	Distraction	4	0	4	0	0	0	4	0	4	3	0	2	4	0	2	1	1.75
	Fear	0	0	0	2	0	1	2	2	1	2	0	0	0	0	0	0	0.625
	Interest	5	4	2	3	3	0	3	2	4	4	3	5	0	5	2	4	3.0625
	Joy	5	5	3	1	2	0	3	4	4	2	4	5	0	5	2	1	2.875
	Pensiveness	1	4	4	0	0	1	3	1	4	4	3	4	0	2	1	4	2.25
	Sadness	0	0	2	3	0	0	2	0	1	3	0	0	0	0	0	0	0.6875
	Serenity	4	5	4	1	2	0	2	2	4	3	3	4	0	5	0	4	2.6875
	Surprise	5	0	1	0	2	1	3	3	3	3	2	2	0	0	4	0	1.8125
	Trust	5	4	2	0	2	0	3	3	4	2	2	4	0	5	0	2	2.375

	MALE RESULTS	Pattern 6														
Emotive intensity	Acceptence	4	5	5	3	1	5	4	2	2	3	1	5	2	0	3
	Anger	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0.428571
	Annoyance	0	0	0	2	2	1	0	4	2	1	0	2	1	3	1.285714
	Anticipation	3	2	5	1	2	1	0	3	2	3	0	3	1	0	1.857143
	Apprehension	0	0	0	0	1	1	1	4	2	1	0	1	1	0	0.857143
	Boredom	0	1	0	1	2	0	2	1	2	0	0	1	1	0	0.785714
	Disgust	0	0	0	0	0	1	0	5	2	0	0	1	3	0	0.857143
	Distraction	0	2	5	3	1	2	0	2	3	4	2	3	1	2	2.142857
	Fear	0	0	0	0	0	1	0	3	1	0	0	1	1	0	0.5
	Interest	4	1	5	3	1	3	5	4	3	3	2	4	2	0	2.857143
	Joy	4	3	5	2	4	3	3	2	3	4	2	4	2	4	3.214286
	Pensiveness	1	2	2	3	4	1	1	2	2	3	1	3	1	1	1.928571
	Sadness	0	2	0	0	1	4	0	3	1	1	0	2	2	0	1.142857
	Serenity	4	3	5	3	3	4	3	1	3	3	2	4	3	1	3
	Surprise	3	0	2	1	4	1	0	3	3	1	2	4	2	2	2
	Trust	4	3	5	3	1	3	4	1	3	4	2	4	3	0	2.857143

	FEMALE RESULTS	Pattern 7																
Emotive intensity	Surprise	4	2	0	0	3	3	3	3	4	3	1	4	5	4	0	3	2.625
	Sadness	0	0	0	0	0	1	2	1	4	2	0	0	0	1	1	2	0.875
	Interest	5	2	5	0	5	3	2	3	1	4	2	4	5	5	5	2	3.3125
	Trust	1	2	4	0	5	2	2	3	0	4	3	3	3	1	5	2	2.5
	Boredom	0	0	0	0	0	0	3	2	1	1	0	0	0	0	0	4	0.6875
	Apprehension	2	2	1	0	1	3	2	1	4	2	0	0	2	3	2	4	1.8125
	Joy	2	2	4	3	5	3	2	4	0	3	3	3	4	2	4	1	2.8125
	Fear	0	0	0	0	0	0	2	1	2	2	0	0	0	2	0	2	0.6875
	Anger	0	0	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0.3125
	Anticipation	1	0	0	0	4	2	2	3	1	3	0	0	4	2	1	0	1.4375
	Distraction	5	2	2	3	0	0	2	3	1	3	1	0	5	3	2	4	2.25
	Pensiveness	2	0	3	0	4	3	2	4	5	3	1	0	3	1	5	3	2.4375
	Serenity	0	0	5	0	4	1	3	4	0	4	1	0	1	0	3	0	1.625
	Acceptance	0	0	5	0	4	2	2	3	0	3	2	3	3	2	4	2	2.1875
	Disgust	0	0	0	0	0	0	2	1	2	1	0	0	0	1	0	2	0.5625
	Annoyance	1	0	0	0	0	0	2	1	4	1	0	0	0	1	0	3	0.8125

	MALE RESULTS	Pattern 7														
Emotive intensity	Surprise	0	3	3	2	3	3	3	4	2	1	0	5	1	4	2.42857
	Sadness	0	2	1	0	1	2	3	2	2	0	1	0	0	0	1
	Interest	4	1	4	2	4	2	2	5	5	3	3	4	4	3	3.28571
	Trust	0	2	5	2	4	1	2	4	1	3	1	0	3	3	2.21429
	Boredom	0	1	1	0	0	2	1	0	2	1	3	0	2	0	0.92857
	Apprehension	0	2	2	0	2	2	2	0	4	2	3	0	1	0	1.42857
	Joy	0	1	4	1	1	2	1	4	1	1	2	3	1	3	1.78571
	Fear	0	1	0	0	1	2	3	0	4	0	2	3	1	0	1.21429
	Anger	0	1	1	0	1	2	2	0	2	0	1	2	0	0	0.85714
	Anticipation	0	1	2	0	3	1	3	1	2	2	3	2	0	3	1.64286
	Distraction	2	4	4	2	3	3	2	0	2	3	2	5	2	0	2.42857
	Pensiveness	4	1	3	2	4	3	3	4	4	4	3	3	2	1	2.92857
	Serenity	3	1	3	2	3	3	1	4	2	1	1	0	3	2	2.07143
	Acceptance	0	3	3	1	4	2	2	5	1	1	1	2	3	3	2.21429
	Disgust	0	1	1	0	1	2	2	0	4	0	1	3	1	0	1.14286
	Annoyance	0	1	1	0	2	3	3	0	3	2	1	4	0	0	1.42857

	FEMALE RESULTS	Pattern 8																
Emotive intensity	Acceptance	0	2	3	0	0	0	3	2	2	2	0	3	0	0	0	0	1.0625
	Anger	4	3	0	4	0	1	2	2	2	0	2	0	0	3	2	2	1.6875
	Annoyance	4	0	0	4	3	1	3	1	3	2	3	0	5	5	2	5	2.5625
	Anticipation	1	3	2	4	2	1	1	1	2	2	0	5	0	4	0	0	1.75
	Apprehension	3	3	1	5	2	2	3	4	3	2	1	2	0	4	0	2	2.3125
	Boredom	1	0	0	0	0	2	3	0	2	1	4	0	0	0	0	0	0.8125
	Disgust	4	0	0	3	0	1	3	1	1	3	2	0	0	2	1	0	1.3125
	Distraction	4	4	2	1	3	1	2	4	3	2	3	5	4	3	3	1	2.8125
	Fear	3	3	0	5	0	1	3	4	2	2	3	2	0	4	1	0	2.0625
	Interest	1	5	5	3	4	2	3	3	2	2	1	3	0	3	0	1	2.375
	Joy	0	0	4	0	0	0	1	1	1	2	0	3	0	0	0	0	0.75
	Pensiveness	4	5	0	1	0	2	4	1	3	2	2	3	0	3	0	0	1.875
	Sadness	4	0	0	1	0	2	3	1	3	3	3	0	0	0	0	0	1.25
	Serenity	0	2	2	0	0	0	1	0	1	1	0	2	0	0	0	0	0.5625
	Surprise	1	5	5	2	3	3	4	5	2	3	0	4	0	4	2	0	2.6875
	Trust	1	2	3	0	0	0	1	0	3	2	0	2	0	0	0	0	0.875

	MALE RESULTS	Pattern 8														
Emotive intensity	*Acceptance*	3	0	0	3	0	2	0	2	3	3	0	4	0	0	1.42857
	Anger	0	2	3	1	0	4	4	2	1	1	0	0	1	0	1.35714
	Annoyance	0	4	4	1	1	4	4	2	2	2	0	2	5	0	2.21429
	Anticipation	1	0	2	3	3	4	0	4	3	1	2	4	0	0	1.92857
	Apprehension	0	3	3	2	2	5	1	3	3	2	0	1	2	0	1.92857
	Boredom	0	1	2	1	1	1	3	1	3	2	0	1	1	0	1.21429
	Disgust	0	2	4	1	2	3	5	3	2	2	0	1	4	0	2.07143
	Distraction	0	1	4	3	2	5	2	3	1	1	1	2	3	4	2.28571
	Fear	0	4	4	2	1	2	4	4	2	1	0	2	0	0	1.85714
	Interest	1	1	3	1	2	5	3	3	3	1	3	4	3	0	2.35714
	Joy	1	0	1	2	2	2	0	2	2	1	2	3	0	0	1.28571
	Pensiveness	1	3	2	1	4	0	0	3	3	1	1	2	1	1	1.64286
	Sadness	0	0	4	1	2	1	4	3	2	2	0	2	0	0	1.5
	Serenity	1	0	3	3	2	0	0	3	2	1	1	2	0	1	1.35714
	Surprise	1	0	3	2	3	5	5	4	2	1	1	3	3	0	2.35714
	Trust	1	0	0	2	0	1	0	1	2	1	1	4	0	0	0.92857

	FEMALE RESULTS	Pattern 9																
Emotive intensity	*Acceptance*	0	0	3	0	2	3	3	2	4	4	1	3	2	1	5	4	2.3125
	Anger	0	0	0	0	1	0	1	1	3	1	0	0	0	4	1	1	0.8125
	Annoyance	1	3	0	1	1	0	1	2	3	2	1	0	0	4	2	1	1.375
	Anticipation	0	0	4	0	0	3	2	4	4	4	2	2	4	2	3	3	2.3125
	Apprehension	0	0	4	0	0	3	1	2	4	2	3	0	0	4	4	2	1.8125
	Boredom	0	0	1	0	1	0	1	2	2	2	0	0	0	2	0	1	0.75
	Disgust	0	0	0	0	0	0	1	1	2	2	0	0	0	3	1	1	0.6875
	Distraction	2	3	3	2	2	0	3	4	3	3	1	3	5	4	5	2	2.8125
	Fear	0	0	0	0	1	0	1	1	2	2	0	0	0	3	2	1	0.8125
	Interest	2	2	4	5	1	3	3	4	5	4	2	4	5	1	3	4	3.25
	Joy	0	1	0	2	2	1	4	2	2	3	0	2	3	2	1	3	1.75
	Pensiveness	1	1	4	3	2	4	3	4	2	3	1	0	3	1	4	3	2.4375
	Sadness	0	1	0	0	1	0	1	1	1	2	0	0	0	3	0	1	0.6875
	Serenity	0	0	0	0	2	1	2	2	0	3	1	0	3	0	3	4	1.3125
	Surprise	1	4	0	2	4	4	4	3	4	4	1	3	4	3	0	3	2.75
	Trust	0	0	0	0	2	3	3	3	1	3	0	0	3	0	2	5	1.5625

	MALE RESULTS	Pattern 9														
Emotive intensity	*Acceptance*	0	0	5	1	3	2	2	0	0	3	3	3	3	3	2
	Anger	0	1	1	0	2	3	1	4	4	1	1	1	3	0	1.57143
	Annoyance	4	3	1	1	2	4	1	5	5	1	2	3	2	0	2.42857
	Anticipation	0	1	3	2	3	2	3	0	0	3	3	3	1	2	1.85714
	Apprehension	0	1	1	1	3	3	2	0	4	2	3	1	3	0	1.71429
	Boredom	0	0	1	0	1	1	1	1	1	2	0	4	4	0	1.14286
	Disgust	0	3	2	0	1	4	1	5	4	1	1	0	1	3	1.85714
	Distraction	5	4	3	3	2	4	2	1	5	2	3	5	3	0	3
	Fear	0	1	0	0	2	4	2	4	1	1	2	1	3	0	1.5
	Interest	4	2	3	3	2	3	4	4	2	5	4	5	1	3	3.21429
	Joy	0	1	2	2	3	2	1	0	0	3	2	4	1	3	1.71429
	Pensiveness	0	1	2	1	3	2	2	0	2	2	4	2	1	1	1.64286
	Sadness	0	3	2	0	1	3	3	2	0	0	1	0	1	0	1.14286
	Serenity	1	1	4	2	3	1	2	0	4	1	4	0	0	2	1.78571
	Surprise	3	1	4	3	3	3	1	2	1	2	3	3	0	2	2.21429
	Trust	0	1	5	1	3	1	1	0	2	3	1	3	0	2	1.64286

	FEMALE RESULTS	Pattern 10																
Emotive intensity	*Acceptance*	2	2	2	0	0	1	2	0	3	2	0	0	0	4	0	0	1.125
	Anger	3	0	0	4	0	1	3	4	1	0	3	0	0	0	3	0	1.375
	Annoyance	4	0	2	3	2	3	3	4	3	2	3	4	0	3	2	2	2.5
	Anticipation	2	5	2	2	1	1	4	3	3	2	2	3	0	3	0	0	2.0625
	Apprehension	5	3	2	3	2	2	2	2	2	1	1	1	2	0	0	0	1.75
	Boredom	1	0	3	0	0	1	3	1	2	1	4	0	2	0	0	0	1.125
	Disgust	2	0	1	3	0	1	3	5	1	0	1	0	0	0	1	0	1.125
	Distraction	5	5	3	4	3	1	3	2	4	1	2	5	3	4	3	2	3.125
	Fear	4	1	1	4	0	2	2	4	1	2	4	4	0	0	3	1	2.0625
	Interest	3	5	4	3	2	0	3	4	3	1	1	2	0	4	0	1	2.25
	Joy	0	2	1	0	0	0	2	0	2	1	0	1	0	0	0	0	0.5625
	Pensiveness	2	5	1	1	0	1	3	3	4	1	2	0	3	0	2	1	1.8125
	Sadness	3	0	1	1	0	2	3	1	1	1	1	0	0	0	0	0	0.875
	Serenity	1	0	0	0	0	0	2	0	2	1	0	0	0	2	0	0	0.5
	Surprise	4	3	3	1	3	1	3	3	2	2	3	5	0	0	0	1	2.125
	Trust	0	1	2	0	0	0	2	0	3	2	0	0	0	0	0	0	0.625

	MALE RESULTS	Pattern 10														
Emotive intensity	*Acceptance*	3	0	2	2	1	1	0	1	3	2	1	1	0	0	1.21429
	Anger	0	2	4	2	2	4	3	0	1	3	0	2	2	0	1.78571
	Annoyance	0	2	5	2	0	4	4	1	2	4	0	3	3	0	2.14286
	Anticipation	2	1	3	1	2	2	1	2	2	3	1	2	1	0	1.64286
	Apprehension	0	5	2	2	2	4	2	2	3	3	1	4	1	0	2.21429
	Boredom	0	1	1	1	4	1	2	3	2	2	0	1	1	1	1.42857
	Disgust	0	2	4	1	0	4	4	1	2	1	0	2	3	0	1.71429
	Distraction	0	3	4	2	0	4	0	2	1	2	4	3	3	2	2.14286
	Fear	0	3	4	1	1	5	3	2	3	3	0	2	2	0	2.07143
	Interest	3	0	5	3	2	3	2	1	2	3	3	2	1	4	2.42857
	Joy	2	0	2	1	1	1	0	0	2	1	3	1	0	0	1
	Pensiveness	2	1	2	3	3	2	4	0	1	4	0	2	2	0	1.85714
	Sadness	0	1	3	1	1	1	4	3	3	3	0	2	0	0	1.57143
	Serenity	2	0	1	2	1	1	1	2	1	1	1	2	0	1	1.14286
	Surprise	2	3	2	3	3	4	1	2	2	3	2	4	2	3	2.57143
	Trust	3	0	0	2	0	1	2	1	3	3	1	3	0	0	1.35714

	FEMALE RESULTS	Pattern 11																
Emotive intensity	*Acceptance*	2	3	3	1	0	3	2	3	5	4	2	4	3	1	5	3	2.75
	Anger	0	0	4	0	5	0	0	1	1	2	0	0	0	2	0	4	1.1875
	Annoyance	0	0	2	0	5	0	2	1	1	1	0	0	0	2	0	5	1.1875
	Anticipation	1	0	3	5	0	4	3	4	1	2	1	1	3	2	0	1	1.9375
	Apprehension	0	0	0	0	3	3	1	2	5	2	0	0	1	2	0	4	1.4375
	Boredom	0	0	4	2	1	0	1	2	1	2	0	0	0	0	0	1	0.875
	Disgust	0	0	0	0	5	0	1	1	0	1	0	0	0	3	0	0	0.6875
	Distraction	0	0	4	2	5	0	2	4	2	2	3	1	4	4	3	5	2.5625
	Fear	0	0	0	0	5	0	3	1	0	2	0	0	0	1	0	0	0.75
	Interest	3	3	3	0	0	2	1	3	2	3	3	4	5	1	3	2	2.375
	Joy	2	0	3	0	0	1	1	4	4	4	3	4	3	2	5	1	2.3125
	Pensiveness	0	2	4	0	3	4	3	4	0	2	1	0	4	0	3	2	2
	Sadness	0	0	0	0	5	1	2	1	0	2	0	0	1	0	0	4	1
	Serenity	1	0	4	0	0	3	0	4	3	4	3	3	2	1	5	1	2.125
	Surprise	3	0	0	0	2	0	2	3	0	3	3	3	4	4	0	5	2
	Trust	2	4	0	0	0	2	2	3	3	3	3	3	3	2	5	4	2.4375

	MALE RESULTS	Pattern 11														
Emotive intensity	*Acceptance*	0	2	4	0	4	3	2	4	4	4	3	2	4	3	2.78571
	Anger	0	0	1	0	1	1	1	2	2	1	1	0	1	0	0.78571
	Annoyance	0	1	2	0	2	1	1	1	2	2	1	0	0	0	0.92857
	Anticipation	0	1	3	2	1	2	1	0	3	4	1	1	0	3	1.57143
	Apprehension	0	3	1	0	1	4	3	2	4	1	0	3	2	0	1.71429
	Boredom	0	1	2	0	1	2	4	0	0	0	3	0	0	0	0.92857
	Disgust	0	1	2	0	1	2	1	0	1	0	0	0	3	0	0.78571
	Distraction	2	2	2	3	2	3	3	0	1	0	3	4	2	0	1.92857
	Fear	0	4	1	0	1	1	3	0	2	0	0	0	3	0	1.07143
	Interest	3	1	2	3	3	3	2	3	4	3	1	4	1	3	2.57143
	Joy	0	0	4	0	1	3	2	3	2	2	2	5	0	2	1.85714
	Pensiveness	2	2	3	1	3	3	3	4	5	1	1	2	2	1	2.35714
	Sadness	0	2	0	0	1	2	4	1	4	1	0	0	5	0	1.42857
	Serenity	4	0	4	0	2	3	1	2	1	2	2	5	2	1	2.07143
	Surprise	0	2	3	1	1	3	1	3	1	4	0	4	0	2	1.78571
	Trust	0	2	5	1	4	3	5	3	3	2	2	3	2	3	2.71429

	FEMALE RESULTS	Pattern 12																
Emotive intensity	*Acceptance*	4	5	1	5	3	2	4	5	3	3	0	2	0	0	0	1	2.375
	Anger	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0.1875
	Annoyance	1	0	0	0	0	0	1	1	1	1	3	1	0	3	0	0	0.75
	Anticipation	4	0	2	1	0	2	3	1	4	3	2	2	0	4	0	0	1.75
	Apprehension	1	0	2	1	0	1	1	2	2	1	0	3	0	4	0	0	1.125
	Boredom	1	0	1	0	0	0	2	1	2	0	5	4	0	0	0	0	1
	Disgust	1	0	2	0	0	0	1	0	1	1	0	0	0	3	0	0	0.5625
	Distraction	3	2	3	1	2	2	1	3	4	3	0	0	0	0	5	2	1.9375
	Fear	0	0	1	0	0	1	1	2	1	1	2	3	0	0	0	0	0.75
	Interest	4	4	1	5	4	2	4	0	4	3	0	0	5	0	3	2	2.5625
	Joy	3	5	2	4	4	2	3	5	3	3	0	2	3	0	3	0	2.625
	Pensiveness	4	4	2	4	0	2	2	1	4	3	4	1	0	4	2	0	2.3125
	Sadness	0	3	0	0	0	1	2	0	1	1	2	2	0	4	0	0	1
	Serenity	5	2	0	4	3	1	4	5	4	3	1	0	0	4	0	1	2.3125
	Surprise	5	2	4	5	3	4	4	3	3	3	3	0	3	4	2	3	3.1875
	Trust	4	5	1	4	1	1	3	1	3	3	1	4	0	0	1	0	2

	MALE RESULTS	Pattern 12														
Emotive intensity	*Acceptance*	2	3	4	2	3	4	4	2	2	3	3	5	1	0	2.71429
	Anger	0	0	0	0	0	2	0	1	1	0	0	2	1	0	0.5
	Annoyance	0	1	0	2	1	0	0	1	2	1	0	2	1	0	0.78571
	Anticipation	1	1	1	0	4	3	0	2	2	4	2	2	1	0	1.64286
	Apprehension	0	0	0	0	2	0	0	3	2	1	0	1	2	0	0.78571
	Boredom	0	3	0	4	1	0	0	4	3	1	0	2	1	0	1.35714
	Disgust	0	1	0	0	0	0	0	2	3	0	0	2	2	0	0.71429
	Distraction	0	2	4	1	0	2	0	4	2	4	3	2	1	0	1.78571
	Fear	0	1	0	0	0	1	0	0	2	0	0	1	1	0	0.42857
	Interest	1	0	5	0	5	4	4	1	2	4	3	4	2	0	2.5
	Joy	1	2	4	1	2	2	3	1	3	4	3	4	0	0	2.14286
	Pensiveness	1	3	2	1	2	1	1	3	2	4	2	3	1	3	2.07143
	Sadness	0	1	0	0	1	2	0	4	2	2	0	2	3	2	1.35714
	Serenity	1	5	3	1	1	4	4	1	3	3	3	4	1	1	2.5
	Surprise	1	2	3	1	5	1	3	1	3	4	3	2	1	0	2.14286
	Trust	1	1	3	0	2	3	5	0	3	3	2	5	1	0	2.07143

	FEMALE RESULTS	Pattern 13																
Emotive intensity	*Acceptance*	0	2	5	0	2	0	3	2	2	4	4	4	4	1	4	4	2.5625
	Anger	0	0	0	0	0	0	1	2	0	1	0	0	0	3	0	1	0.5
	Annoyance	0	0	0	0	0	2	1	2	3	3	0	0	0	3	0	2	1
	Anticipation	2	2	0	0	0	0	3	3	1	2	2	1	0	0	0	4	1.25
	Apprehension	0	0	0	0	0	2	1	2	1	2	1	0	0	0	0	1	0.625
	Boredom	0	0	0	3	1	4	1	2	0	2	0	0	5	2	2	1	1.4375
	Disgust	0	0	0	0	0	3	1	1	0	1	0	0	0	4	0	2	0.75
	Distraction	3	0	0	0	0	0	3	3	2	3	3	0	0	2	2	2	1.4375
	Fear	0	0	0	0	0	0	1	2	0	2	0	0	0	0	0	1	0.375
	Interest	2	1	4	0	3	0	1	2	1	4	4	4	0	0	3	4	2.0625
	Joy	2	3	5	0	2	1	3	2	1	3	3	4	0	1	5	4	2.4375
	Pensiveness	1	0	3	0	0	2	4	3	1	3	4	0	0	0	5	3	1.8125
	Sadness	0	0	3	0	0	2	1	2	1	1	0	0	0	0	2	1	0.8125
	Serenity	1	0	4	0	0	0	3	2	4	3	4	3	2	2	5	3	2.25
	Surprise	2	0	0	0	0	1	4	2	3	3	5	4	1	4	0	5	2.125
	Trust	1	4	5	0	1	1	4	3	5	2	5	4	4	1	5	5	3.125

	MALE RESULTS	Pattern 13														
Emotive intensity	*Apprehension*	0	2	2	0	1	3	4	0	3	0	3	3	3	0	1.71429
	Annoyance	0	2	2	1	1	1	1	3	2	2	0	1	0	0	1.14286
	Distraction	3	2	5	2	1	3	2	2	2	0	1	5	5	0	2.35714
	Anger	0	2	1	0	1	1	1	1	3	0	0	1	0	0	0.78571
	Disgust	0	2	1	0	1	2	1	3	1	0	1	0	1	0	0.92857
	Fear	0	1	2	0	0	1	3	2	2	1	3	1	1	0	1.21429
	Boredom	4	1	1	0	3	2	1	0	3	0	2	0	0	0	1.21429
	Sadness	1	2	2	0	3	2	1	1	1	0	1	0	3	0	1.21429
	Pensiveness	2	2	1	3	3	3	1	2	2	3	3	2	4	1	2.28571
	Anticipation	0	0	3	2	1	3	3	1	2	4	2	1	3	3	2
	Serenity	1	2	2	2	3	3	1	0	3	1	1	3	4	3	2.07143
	Interest	1	2	4	2	3	4	3	3	4	5	3	5	5	3	3.35714
	Surprise	0	0	4	2	0	3	3	0	3	2	3	5	4	4	2.35714
	Trust	0	2	2	3	4	3	1	1	4	4	2	4	2	4	2.57143
	Joy	1	1	3	2	2	3	1	1	3	3	1	4	1	4	2.14286
	Acceptance	0	1	2	2	4	4	1	0	2	3	3	3	4	4	2.35714

	FEMALE RESULTS	Pattern 14																
Emotive intensity	*Acceptance*	4	0	2	1	4	1	3	4	2	3	0	2	0	0	0	0	1.625
	Anger	3	0	0	1	0	2	1	0	1	0	2	0	0	0	0	1	0.6875
	Annoyance	2	0	1	5	0	1	1	0	1	0	4	0	5	5	0	3	1.75
	Anticipation	3	0	3	4	2	2	3	0	4	1	0	5	0	0	0	0	1.6875
	Apprehension	2	0	0	2	0	1	1	0	2	1	0	2	0	3	2	0	1
	Boredom	2	1	0	0	0	3	2	0	2	3	4	0	0	4	0	0	1.3125
	Disgust	3	0	0	3	0	1	3	0	1	0	3	0	0	5	0	0	1.1875
	Distraction	4	5	4	3	0	1	3	0	4	1	0	0	4	4	3	3	2.4375
	Fear	2	0	1	4	0	2	1	1	1	0	3	0	0	0	0	0	0.9375
	Interest	4	5	5	3	4	1	3	0	4	1	0	1	0	0	3	1	2.1875
	Joy	0	5	4	0	3	0	3	0	4	1	0	2	0	0	2	0	1.5
	Pensiveness	3	5	4	1	0	1	2	1	4	2	0	0	0	0	3	0	1.625
	Sadness	2	4	0	3	0	2	1	1	1	0	3	0	0	0	0	0	1.0625
	Serenity	2	4	2	0	3	0	3	1	4	0	0	2	0	0	0	0	1.3125
	Surprise	4	1	4	0	3	1	4	1	3	1	0	5	0	0	0	0	1.6875
	Trust	3	3	3	0	2	0	3	3	3	2	0	2	0	0	1	1	1.625

	MALE RESULTS	Pattern 14														
Emotive intensity	*Acceptance*	2	0	2	2	2	2	5	1	1	1	2	2	0	0	1.57143
	Anger	0	5	2	1	3	1	0	1	2	1	0	3	0	1	1.42857
	Annoyance	0	5	5	2	5	0	0	2	3	4	0	2	2	0	2.14286
	Anticipation	2	2	1	1	1	2	0	2	1	4	1	1	0	1	1.35714
	Apprehension	0	4	1	2	2	1	0	3	2	4	0	3	0	0	1.57143
	Boredom	0	1	3	1	5	2	0	4	2	1	0	3	0	1	1.64286
	Disgust	0	5	4	1	3	3	5	3	3	2	0	3	0	3	2.5
	Distraction	0	2	4	2	5	2	0	2	2	4	3	2	4	1	2.35714
	Fear	0	4	2	1	2	1	0	3	2	1	0	3	0	1	1.42857
	Interest	2	2	2	2	1	3	5	3	3	4	2	2	2	1	2.42857
	Joy	2	0	3	0	2	0	5	1	1	3	4	1	0	0	1.57143
	Pensiveness	0	3	3	1	1	1	0	1	3	3	2	2	0	0	1.42857
	Sadness	0	0	3	1	1	3	0	1	2	1	0	5	0	2	1.35714
	Serenity	2	0	1	2	1	1	5	1	3	0	2	3	0	0	1.5
	Surprise	2	1	1	0	1	1	0	1	2	4	2	2	0	0	1.21429
	Trust	2	0	1	3	0	1	5	0	2	1	2	1	0	0	1.28571

	FEMALE RESULTS	Pattern 15																
Emotive intensity	*Acceptance*	1	0	4	0	5	2	3	2	1	3	0	4	1	0	3	5	2.125
	Anger	0	2	0	2	0	0	1	1	0	2	1	0	0	5	1	0	0.9375
	Annoyance	0	2	0	5	0	3	0	2	2	2	1	0	0	5	2	3	1.6875
	Anticipation	0	0	0	0	3	2	2	4	1	4	2	1	0	1	4	3	1.6875
	Apprehension	0	0	3	0	3	2	1	3	0	1	2	0	3	5	4	3	1.875
	Boredom	0	3	4	0	0	0	1	2	0	0	1	0	0	0	1	0	0.75
	Disgust	0	0	0	0	0	0	1	1	2	1	1	0	0	2	1	1	0.625
	Distraction	0	3	0	5	0	0	2	4	0	4	2	0	4	3	5	5	2.3125
	Fear	0	0	0	0	0	0	1	1	0	1	2	0	0	4	1	4	0.875
	Interest	2	0	1	0	5	2	4	5	2	4	2	5	4	3	5	5	3.0625
	Joy	2	0	0	0	5	0	3	4	2	3	0	4	2	0	2	3	1.875
	Pensiveness	0	0	0	0	2	3	3	3	1	2	1	0	4	0	5	3	1.6875
	Sadness	0	0	4	0	0	1	2	1	1	1	1	0	0	4	3	1	1.1875
	Serenity	4	0	5	0	5	2	3	4	3	3	0	4	4	0	2	4	2.6875
	Surprise	1	0	0	0	2	0	2	4	1	4	1	3	5	4	2	3	2
	Trust	3	0	0	0	5	0	3	3	2	4	0	4	0	1	0	3	1.75

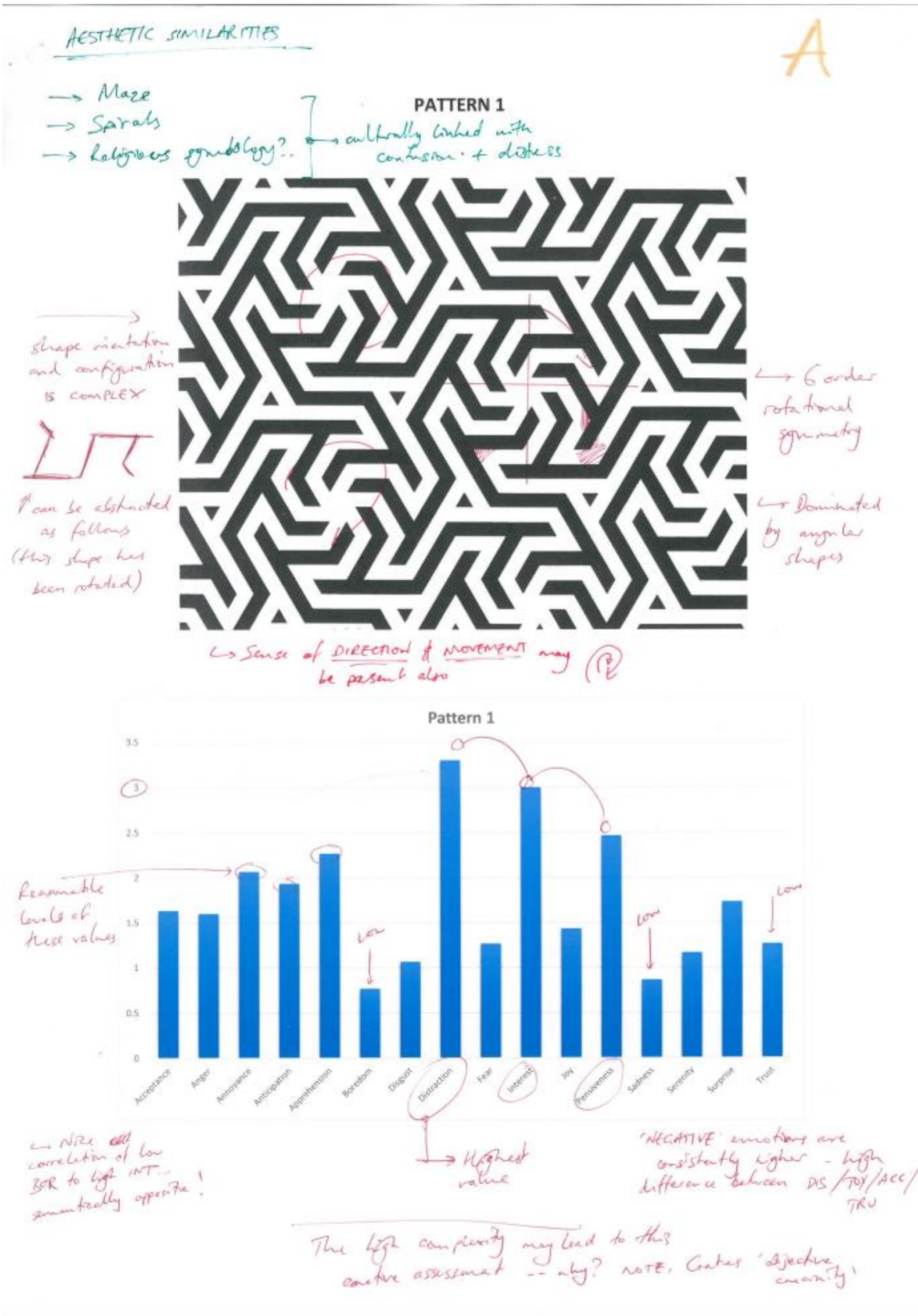
	MALE RESULTS	Pattern 15														
Emotive intensity	*Acceptance*	0	0	1	1	4	3	4	4	2	1	3	4	1	3	2.21429
	Anger	0	0	2	0	1	1	2	0	1	1	1	0	1	0	0.71429
	Annoyance	3	1	3	0	3	1	2	0	1	1	0	2	4	0	1.5
	Anticipation	0	0	2	0	3	2	2	1	3	2	0	1	1	3	1.42857
	Apprehension	0	0	3	0	3	2	1	1	4	1	0	2	3	0	1.42857
	Boredom	0	1	5	0	1	3	1	1	1	0	2	1	0	0	1.14286
	Disgust	2	1	3	0	2	2	2	0	1	0	0	0	3	0	1.14286
	Distraction	1	4	1	0	4	3	3	1	0	1	2	3	4	0	1.92857
	Fear	0	0	2	0	1	1	2	0	4	4	1	1	4	0	1.42857
	Interest	4	4	2	1	4	3	3	3	2	5	1	3	2	4	2.92857
	Joy	0	1	1	1	2	2	1	3	1	1	0	4	0	3	1.42857
	Pensiveness	0	1	3	0	3	2	4	4	1	4	0	2	1	1	1.85714
	Sadness	0	2	4	0	2	1	2	0	1	0	1	0	0	0	0.92857
	Serenity	0	1	4	2	3	2	3	4	1	1	2	4	2	3	2.28571
	Surprise	0	2	2	2	3	2	1	0	2	1	1	2	0	4	1.57143
	Trust	0	0	2	1	4	2	4	4	1	3	2	3	1	4	2.21429

	FEMALE RESULTS	Pattern 16																
Emotive intensity	*Acceptance*	1	3	3	0	2	1	4	1	3	1	3	2	2	0	3	1	1.875
	Anger	3	0	0	2	0	1	1	1	1	2	0	0	0	0	0	0	0.6875
	Annoyance	4	5	1	1	0	2	1	0	2	3	0	0	0	0	0	0	1.1875
	Anticipation	0	0	0	1	0	2	2	1	2	2	2	2	0	3	0	0	1.0625
	Apprehension	5	3	0	0	0	1	2	0	2	2	3	4	0	0	0	0	1.375
	Boredom	4	5	0	0	0	2	2	1	2	2	0	0	0	5	2	0	1.5625
	Disgust	3	4	0	1	0	0	1	0	1	3	0	0	0	3	0	0	1
	Distraction	3	0	1	0	0	3	1	4	3	1	0	3	0	0	0	0	1.1875
	Fear	4	2	2	1	0	1	1	0	1	3	0	0	0	5	0	0	1.25
	Interest	0	0	3	3	2	2	4	1	2	1	2	4	5	2	2	2	2.1875
	Joy	0	1	2	0	2	0	3	1	2	1	1	5	3	0	0	2	1.4375
	Pensiveness	4	0	5	1	0	1	1	3	3	3	3	3	0	3	1	0	1.9375
	Sadness	3	4	1	2	0	2	1	0	1	3	2	0	0	0	0	0	1.1875
	Serenity	0	1	2	0	0	0	4	1	2	1	3	2	3	0	0	1	1.25
	Surprise	1	0	2	0	0	2	3	1	2	3	0	2	0	0	0	0	1
	Trust	4	3	2	0	2	1	4	3	3	1	4	5	2	0	3	0	2.3125

	MALE RESULTS	Pattern 16														
Emotive intensity	***Acceptance***	3	3	3	3	4	3	4	2	3	3	2	1	3	0	2.64286
	Anger	0	1	2	2	0	1	0	1	1	1	0	5	0	0	1
	Annoyance	0	0	5	4	1	2	0	1	2	1	0	5	0	0	1.5
	Anticipation	2	0	4	1	3	4	1	0	3	2	3	1	0	0	1.71429
	Apprehension	0	0	3	3	2	4	0	1	3	1	0	3	0	0	1.42857
	Boredom	0	2	0	1	0	1	0	3	2	2	0	3	0	0	1
	Disgust	0	0	0	3	0	3	0	0	2	1	0	2	0	0	0.78571
	Distraction	0	2	4	2	1	4	0	2	3	1	3	4	1	0	1.92857
	Fear	0	0	4	1	0	3	0	1	2	2	0	3	0	0	1.14286
	Interest	2	3	3	2	2	4	4	2	3	2	3	2	4	3	2.78571
	Joy	3	1	0	2	4	3	2	1	2	1	3	2	2	0	1.85714
	Pensiveness	1	3	2	2	5	2	3	3	3	3	3	1	0	2	2.35714
	Sadness	0	1	2	1	1	1	0	1	2	2	0	4	0	0	1.07143
	Serenity	3	1	0	2	1	2	0	0	3	4	2	0	1	3	1.57143
	Surprise	3	1	2	3	2	3	0	1	2	1	3	1	0	0	1.57143
	Trust	3	3	0	2	2	3	3	3	3	3	2	3	3	3	2.57143

11.1.2 Pattern study 1 – aesthetic analysis

Excerpt, all analysis available on request



AESTHETIC SIMILARITIES

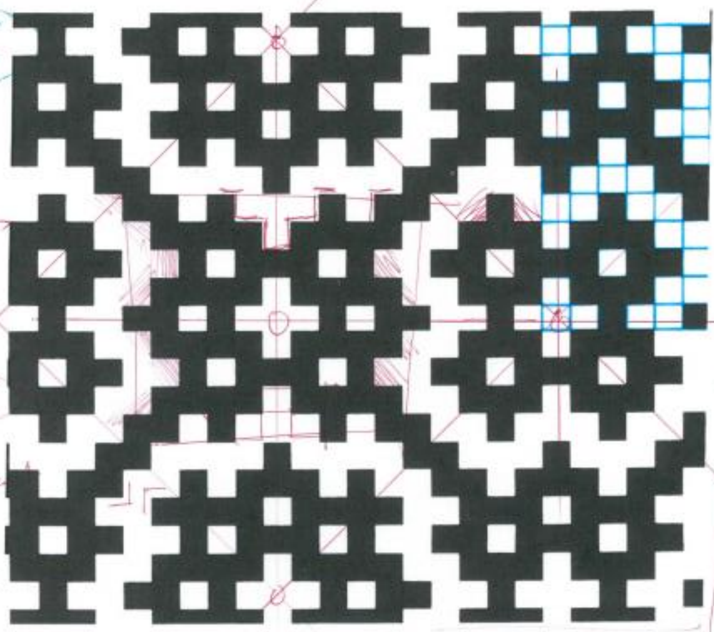
A

↳ Abstracted flowers?

↳ TETRIS?

↳ Confusion & complexity

PATTERN 2



Built from sets of squares!

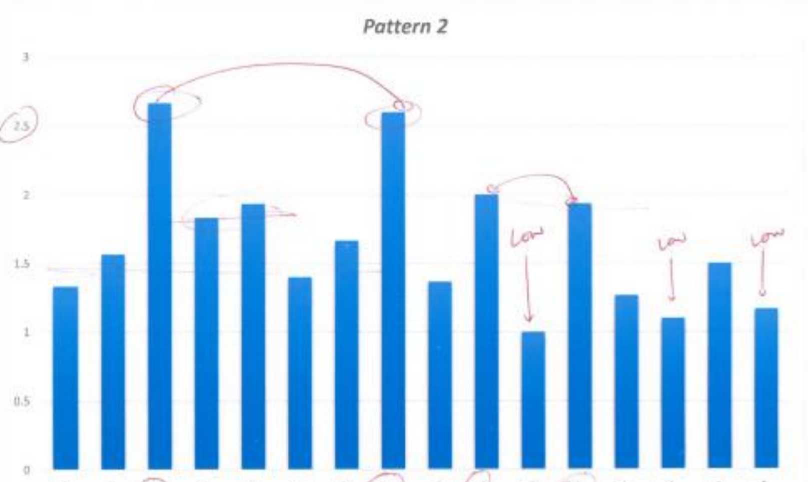
simple symmetric structure

↳ the arrangement of the elements leads to a complex aesthetic

MANY INTERLOCKING ELEMENTS

↳ form + structural design is quite simple

↳ fundamentally ANGULAR



↳ Associated with 'NEGATIVE' emotional spectrum

Again DIS/INT/PEN all recieve high values } — My link again to Coates idea of 'conativity'

AESTHETIC SIMILARITIES

M

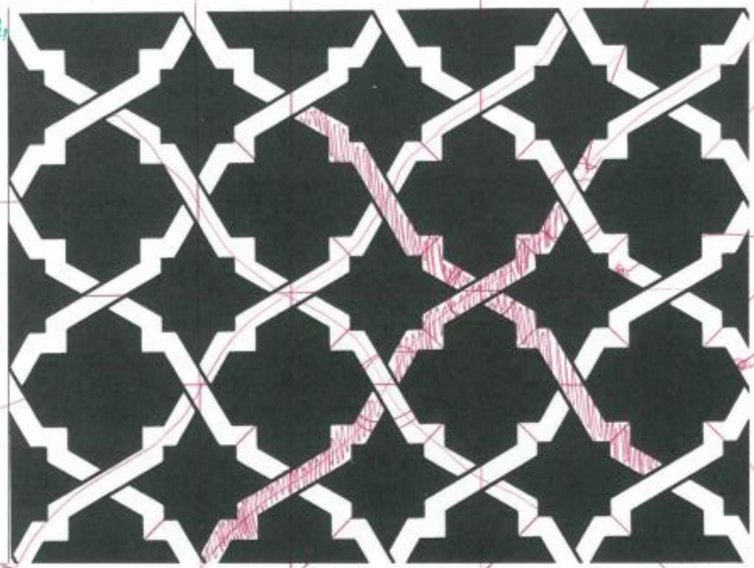
↳ Stars / star of David? (negative space)

↳ Interweaving paths

↳ Threads

PATTERN 3

These circled areas disrupt the symmetry



↳ This only has a quasi-symmetry

How much is the negative space affecting the interpretation of the pattern?

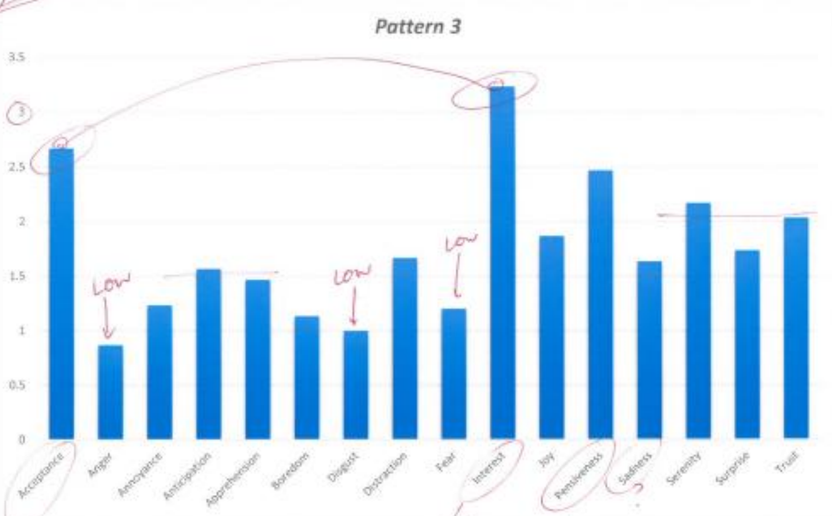
High amount of negative space!

↳ Highly angular structure

↳ NOTE CURVING ILLUSION (Gestalt)

Symmetry within the negative space

Curving illusion



what is the relationship here ... if any??

It seems many people find this pattern 'interesting' (INT)
→ associated with more POSITIVE emotive experience

11.2 Participant information sheet – Pattern and Line study

University of Strathclyde Glasgow

Participant Information Sheet

Name of department: DMEM
Title of the study: ***The emotive qualities of patterns***

Introduction
This study will analyse the emotive qualities of patterns. I am investigating the emotive qualities of form generally and am using patterns as a platform for this analysis. Patterns have interesting structural complexity and have been shown to be laden with semantic meaning. A thorough emotive analysis of pattern forms has not yet been conducted.

What will you do in the project?
TASK 1:

You will be asked to analyse a series of patterns over a period of roughly 35 minutes. Every pattern has different form qualities and you will have 1.5 minutes to analyse each of the 16 patterns. You will be provided with a worksheet containing lists of emotions and associated Likert scales of emotive intensity. You must rank the intensity of each emotion perceived when observing the pattern.

TASK 2:

You will be presented with a worksheet containing two points and an emotive word. The task is to draw a continuous line that represents the emotive work shown. You will have 30 seconds to complete each line.

What happens to the information in the project?
Participants will remain anonymous. The information gathered will be used in further form theory work, primarily the construction of bespoke "emotive patterns".

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

Consent Form

Name of department: DMEM
Title of the study: *The emotive qualities of patterns*

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences. If I exercise my right to withdraw and I don't want my data to be used, any data which have been collected from me will be destroyed.
- I understand that I can withdraw from the study any personal data (i.e. data which identify me personally) at any time.
- I understand that anonymised data (i.e. .data which do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project

(PRINT NAME)	
Signature of Participant:	Date:

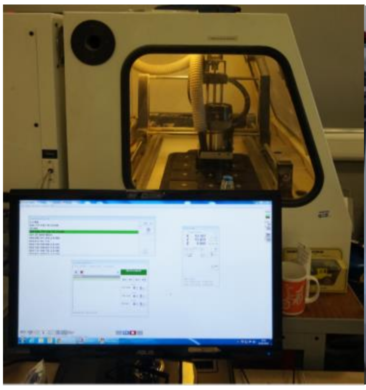
The place of useful learning

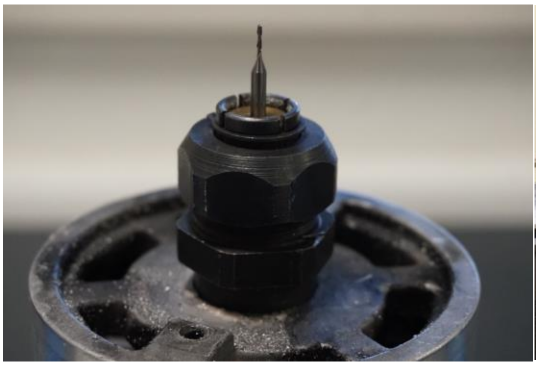
11.3 Review of subtractive machining technologies

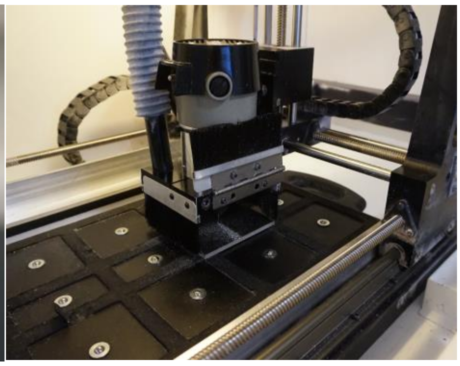
PROCESS	DESCRIPTION	APPLICATIONS	GEOMETRIC RANGE	COSTS	MATERIAL RANGE	CNC
MILLING	Rotary cutting by machining tools (typically end mills, ball nose cutters and side/face cutters) remove material to form desired shape. Modern milling machines use advanced mechanical and robotic designs to position the path of the cutting tools	Wide range of applications; machined parts are used in aerospace, automotive and other large-scale industrial applications. Smaller scale applications include consumer electronics, furniture, clothing and jewellery	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling equipment and path. Angled edges may be impossible to produce due to intrinsic geometry. CAM technology is required to simulate tool paths before production	Costs range from very cheap to very expensive. Function of the tooling requirements and material usage	Excellent material range; virtually any material can be used that has a suitable hardness and is not prone to fracturing under strain (wood, plastics, metals, alloys)	YES
PHOTOCHEMICAL MACHINING	Material is removed using corrosive chemicals coupled with photoresist material to achieve the desired form. The photoresist material will resist the chemical corrosion. Process is "unconventional" as it is not based on removal by mechanical forces	Wide range of applications; commonly applied in electronics and for forming sheet metals eg. producing fine screens and meshes. It is also used in jewellery production	Geometric capability is limited; excellent for forming sheet metal as any shape profile can be translated but lacks the dynamic forming qualities of traditional milling. Filleted edged cannot be produced for examples	Costs are generally inexpensive; less than $350	Good material range – limited to metals and alloys; aluminium, brass, copper, Inconel, manganese, nickel, steel, stainless steel, zinc and titanium	NO
ELECTRICAL DISCHARGE MACHINING (EDM)	Material is removed by a process of electrical discharges (sparks); Rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. Process is "unconventional" as it is not based on removal by mechanical forces.	Applications are limited; commonly used within the die and mold-making industries. Also used in producing dies for coinage and jewellery, and small hole drilling where tapered holes can be produced	Geometric capability is excellent as the process is not constrained by the geometry of tooling. Very complex shapes and very fine holes can be produced	Costs are generally very high when using this process; expertise can be difficult to source; material removal rate is slow and overhead costs are high	Good material range – limited to metals because the workpiece must be conductive. Virtually all metals, alloys and super-alloys can be used including steel, aluminium and brass	YES
ULTRASONIC MACHINING	Material is removed through high frequency, low amplitude vibrations of the tool against the workpiece in the presence of fine abrasive particles. Two typical types of ultrasonic machining – rotary and chemical-assisted	Often used to machine more brittle materials that may be more sensitive than other machining metals. Process is often applied in electronics and optics production. Its high tolerances mean it can be used for important structural components	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling equipment and path. Angled edges may be impossible to produce due to intrinsic geometry. CAM technology is required to simulate tool paths before production	Costs are generally very high when using this process; tolerances are very high; material removal rate is slow and material limitations can cause difficulties in the process	Good material range; the process is not limited to the intrinsic conductive properties of the material, but it is preferable to use a material with low ductility. Hardness of the material used must be above 45 HCR (Rockwell hardness); ceramics, carbides, glass, precious stones, hardened steels	YES
ELECTROCHEMICAL MACHINING (ECM)	Material is removed by a process of workpiece interaction with an electrical current. Metal is dissolved from a workpiece with direct current at a controlled rate in an electrolytic cell. The workpiece serves as the anode and is separated by a gap (which can be as small as 10 μm) from the tool, which serves as the cathode. It is often described as "reverse electroplating"	The process can create simple to very complex shapes and benefits from near zero tool wear – one tool can be used an infinite number of times. Typically used to produce turbine blades, in die sinking operations and for multiple hole drilling	Geometric capability is excellent, and machines can be configured in 6-axis setups allowing for high complex geometries. Some of the constraints associated with conventional mechanical machining are not present. Tolerances are excellent and de-burring is fast	Costs are generally very high when using this process; the process is still niche and requires specialist knowledge, machining equipment can also be expensive and has high running costs	Good material range – limited to metals because the workpiece must be conductive. Brass, graphite and copper-tungsten and steel are commonly used due to their good machinability	NO

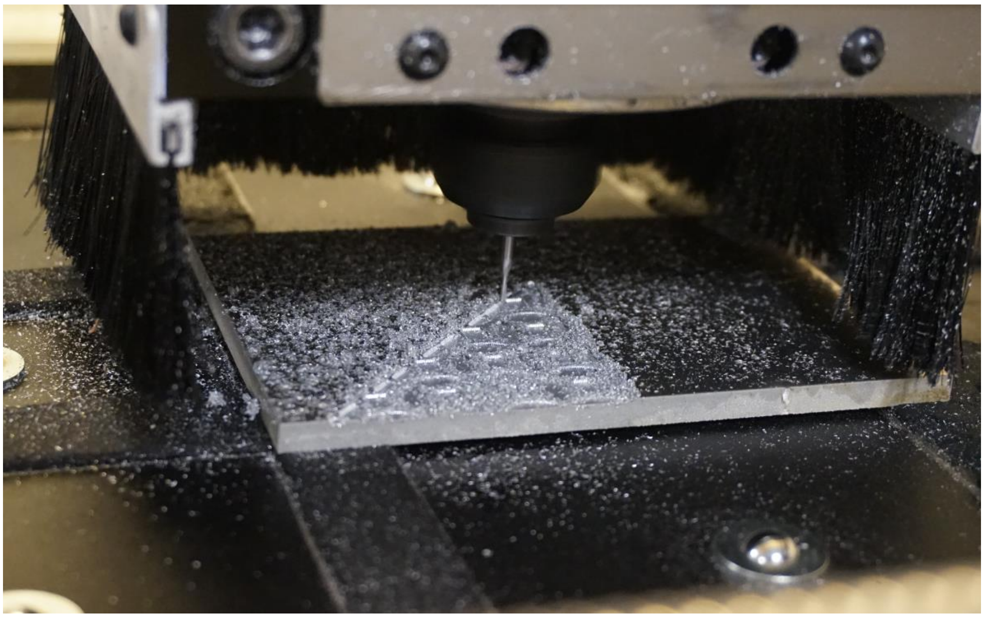
PROCESS	DESCRIPTION	APPLICATIONS	GEOMETRIC RANGE	COSTS	MATERIAL RANGE
MILLING	Rotary cutting by machining tools (typically end mills, ball nose cutters and side/face cutters) remove material to form desired shape. Modern milling machines use advanced mechanical and robotic designs to position the path of the cutting tools	Wide range of applications; machined parts are used in aerospace, automotive and other large-scale industrial applications. Smaller scale applications include consumer electronics, furniture, and jewellery	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling equipment and path. Angled edges may be impossible to produce due to intrinsic geometry.	LOW-HIGH	Excellent material range; virtually any material can be used that has a suitable hardness and is not prone to fracturing under strain (wood, plastics, metals, alloys)
ELECTRICAL DISCHARGE MACHINING (EDM)	Material is removed by a process of electrical discharges (sparks); Rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage.	Applications are limited; commonly used within the die and mold-making industries. Also used in producing dies for coinage and jewellery	Geometric capability is excellent as the process is not constrained by the geometry of tooling. Very complex shapes and very fine holes can be produced	HIGH	Good material range – limited to metals because the workpiece must be conductive. Virtually all metals, alloys and super-alloys can be used including steel, aluminium and brass
ULTRASONIC MACHINING	Material is removed through high frequency, low amplitude vibrations of the tool against the workpiece in the presence of fine abrasive particles. Two typical types of ultrasonic machining – rotary and chemical-assisted	Often used to machine more brittle materials that may be more sensitive than other machining metals. Process is often applied in electronics and optics production. Its high tolerances mean it can be used for important structural components	Geometric capability is excellent for 5 axis machines but is constrained by the geometry of tooling; cannot create interior geometry – work areas must be accessible for the tooling equipment and path. Angled edges may be impossible to produce due to intrinsic geometry. CAM technology is required to simulate tool paths before production	HIGH	Good material range; Hardness of the material used must be above 45 HCR (Rockwell hardness); ceramics, carbides, glass, precious stones, hardened steels

11.4 Denford CNC machine setup









11.5 Record of machined plates

11.5.1 'Fear' variations

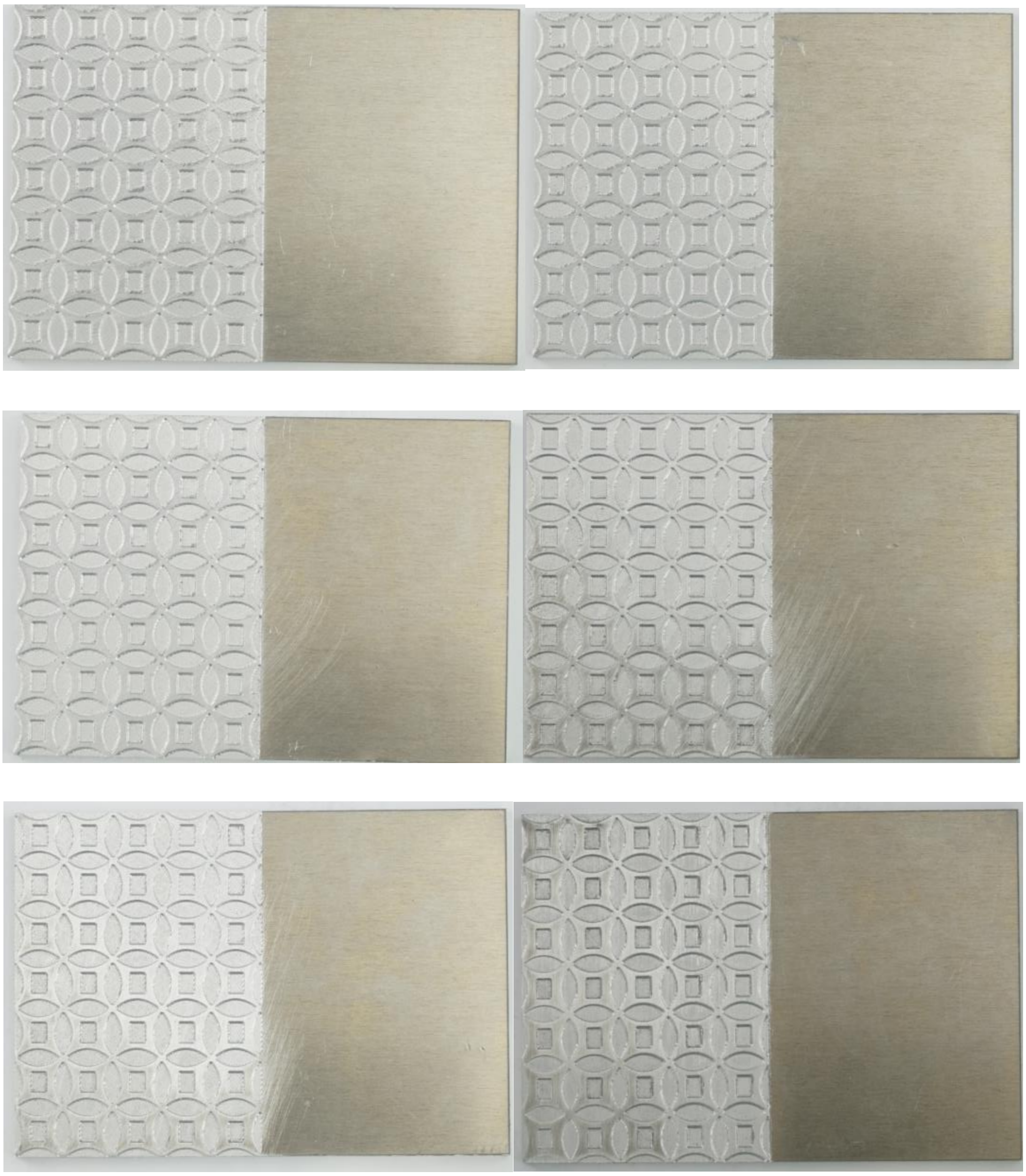



11.5.2 ‘Surprise’ variations






11.5.3 'Trust' variations



11.5.4 'Joy' variations




11.6 Pilot study results

Emotive intensity

ALL RESULTS	Pattern 1 - Trust				
Acceptance	3	4	1	3	2.75
Anger	1	1	2	0	1
Annoyance	1	2	3	1	1.75
Anticipation	2	3	2	1	2
Appehension	1	1	4	2	2
Boredom	2.5	2	0	2	1.625
Disgust	2	1	1	1	1.25
Distraction	2	4	4	4	3.5
Fear	1	0	1	0	0.5
Interest	3	3	1	3	2.5
Joy	3	4	1	2	2.5
Pensiveness	2	3	3	3	2.75
Sadness	3	0	0	2	1.25
Serenity	3.5	4	0	3	2.625
Surprise	1	4	3	0	2
Trust	3	4	2	4	3.25

Emotive intensity

ALL RESULTS	Pattern 2 - Surprise				
Acceptance	3	3	1	0	1.75
Anger	3	2	1	3	2.25
Annoyance	3	0	2	4	2.25
Anticipation	2	1	1	2	1.5
Appehension	3	2	2	3	2.5
Boredom	1	2	0	0	0.75
Disgust	3	2	3	5	3.25
Distraction	4	3	3	3	3.25
Fear	3	3	2	3	2.75
Interest	3	3	2	3	2.75
Joy	3.5	4	1	1	2.375
Pensiveness	3	2	2	1	2
Sadness	2.5	1	1	1	1.375
Serenity	2	1	1	0	1
Surprise	3	4	3	1	2.75
Trust	2	2	1	0	1.25

Emotive intensity

ALL RESULTS	Pattern 3 - Joy				
Acceptance	2	2	3	4	2.75
Anger	3	0	0	0	0.75
Annoyance	3	1	1	1	1.5
Anticipation	2	1	0	1	1
Appehension	2	1	0	1	1
Boredom	3	3	1	3	2.5
Disgust	3	2	0	0	1.25
Distraction	4	4	0	3	2.75
Fear	2	0	0	2	1
Interest	1	1	2	3	1.75
Joy	1	2	3	4	2.5
Pensiveness	3	2	2	2	2.25
Sadness	3	0	1	0	1
Serenity	1	1	4	5	2.75
Surprise	3	1	1	0	1.25
Trust	2	1	4	4	2.75

Emotive intensity

ALL RESULTS	Pattern 4 - Fear				
Acceptance	3	1	0	5	2.25
Anger	3	4	4	5	4
Annoyance	3	4	4	4	3.75
Anticipation	4	2	2	3	2.75
Appehension	4	3	4	3	3.5
Boredom	1	1	1	0	0.75
Disgust	2	1	2	4	2.25
Distraction	4	5	4	4	4.25
Fear	2	2	4	4	3
Interest	4	2	0	3	2.25
Joy	3	2	0	1	1.5
Pensiveness	4	1	1	1	1.75
Sadness	2	1	2	0	1.25
Serenity	3	0	0	3	1.5
Surprise	4	3	1	4	3
Trust	3	2	0	4	2.25

Visual

JOY	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Visually prefer	1		1	1		1
Visually don't prefer	3	2	3	2	3	2
No visual preference		2		1	1	1

TRUST	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Visually prefer	2	3	2	2		1
Visually don't prefer	2		1	2	3	1
No visual preference		1	1		1	2

FEAR	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Visually prefer	1	1		2	2	2
Visually don't prefer	2	3	4	2	2	2
No visual preference	1					

SURPRISE	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Visually prefer	2	2	2	2		1
Visually don't prefer	2	2	1	1	3	3
No visual preference			1	1	1	

Tactile

JOY	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
More comfortable		1	1			
Less comfortable	2	3	3	3	3	4
No preference	2			1	1	

TRUST	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
More comfortable	2	1		2		1
Less comfortable	2	3	4	2	4	2
No preference						1

FEAR	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
More comfortable				1	1	
Less comfortable	4	4	4	3	2	4
No preference					1	

SURPRISE	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
More comfortable			1	1		
Less comfortable	3	3	3	3	2	3
No preference	1	1			2	1

11.7 Participant worksheet – study 3

Participant Worksheet

Pilot study: *Visual and tactile examination of pattern and textured metal surfaces*

Part 1

You will see patterns appear on the screen. After examining a pattern for a maximum of 20 seconds indicate on the scales below the extent to which the pattern conveys each emotion to you (low to high / 0 to 5).

Please provide an answer for each emotive value.

Use worksheets on the following pages

Excerpt – worksheet variations for all 4 patterns available on request

Pattern 1

EMOTIVE VALUES	PERCEIVED INTENSITY (Low to high)					
Sadness	0	1	2	3	4	5
Fear	0	1	2	3	4	5
Aggressiveness	0	1	2	3	4	5
Remorse	0	1	2	3	4	5
Disapproval	0	1	2	3	4	5
Anticipation	0	1	2	3	4	5
Awe	0	1	2	3	4	5
Trust	0	1	2	3	4	5
Love	0	1	2	3	4	5
Disgust	0	1	2	3	4	5
Contempt	0	1	2	3	4	5
Submission	0	1	2	3	4	5
Joy	0	1	2	3	4	5
Anger	0	1	2	3	4	5
Surprise	0	1	2	3	4	5
Optimism	0	1	2	3	4	5

Part 2

You will be presented with a series of textured metal plates, the designs of which were based on the patterns you saw in part one. After examining each texture for a maximum of 20 seconds indicate on the scales the extent to which the pattern conveys each emotion to you (low to high / 0 to 5).

Please provide an answer for each emotive value.

Use worksheets on the following pages

Excerpt – worksheet variations for all 4 textures available on request

Texture 1

EMOTIVE VALUES	PERCEIVED INTENSITY (Low to high)					
Disapproval	0	1	2	3	4	5
Contempt	0	1	2	3	4	5
Love	0	1	2	3	4	5
Optimism	0	1	2	3	4	5
Sadness	0	1	2	3	4	5
Disgust	0	1	2	3	4	5
Remorse	0	1	2	3	4	5
Joy	0	1	2	3	4	5
Aggressiveness	0	1	2	3	4	5
Anger	0	1	2	3	4	5
Submission	0	1	2	3	4	5
Anticipation	0	1	2	3	4	5
Awe	0	1	2	3	4	5
Fear	0	1	2	3	4	5
Surprise	0	1	2	3	4	5
Trust	0	1	2	3	4	5

Excerpt – worksheet repeated for all 4 textures available on request

Part 3

You will be presented with a series of textured metal plates, the designs of which were based on the patterns you saw in part one. There are small differences in each plate which can be compared to a datum plate provided.

Visually examine and compare both plates for no more than 20 seconds.

When ready, indicate on the worksheet whether the provided plate is visually preferred, visually less preferred or there is no preference when compared to the datum

Use worksheets on the following pages

TEXTURE 1

Plate 1

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Plate 2

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Plate 3

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Plate 4

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Plate 5

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Plate 6

Visually prefer ☐

Visually don't prefer ☐

No visual preference ☐

Excerpt – worksheet repeated for all 4 textures available on request

Part 4

You will be presented with the same series of textured metal plates.

Interact with first the datum plate and then the presented plate by rubbing your index and middle fingers up and down and side to side, applying some pressure for a few seconds each.

When ready, indicate on the worksheets whether the provided plate affords a tactile interaction that is preferable, a less preferable interaction or there is no preference when compared to the datum plate

Use the worksheets below and overleaf

TEXTURE 1

Plate 1

More comfortable ☐

Less comfortable ☐

No preference ☐

Plate 2

More comfortable ☐

Less comfortable ☐

No preference ☐

Plate 3

More comfortable ☐

Less comfortable ☐

No preference ☐

Plate 4

More comfortable ☐

Less comfortable ☐

No preference ☐

Plate 5

More comfortable ☐

Less comfortable ☐

No preference ☐

Plate 6

More comfortable ☐

Less comfortable ☐

No preference ☐

11.7.1 Study 3 results – raw data (pattern 1)

29 Female participants

	FEMALE RESULTS																														
Emotive intensity	Aggressiveness	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0	0	2	0	0	3	1	0	0	0	0	0.37931
	Anger	0	2	0	1	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	2	1	0	2	1	0	0	0	0	0.51724
	Anticipation	3	2	3	1	3	0	1	1	3	0	0	0	0	2	2	1	3	2	0	0	3	2	0	1	0	2	0	0	0	1.2069
	Awe	0	3	1	4	4	4	1	2	3	2	0	0	2	1	3	2	1	1	0	0	4	4	1	2	0	4	2	1	1	1.82759
	Contempt	0	1	3	0	0	1	0	0	0	0	0	1	2	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0.37931
	Disapproval	1	0	2	0	1	0	0	0	1	0	1	2	3	2	0	1	0	1	0	1	1	0	0	2	0	0	0	0	0	0.65517
	Disgust	0	1	1	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0.27586
	Fear	0	2	3	0	0	0	0	0	1	1	0	0	2	1	0	0	1	0	0	0	2	0	0	3	2	1	0	0	0	0.65517
	Joy	0	3	2	3	2	4	2	2	1	4	0	2	0	2	4	2	1	2	4	1	4	5	0	1	3	4	3	2	2	2.24138
	Love	0	3	2	4	3	3	0	2	2	2	0	0	0	3	4	2	0	2	4	1	3	5	3	1	2	3	3	1	2	2.06897
	Optimism	1	3	1	3	4	5	2	4	2	4	0	4	0	2	4	4	0	1	4	3	4	5	3	2	2	5	0	2	0	2.55172
	Remorse	2	0	0	2	3	0	0	1	0	0	0	1	0	2	0	1	0	0	0	3	1	1	3	2	1	0	0	0	0	0.7931
	Sadness	2	0	1	1	2	0	0	1	0	0	1	1	0	4	0	1	0	0	0	1	1	1	4	3	1	0	0	0	0	0.86207
	Submission	2	3	2	0	2	1	2	0	2	0	0	2	0	0	0	1	1	0	0	1	0	0	0	3	0	0	0	1	0	0.7931
	Surprise	0	1	1	0	3	3	0	0	0	3	0	0	2	1	3	2	0	1	0	0	2	5	0	0	0	3	2	0	0	1.10345
	Trust	2	4	1	4	4	3	2	4	2	3	1	5	0	4	4	2	0	1	2	4	4	4	3	3	2	5	2	2	3	2.75862

33 Male participants

	MALE RESULTS																																		
Emotive intensity	Aggressiveness	0	0	1	0	0	2	0	0	0	0	3	0	0	0	1	1	0	1	3	4	0	0	0	3	1	0	0	1	0	0	2	2	1	0.78788
	Anger	0	0	0	2	0	2	3	0	0	0	3	0	0	0	0	0	0	3	4	0	0	0	0	4	0	0	0	0	0	1	3	3	0	0.84848
	Anticipation	2	0	1	3	0	1	1	0	0	2	0	0	1	0	1	2	0	2	1	2	1	0	0	3	0	1	0	2	1	3	3	3	0	1.09091
	Awe	3	0	1	4	1	1	0	2	0	3	2	1	3	0	1	2	4	0	3	2	0	0	0	2	0	0	0	3	4	3	3	2	0	1.51515
	Contempt	0	0	0	5	0	2	2	0	0	0	0	1	0	0	0	0	0	0	1	2	0	1	1	3	0	2	3	0	0	3	0	1	0	0.81818
	Disapproval	1	0	2	2	0	2	1	0	0	0	0	2	1	0	0	0	1	2	1	2	0	0	0	4	0	0	1	0	0	0	1	0	0	0.69697
	Disgust	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	1	1	0	1	1	0	0	0	3	0	0	3	0	0	0	0	0	0	0.39394
	Fear	0	2	0	1	0	2	0	0	0	0	2	1	1	0	0	1	1	1	1	0	0	0	0	3	2	0	0	2	0	0	0	1	0	0.63636
	Joy	4	1	4	2	2	0	1	4	0	4	1	2	3	1	2	3	4	0	1	0	1	1	2	1	2	2	0	1	2	3	2	2	0	1.75758
	Love	4	1	3	3	0	1	1	3	0	4	2	3	4	2	1	4	4	2	0	0	0	0	1	1	1	1	0	1	0	2	0	1	0	1.51515
	Optimism	4	2	3	3	3	0	3	4	0	5	0	2	4	2	0	4	5	0	1	1	3	2	1	3	2	2	0	1	1	3	4	2	0	2.12121
	Remorse	0	0	0	4	0	3	3	0	0	0	0	3	4	0	0	3	2	1	1	0	2	0	0	2	0	0	2	0	0	0	0	3	0	1
	Sadness	1	0	2	2	0	3	1	0	0	0	1	4	4	2	0	3	3	3	1	0	1	0	0	2	2	0	1	1	0	1	0	4	0	1.27273
	Submission	2	0	1	1	0	2	3	0	0	2	0	3	3	0	0	2	3	0	3	4	1	0	0	4	2	0	1	3	0	0	0	0	0	1.21212
	Surprise	2	0	3	3	0	2	2	2	0	3	0	1	4	0	0	3	1	0	1	0	0	1	0	4	3	1	0	1	1	0	1	0	0	1.18182
	Trust	3	4	3	4	1	1	4	2	0	4	3	5	4	4	2	4	5	3	0	4	4	0	2	4	2	2	0	3	1	3	4	4	0	2.69697

11.7.2 Study 3 results – raw data (pattern 2)

	FEMALE RESULTS																														
Emotive intensity	Aggressiveness	0	0	0	1	3	0	1	1	3	0	0	0	1	1	0	0	0	2	2	0	1	2	3	1	5	4	2	2	0	1.2069
	Anger	0	0	0	1	2	0	0	2	3	0	0	0	1	2	0	0	0	4	2	1	0	1	1	0	4	4	2	3	0	1.13793
	Anticipation	1	2	0	4	1	2	1	4	3	5	2	1	3	1	4	0	1	4	2	1	4	1	2	0	4	5	1	3	3	2.24138
	Awe	2	3	2	4	0	4	0	2	2	4	0	3	0	1	4	4	1	0	0	2	3	1	2	3	0	2	1	4	0	1.86207
	Contempt	0	0	0	0	1	0	4	3	4	0	0	1	0	1	0	1	0	4	1	0	0	3	0	2	3	3	3	1	0	1.2069
	Disapproval	0	0	0	0	2	0	3	1	4	0	0	0	0	3	0	1	0	2	2	2	0	1	0	1	1	0	3	0	0	0.89655
	Disgust	2	0	0	0	0	0	4	4	4	0	4	0	0	1	0	2	0	4	0	3	0	3	1	0	2	4	1	1	0	1.37931
	Fear	0	0	0	0	2	0	2	1	4	0	0	0	0	2	1	1	0	5	0	1	1	3	2	0	5	3	4	3	1	1.41379
	Joy	4	2	2	4	3	5	0	1	2	4	0	2	2	0	5	3	4	0	1	5	0	1	0	4	5	1	2	4	0	2.27586
	Love	2	2	2	3	0	2	0	1	2	1	0	3	0	1	3	4	2	0	0	1	1	2	0	2	0	0	1	1	0	1.24138
	Optimism	4	3	1	4	3	3	0	1	3	3	0	2	2	1	5	4	3	0	2	5	2	2	0	3	4	1	2	3	0	2.27586
	Remorse	0	0	0	0	0	0	2	4	2	0	1	0	0	3	0	1	0	0	0	0	0	1	0	1	0	0	2	0	1	0.62069
	Sadness	0	1	0	0	0	0	0	4	3	0	1	0	0	2	0	1	0	2	1	0	0	2	2	1	0	0	2	0	1	0.7931
	Submission	0	1	0	0	2	0	1	3	2	0	0	0	0	1	0	0	1	2	1	0	2	2	1	0	0	0	0	0	1	0.68966
	Surprise	2	3	1	5	1	3	1	2	2	3	0	4	1	1	5	4	0	4	1	5	3	3	3	4	5	2	1	4	4	2.65517
	Trust	2	1	1	3	1	1	0	0	1	1	0	2	0	1	4	4	2	0	0	0	3	1	0	2	0	0	3	0	1	1.17241

	MALE RESULTS																																		
Emotive intensity	Aggressiveness	1	0	0	1	0	2	0	1	0	1	2	3	2	3	0	5	2	2	1	1	1	3	3	1	0	0	0	3	0	1	0	1	2	1.27273
	Anger	0	0	1	0	0	1	1	0	0	1	3	3	0	2	0	5	2	2	0	0	1	3	3	0	0	0	0	2	0	0	0	1	2	1
	Anticipation	2	1	2	2	4	2	1	2	1	3	2	3	0	2	1	4	5	4	0	2	1	4	1	3	0	0	0	2	0	1	0	0	3	1.75758
	Awe	0	1	0	4	5	3	0	0	3	3	0	2	3	2	0	0	4	5	0	1	3	3	0	5	0	2	3	3	3	5	0	2	1	2
	Contempt	0	1	1	2	0	1	1	1	1	3	0	0	0	0	0	2	3	1	1	0	2	3	0	0	1	1	2	1	0	1	0	0	2	0.93939
	Disapproval	0	0	1	2	1	2	3	1	0	1	1	0	1	0	0	3	1	0	0	0	2	4	0	0	3	0	0	1	0	1	3	0	1	0.9697
	Disgust	0	0	1	0	0	0	2	0	1	1	1	4	0	0	1	3	2	1	0	0	3	4	0	0	3	0	1	1	0	1	2	0	3	1.06061
	Fear	0	2	0	1	0	1	0	0	4	1	2	0	0	1	0	3	2	1	1	0	2	4	2	1	0	0	0	2	0	2	1	0	3	1.09091
	Joy	0	3	3	2	3	3	0	2	2	4	1	0	1	1	1	0	3	4	0	2	1	0	1	2	0	1	4	2	1	5	2	4	1	1.78788
	Love	0	2	1	0	0	3	0	0	3	3	0	0	0	3	3	0	0	2	0	1	1	0	1	3	0	1	4	1	1	4	3	3	0	1.30303
	Optimism	0	3	1	3	2	1	0	3	1	3	1	1	3	0	1	0	3	4	0	3	1	1	0	2	0	1	4	3	2	4	2	4	1	1.75758
	Remorse	0	1	2	0	0	1	2	0	1	2	0	0	0	0	3	0	3	1	0	0	2	2	0	0	0	0	0	1	0	2	2	0	2	0.81818
	Sadness	0	1	2	0	0	1	1	0	3	2	2	0	0	0	2	0	1	1	1	0	4	2	1	1	0	0	1	1	0	0	4	0	3	1.0303
	Submission	0	1	2	0	0	2	0	0	3	1	0	4	1	3	4	1	0	2	0	0	2	3	0	4	0	0	2	1	0	0	0	0	3	1.18182
	Surprise	1	4	1	4	1	4	2	3	2	4	1	1	3	3	1	1	5	4	2	4	3	4	2	2	0	3	4	3	1	4	5	3	5	2.72727
	Trust	1	2	1	1	0	1	0	1	0	3	0	0	4	4	1	0	0	1	0	3	2	3	0	4	0	2	3	2	2	0	0	2	0	1.30303

11.7.3 Study 3 results – raw data (pattern 3)

	FEMALE RESULTS																														
Emotive intensity	*Aggressiveness*	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	1	2	0	0	0	0	0	0	0	0	1	0	0	3	0.41379
	Anger	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0.27586
	Anticipation	3	1	3	3	4	1	2	2	4	1	3	2	0	0	0	3	4	1	0	0	4	1	0	2	0	3	0	2	0	1.68966
	Awe	2	3	4	3	4	3	1	4	4	1	0	0	3	2	4	2	0	2	2	2	2	3	0	1	2	5	2	3	0	2.2069
	Contempt	0	0	0	0	0	0	0	1	2	0	0	1	0	3	0	1	0	0	2	0	2	2	0	1	0	0	0	0	0	0.51724
	Disapproval	0	0	1	0	0	0	0	0	2	3	0	1	0	4	0	1	2	0	0	0	4	1	2	2	0	0	0	0	0	0.7931
	Disgust	0	0	0	0	0	0	0	0	1	3	0	1	0	5	0	1	0	0	0	0	3	1	1	0	0	0	0	0	3	0.65517
	Fear	0	1	1	0	0	1	0	0	3	0	1	3	0	4	0	1	0	1	0	0	3	0	1	1	1	2	0	0	0	0.82759
	Joy	0	2	2	0	3	2	2	4	0	2	3	0	0	2	5	3	0	3	0	0	1	4	1	2	1	3	1	2	0	1.65517
	Love	3	4	4	2	5	2	1	3	0	1	2	2	2	2	5	3	0	2	4	4	1	5	0	4	3	3	1	1	0	2.37931
	Optimism	2	3	4	2	4	3	2	4	0	0	4	0	2	1	5	3	1	2	2	1	1	4	0	3	1	3	0	3	0	2.06897
	Remorse	0	0	1	3	3	1	0	1	1	0	0	4	0	2	0	1	0	0	0	0	2	1	0	0	2	1	0	1	0	0.82759
	Sadness	0	2	1	1	4	1	0	2	2	0	0	5	0	2	0	1	0	0	0	1	3	3	1	1	2	1	0	1	0	1.17241
	Submission	0	0	0	2	2	0	2	2	4	0	2	5	2	2	0	1	0	0	4	2	2	2	3	3	0	0	0	1	0	1.41379
	Surprise	2	1	2	0	2	3	1	1	3	1	3	0	2	1	3	3	2	2	0	0	2	4	1	1	0	3	1	1	0	1.55172
	Trust	3	3	3	2	5	2	2	3	0	0	4	4	3	0	5	4	0	1	4	3	0	5	0	3	2	3	1	2	0	2.31034

	MALE RESULTS																																		
Emotive intensity	*Aggressiveness*	0	1	1	4	1	4	4	0	0	1	0	2	4	2	1	1	4	5	2	4	0	0	1	4	0	0	0	1	4	4	0	4	0	1.78788
	Anger	0	1	0	4	0	2	3	0	0	3	2	0	0	0	0	0	0	1	3	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0.69697
	Anticipation	0	0	0	1	0	1	0	3	0	0	1	0	1	0	1	1	0	0	4	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0.48485
	Awe	1	4	2	0	0	3	4	0	1	4	0	3	2	3	0	3	2	5	4	0	3	3	1	3	1	0	0	2	5	3	1	2	2	2.0303
	Contempt	0	0	1	2	0	0	3	1	0	0	0	1	1	0	0	0	3	1	4	2	0	3	2	3	0	3	0	0	0	4	2	2	0	1.15152
	Disapproval	0	0	0	4	0	0	0	4	0	0	0	2	0	0	0	3	5	1	4	1	0	4	0	1	0	0	3	0	0	0	4	0	0	1.09091
	Disgust	0	0	0	2	0	1	0	4	0	1	0	1	1	0	0	1	4	4	4	1	1	1	0	3	0	0	3	1	0	0	3	0	0	1.09091
	Fear	0	0	0	4	0	1	0	0	0	2	3	1	0	0	1	1	5	2	4	0	1	3	1	3	0	0	0	2	0	1	1	1	0	1.12121
	Joy	3	3	0	4	1	3	3	0	2	3	2	2	2	3	0	3	0	4	1	0	0	3	2	4	2	3	0	1	1	4	0	5	0	1.93939
	Love	5	4	4	5	1	3	4	0	1	5	2	3	2	3	0	4	1	5	0	3	3	2	2	4	3	1	0	1	0	4	3	5	1	2.54545
	Optimism	3	4	3	3	1	3	4	0	4	2	0	3	2	3	0	4	2	4	0	0	0	4	4	4	3	1	0	1	4	5	1	4	1	2.33333
	Remorse	0	1	3	1	0	0	0	1	0	0	0	4	3	0	0	1	4	0	0	1	1	0	0	3	2	0	1	3	0	1	2	3	0	1.06061
	Sadness	3	0	3	1	0	1	0	0	0	0	2	3	3	0	0	2	3	0	0	2	2	3	1	2	0	0	1	3	0	0	1	1	0	1.12121
	Submission	2	0	0	2	0	3	4	0	0	3	0	4	0	0	1	2	3	4	2	3	2	0	0	4	2	0	0	3	0	0	2	4	1	1.54545
	Surprise	1	2	0	4	1	3	4	3	0	0	2	3	4	3	2	3	4	1	3	0	0	2	0	2	1	2	0	1	3	3	2	4	1	1.93939
	Trust	3	3	0	3	0	3	3	1	0	3	2	1	3	3	0	2	1	1	0	4	2	3	2	4	2	3	0	2	0	3	0	3	2	1.87879

11.7.4 Study 3 results – raw data (pattern 4)

Emotive intensity

FEMALE RESULTS																														
Aggressiveness	2	3	0	5	4	2	4	4	5	5	4	0	0	4	5	0	2	4	5	5	5	3	1	3	5	4	4	4	4	3.31034
Anger	2	3	0	5	3	1	4	5	4	4	5	0	0	3	4	0	0	3	2	4	4	2	1	2	4	4	4	3	4	2.75862
Anticipation	2	1	0	3	0	1	2	5	3	4	2	3	1	1	5	4	2	4	1	1	0	1	1	0	2	0	3	2	2	1.93103
Awe	0	2	0	2	1	4	2	2	2	0	0	2	0	1	2	4	4	2	1	0	0	2	0	2	0	0	1	2	0	1.31034
Contempt	0	3	0	3	2	0	0	4	3	3	0	0	0	2	3	1	0	1	1	2	2	3	0	1	4	4	4	3	0	1.68966
Disapproval	2	1	0	3	0	0	0	4	1	2	4	0	3	2	4	0	0	2	4	1	4	0	2	0	4	3	3	3	3	1.89655
Disgust	0	0	0	2	1	0	0	1	2	3	3	0	0	2	0	0	0	0	1	1	1	2	0	0	3	2	2	2	1	1
Fear	2	2	0	3	1	1	2	4	3	4	5	0	0	1	4	1	1	2	4	3	4	3	2	2	5	3	4	4	4	2.55172
Joy	0	1	2	1	1	3	2	1	1	0	0	3	2	0	0	4	0	5	3	2	0	1	0	1	1	0	1	1	0	1.24138
Love	0	0	2	1	0	0	1	2	2	0	0	3	0	1	0	5	0	0	2	0	0	2	0	1	0	1	1	0	0	0.82759
Optimism	0	1	0	1	1	2	3	0	2	0	1	1	0	1	0	5	0	4	2	1	0	3	0	0	1	0	2	1	0	1.10345
Remorse	0	1	0	3	0	0	0	2	1	0	0	0	0	1	4	0	0	0	1	0	0	2	0	1	1	1	1	1	2	0.75862
Sadness	0	2	0	3	0	0	0	3	1	1	0	0	0	1	3	0	0	1	0	0	0	0	1	1	1	2	1	0	2	0.7931
Submission	0	0	0	3	0	0	0	3	2	1	0	0	0	1	4	1	4	0	1	0	2	2	0	0	2	1	1	2	2	1.10345
Surprise	0	3	2	1	2	2	4	3	3	2	2	4	0	1	3	0	4	4	4	5	3	2	3	3	5	0	4	3	1	2.51724
Trust	1	1	2	1	0	1	2	1	3	0	0	2	0	1	0	4	0	2	2	0	0	1	0	0	2	0	1	0	0	0.93103

Emotive intensity

MALE RESULTS																																	
Aggressiveness	2	5	4	1	0	5	5	3	4	4	0	4	4	5	1	5	5	4	2	5	5	5	4	4	3	0	3	2	2	4	4	4	5	3.42424
Anger	2	1	4	1	0	2	0	3	3	4	0	5	1	5	1	4	5	5	1	1	4	5	4	3	0	1	4	1	2	3	4	4	4	2.63636
Anticipation	1	2	5	3	0	2	3	3	1	3	2	0	4	2	4	3	4	1	0	4	2	4	0	2	4	2	0	2	1	4	0	0	0	2.06061
Awe	2	2	5	3	2	3	0	2	1	3	0	0	2	3	4	0	3	0	1	4	3	4	0	3	0	3	1	3	2	1	0	3	2	1.9697
Contempt	1	3	0	4	0	0	0	0	1	3	1	0	0	4	0	3	4	4	0	0	1	3	0	1	0	1	2	0	0	1	4	3	3	1.42424
Disapproval	0	0	0	0	0	1	0	2	2	5	1	4	2	4	0	5	4	3	1	1	1	3	0	3	0	1	1	0	0	3	4	4	3	1.75758
Disgust	0	0	0	0	0	1	0	1	2	4	0	5	0	4	0	4	3	3	0	0	3	3	0	3	0	0	0	0	0	1	0	3	1	1.24242
Fear	2	1	3	0	0	3	0	1	3	5	1	3	4	2	3	5	3	4	1	3	3	5	3	4	0	2	2	0	0	2	5	3	2	2.36364
Joy	0	4	4	4	4	0	3	0	0	3	0	0	0	0	3	0	1	1	0	3	1	3	1	2	4	3	3	3	1	1	0	1	0	1.60606
Love	0	5	0	3	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	1	1	0	0	0	4	1	2	0	3	0	1	0	0.84848
Optimism	0	3	5	3	2	0	2	0	0	2	1	2	0	1	4	0	1	0	0	3	0	3	0	4	0	4	1	2	1	0	2	1	0	1.42424
Remorse	0	2	0	1	0	0	0	2	0	3	2	0	1	0	0	3	5	3	1	0	2	1	0	1	0	0	0	0	0	4	4	2	0	1.12121
Sadness	1	1	0	1	0	0	0	2	0	1	1	0	0	3	0	4	1	0	0	0	1	1	2	0	0	0	3	0	0	2	3	1	0	0.84848
Submission	0	0	2	2	0	0	2	3	0	4	1	0	1	5	3	4	0	3	0	0	4	0	1	0	0	0	3	2	0	5	0	4	1	1.51515
Surprise	0	5	0	3	1	4	5	3	0	4	1	4	5	3	3	0	2	2	1	5	4	5	0	5	5	5	4	2	2	2	5	2	2	2.84848
Trust	0	4	4	3	1	0	1	0	0	3	2	0	0	2	4	0	0	1	0	2	0	2	3	5	0	5	1	1	0	0	0	1	0	1.36364

11.7.5 Study 3 results – raw data (texture 1)

Emotive intensity

FEMALE RESULTS																														
Aggressiveness	0	0	1	0	0	0	0	1	0	0	0	0	0	3	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0.27586
Anger	0	0	1	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0.27586
Anticipation	2	0	4	0	4	0	1	0	4	0	0	2	2	1	0	1	2	2	0	0	3	1	1	2	0	3	1	3	0	1.34483
Awe	1	1	1	3	3	2	2	3	4	2	0	0	1	1	4	1	0	3	3	2	3	2	1	2	2	4	2	2	0	1.89655
Contempt	2	1	1	0	0	0	0	0	0	0	0	2	0	3	0	1	0	0	0	0	2	2	0	0	1	0	0	0	0	0.51724
Disapproval	0	0	1	1	0	0	0	1	0	0	0	1	0	5	0	1	0	0	0	0	1	4	1	0	0	0	0	0	0	0.55172
Disgust	0	1	1	0	0	0	0	1	0	0	0	2	0	4	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0.37931
Fear	0	0	1	0	0	0	0	1	0	0	0	1	0	3	0	1	0	0	0	0	1	3	0	0	0	0	0	0	0	0.37931
Joy	1	1	4	0	4	2	0	3	3	3	4	0	3	1	5	3	1	3	1	2	3	1	3	4	2	3	2	4	2	2.34483
Love	2	2	3	3	5	2	2	3	2	3	3	2	2	0	5	3	0	2	4	4	3	1	3	4	2	3	2	3	2	2.58621
Optimism	2	1	3	3	5	2	3	3	2	2	4	0	3	1	5	3	1	1	0	3	2	2	3	4	1	4	0	3	2	2.34483
Remorse	0	2	1	3	2	0	0	2	0	1	0	5	0	4	0	0	0	0	3	1	1	4	2	0	1	0	0	2	0	1.17241
Sadness	0	3	1	3	3	1	1	2	0	0	0	5	0	4	0	0	0	0	4	1	1	3	1	0	0	1	0	1	0	1.2069
Submission	0	0	3	2	2	0	1	2	3	0	0	4	2	4	0	1	0	0	4	1	2	3	1	1	0	0	0	1	0	1.27586
Surprise	0	0	3	1	0	3	0	1	0	0	3	0	0	1	2	1	0	1	0	1	2	4	0	2	0	4	3	1	0	1.13793
Trust	3	2	2	3	5	2	2	2	4	3	3	4	3	0	4	3	0	1	2	4	3	2	2	1	1	4	1	2	2	2.41379

Emotive intensity

MALE RESULTS																																		
Aggressiveness	2	1	0	3	0	1	3	0	0	3	1	0	0	0	0	3	3	4	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0.87879
Anger	0	1	0	5	0	0	0	0	0	0	2	0	1	0	0	1	3	1	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0.57576
Anticipation	2	3	0	1	0	2	0	3	0	2	0	1	3	2	1	4	3	5	4	3	2	0	2	3	2	1	0	1	3	2	0	2	2	1.78788
Awe	1	2	0	4	0	2	3	3	0	4	0	2	3	3	0	3	3	5	2	4	0	2	2	3	1	0	0	1	4	2	0	5	0	1.93939
Contempt	0	1	2	1	0	1	2	3	0	1	0	2	2	0	0	2	3	0	0	2	0	0	1	3	0	1	1	1	0	4	2	3	0	1.15152
Disapproval	0	1	1	4	0	1	0	1	0	0	0	4	1	0	0	2	3	0	0	3	0	3	0	2	0	0	2	1	0	0	1	0	0	0.90909
Disgust	0	1	0	0	0	1	0	1	0	0	0	2	2	0	0	1	5	4	0	1	0	3	0	3	0	0	1	2	0	0	2	1	0	0.90909
Fear	0	1	1	4	1	1	1	0	0	3	2	1	1	0	0	1	5	4	1	1	0	0	0	3	0	0	0	1	0	0	0	1	0	1
Joy	3	4	2	2	0	2	3	3	3	4	2	2	3	4	0	2	0	3	3	0	3	0	2	3	3	3	0	1	1	4	2	4	1	2.18182
Love	1	3	1	4	0	2	4	3	4	4	2	3	4	4	1	1	0	4	4	3	4	3	2	3	3	2	1	2	0	4	4	5	2	2.63636
Optimism	4	4	2	3	0	3	4	4	0	3	0	3	3	4	0	3	0	4	3	3	4	2	1	3	1	1	2	1	1	4	3	4	1	2.36364
Remorse	0	1	0	0	1	1	1	0	0	1	0	2	3	0	0	2	3	0	0	4	1	2	0	4	0	0	1	2	0	0	4	2	0	1.06061
Sadness	2	1	3	1	1	1	0	0	0	0	1	3	2	0	0	2	4	1	1	3	0	3	1	4	1	0	0	2	0	0	2	1	1	1.24242
Submission	2	2	0	4	0	2	4	1	0	3	0	3	1	0	0	2	2	5	2	4	1	1	0	3	2	0	0	2	0	1	2	4	0	1.60606
Surprise	2	3	1	4	1	2	3	1	0	1	0	3	4	2	1	3	1	2	2	2	1	2	1	4	0	1	0	1	0	2	1	4	1	1.69697
Trust	3	4	3	1	0	1	3	2	0	4	2	4	4	5	2	4	0	1	4	5	3	1	3	3	2	3	0	2	0	4	0	4	1	2.36364

11.7.6 Study 3 results – raw data (texture 2)

Emotive intensity

FEMALE RESULTS																														
Aggressiveness	1	0	0	1	2	0	3	1	1	0	1	0	2	1	0	1	1	2	3	1	1	3	1	1	1	4	3	2	0	1.27586
Anger	1	2	0	0	1	0	2	1	3	0	0	0	3	2	0	1	1	1	1	2	0	2	0	1	1	3	4	3	0	1.2069
Anticipation	0	2	0	4	1	2	1	5	4	5	3	2	3	1	4	2	0	4	1	3	3	1	3	0	3	0	2	3	2	2.2069
Awe	0	3	1	4	0	4	1	4	2	3	0	3	0	2	4	3	0	0	0	2	4	2	2	2	1	0	1	3	1	1.7931
Contempt	0	2	0	0	0	0	4	1	3	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	4	4	1	2	0.86207
Disapproval	1	1	0	0	0	0	5	1	4	0	2	0	2	0	0	1	0	2	3	1	0	0	0	2	0	2	4	0	0	1.06897
Disgust	0	0	0	0	1	0	4	1	3	0	4	0	0	0	0	1	0	0	2	0	0	2	0	0	0	3	4	0	0	0.86207
Fear	0	0	0	0	1	0	3	2	4	0	0	0	0	1	1	1	1	4	2	3	1	2	0	2	0	1	4	3	0	1.24138
Joy	0	1	2	3	1	5	0	3	0	4	0	3	0	1	4	4	0	3	0	5	0	1	1	1	4	0	1	1	2	1.72414
Love	0	0	1	2	0	2	0	3	1	3	0	2	0	1	2	4	0	0	1	0	0	0	0	2	4	0	1	1	0	1.03448
Optimism	0	2	0	3	2	4	0	4	1	5	1	2	1	1	4	5	0	0	0	4	0	1	2	0	3	0	2	2	3	1.7931
Remorse	0	1	0	0	0	0	1	2	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	1	1	2	0	1	0.48276
Sadness	0	1	0	0	0	0	1	2	3	0	0	0	0	1	0	1	2	2	2	0	0	1	0	1	0	1	2	0	0	0.68966
Submission	0	1	0	0	0	0	0	2	2	0	0	0	1	1	0	3	1	1	1	0	4	2	0	0	1	1	2	0	0	0.7931
Surprise	2	3	1	5	0	3	3	5	3	4	0	3	0	1	4	4	0	3	2	5	3	2	3	3	4	0	1	2	0	2.37931
Trust	0	1	1	1	1	2	0	3	0	0	1	1	0	2	1	5	0	0	2	3	0	0	0	1	3	0	1	0	1	1.03448

Emotive intensity

MALE RESULTS																																		
Aggressiveness	1	1	0	3	0	3	1	1	1	4	3	4	1	2	5	0	3	2	1	0	1	0	3	1	0	0	3	3	1	0	0	3	0	1.54545
Anger	0	1	0	2	0	3	0	0	0	4	1	5	3	0	5	0	1	1	0	0	1	1	2	0	0	0	3	3	0	1	1	3	1	1.27273
Anticipation	1	2	2	3	0	4	0	3	0	3	2	3	2	3	3	0	4	2	1	3	4	2	0	3	3	3	1	3	0	0	0	3	3	2
Awe	0	4	1	4	1	3	0	2	0	3	0	1	2	5	2	3	5	4	0	2	3	2	0	5	0	2	1	2	1	3	0	3	2	2
Contempt	0	2	2	1	0	1	2	0	0	3	0	0	0	2	3	0	3	0	0	0	3	1	0	0	0	0	3	1	1	3	0	1	1	1
Disapproval	0	0	2	3	0	2	2	2	1	4	1	4	0	0	3	0	1	2	1	0	3	0	0	0	0	3	2	1	1	0	3	3	0	1.33333
Disgust	0	0	1	3	0	1	0	0	1	3	3	4	0	0	3	0	3	1	0	0	4	0	0	0	0	0	0	2	1	2	4	2	0	1.15152
Fear	1	2	2	2	0	3	0	1	4	4	3	3	0	0	3	0	4	0	1	0	2	2	3	1	0	0	3	2	1	3	2	3	0	1.66667
Joy	0	4	2	0	0	1	0	0	0	4	1	0	1	5	1	5	4	3	0	3	3	2	3	3	0	2	1	2	0	4	0	3	2	1.78788
Love	0	3	1	0	0	1	0	0	0	3	1	0	1	4	0	4	1	3	0	3	2	1	2	4	0	3	1	1	0	2	3	2	0	1.39394
Optimism	0	3	4	0	0	2	2	3	0	4	1	1	3	5	1	5	3	3	0	4	1	1	0	5	0	4	1	2	1	4	4	3	4	2.24242
Remorse	0	3	3	1	0	1	1	1	0	2	2	0	0	0	1	0	0	0	0	0	3	3	0	0	0	0	3	1	0	4	0	2	0	0.93939
Sadness	0	1	2	2	0	1	1	0	0	3	2	0	0	0	0	0	0	1	1	0	4	3	1	0	0	0	3	2	0	2	1	2	0	0.9697
Submission	1	1	1	4	0	2	1	1	3	2	2	1	0	3	1	1	1	1	0	0	2	0	0	4	0	0	3	1	0	0	0	1	0	1.12121
Surprise	0	4	3	4	1	4	1	2	2	4	2	3	1	3	4	2	2	5	0	3	3	1	3	4	0	2	4	3	1	4	2	4	3	2.54545
Trust	1	2	2	0	0	0	0	1	1	3	0	2	3	5	0	4	1	3	0	5	3	4	0	4	0	2	2	1	1	2	0	2	4	1.75758

11.7.7 Study 3 results – raw data (texture 3)

Emotive intensity

FEMALE RESULTS																														
Aggressiveness	4	2	3	4	4	5	1	4	4	3	4	4	0	0	0	2	0	0	4	3	4	4	1	3	3	4	0	0	2	2.48276
Anger	4	2	3	3	4	4	1	1	4	3	4	4	0	0	0	2	3	0	5	2	3	5	0	4	2	5	0	1	2	2.44828
Anticipation	0	3	3	1	3	1	2	1	1	2	0	5	2	3	4	1	4	1	0	3	3	4	3	1	0	3	0	3	0	1.96552
Awe	0	1	1	0	0	1	0	2	2	1	0	3	4	4	5	1	0	3	0	2	3	3	1	1	0	2	3	2	0	1.55172
Contempt	0	3	4	2	3	0	0	2	1	0	1	1	0	1	0	1	0	0	0	3	3	2	0	2	2	4	0	1	0	1.24138
Disapproval	3	2	1	0	0	2	3	2	3	1	3	2	0	0	0	1	1	0	3	0	2	4	0	1	0	4	0	0	0	1.31034
Disgust	3	2	2	4	1	0	1	1	0	0	1	0	0	0	0	2	0	0	3	1	2	2	0	0	0	1	0	1	0	0.93103
Fear	4	4	4	3	4	3	3	2	2	4	2	3	0	0	0	1	0	0	5	0	4	4	0	4	2	4	0	1	0	2.17241
Joy	0	0	3	0	2	1	0	1	0	1	0	2	3	4	5	1	3	3	3	0	2	0	3	1	1	1	3	2	1	1.58621
Love	0	0	2	0	0	0	0	1	0	0	0	0	2	5	2	0	0	4	0	0	2	1	2	0	0	1	3	1	0	0.89655
Optimism	0	1	1	0	0	0	0	3	0	2	0	3	4	5	4	1	0	3	3	0	1	1	4	0	1	1	0	2	0	1.37931
Remorse	3	0	2	2	0	2	1	0	0	0	1	2	0	1	0	1	0	0	0	0	1	1	0	2	0	3	0	1	0	0.7931
Sadness	3	0	1	1	0	0	1	1	0	0	5	2	0	0	0	1	0	0	1	0	2	3	0	0	0	2	0	1	0	0.82759
Submission	3	0	2	0	0	1	1	3	1	0	1	4	3	3	0	1	0	0	0	0	2	1	1	3	0	3	0	0	0	1.13793
Surprise	2	2	3	0	4	3	2	3	2	5	4	5	2	3	5	2	0	3	5	3	3	5	4	2	2	3	3	2	1	2.86207
Trust	0	0	1	0	0	0	0	1	0	0	1	0	3	5	2	1	0	2	0	0	2	2	3	0	1	0	2	0	0	0.89655

Emotive intensity

MALE RESULTS																																		
Aggressiveness	4	3	5	4	1	2	1	1	3	4	4	4	3	5	2	2	4	0	2	5	5	5	0	4	3	3	4	5	0	1	5	0	2	2.90909
Anger	3	3	4	1	0	2	3	0	0	0	3	4	4	0	0	2	4	0	0	5	5	5	0	4	3	3	1	4	0	1	4	0	2	2.12121
Anticipation	1	2	3	5	1	3	1	2	0	2	0	4	3	4	0	2	5	1	5	3	4	0	1	3	1	3	4	4	1	3	5	2	1	2.39394
Awe	0	3	0	0	2	3	1	2	0	4	0	4	4	5	0	1	4	0	3	2	4	0	0	3	1	2	0	3	3	3	5	5	1	2.06061
Contempt	0	3	2	2	0	1	1	1	0	0	0	3	2	0	0	0	4	0	1	2	1	2	1	3	0	1	0	1	0	4	2	3	1	1.24242
Disapproval	3	2	3	4	0	1	0	0	0	0	0	3	1	0	0	0	2	0	0	0	4	3	0	4	0	3	0	2	0	0	2	0	0	1.12121
Disgust	2	1	4	1	0	0	0	4	0	3	0	1	2	0	0	0	1	1	0	0	0	5	0	4	1	0	0	1	0	0	0	0	0	0.93939
Fear	0	2	5	1	0	1	1	1	0	4	3	4	2	4	0	2	3	1	0	4	4	5	1	4	3	2	0	4	0	0	3	1	1	2
Joy	0	2	0	2	1	4	0	3	3	1	2	1	1	2	1	3	0	2	3	0	0	0	0	4	0	0	0	2	3	4	3	4	0	1.54545
Love	2	2	0	0	0	2	2	4	1	3	1	2	1	0	0	1	0	2	3	0	0	0	1	2	0	0	0	1	3	4	0	5	0	1.27273
Optimism	0	1	1	4	2	3	2	4	0	4	0	3	1	3	0	4	3	2	4	1	0	4	2	4	1	4	4	1	3	4	4	4	2	2.39394
Remorse	3	1	4	4	0	0	0	0	0	1	0	1	1	0	0	0	4	2	0	1	1	1	0	3	1	1	0	1	0	0	0	2	0	0.9697
Sadness	2	4	1	2	0	1	0	0	0	1	2	1	2	0	0	0	1	1	0	1	1	1	1	2	0	1	0	0	0	0	0	1	0	0.78788
Submission	3	1	0	3	0	2	2	0	0	4	2	1	2	0	0	1	0	0	2	5	2	0	1	3	0	2	0	2	0	1	2	1	0	1.27273
Surprise	0	3	5	1	2	4	1	3	0	5	0	4	4	1	0	5	3	3	1	0	4	1	1	5	2	4	5	5	2	4	0	4	1	2.51515
Trust	0	1	0	3	0	2	1	5	0	1	2	1	1	4	1	1	0	3	4	1	1	0	2	3	1	0	0	0	0	4	5	4	1	1.57576

11.7.8 Study 3 results – raw data (texture 4)

	FEMALE RESULTS																														
Emotive intensity	Aggressiveness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0.13793
	Anger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0.06897
	Anticipation	0	1	0	2	0	2	3	1	0	1	0	1	4	1	0	3	0	0	1	1	3	1	3	0	4	2	2	1	1	1.31034
	Awe	0	2	3	5	1	4	1	5	4	1	3	2	0	3	2	2	3	0	0	3	2	3	1	4	4	2	3	3	0	2.27586
	Contempt	0	0	0	0	1	1	0	1	1	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.34483
	Disapproval	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	2	2	1	0	0	1	2	0	0	1	0	0	2	0.51724
	Disgust	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	1	0	1	0.17241
	Fear	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	3	0.34483
	Joy	0	2	3	5	1	2	4	5	3	3	4	3	0	2	2	2	0	1	0	4	3	2	0	5	5	1	3	3	0	2.34483
	Love	0	1	3	4	2	0	3	4	4	3	3	2	0	3	1	2	0	0	1	3	1	4	0	3	5	1	4	3	0	2.06897
	Optimism	2	2	0	4	2	1	5	5	4	3	3	1	0	3	2	3	0	2	0	3	4	3	0	4	4	3	4	2	0	2.37931
	Remorse	0	0	0	0	1	3	0	1	2	0	0	0	0	1	2	2	0	0	1	0	0	1	0	0	1	0	1	0	2	0.62069
	Sadness	0	0	0	0	1	2	3	2	1	0	0	0	0	0	2	1	0	1	3	1	0	2	2	1	2	4	1	1	2	1.10345
	Submission	0	0	0	0	1	4	1	2	2	1	3	0	0	1	0	4	3	2	0	0	3	4	2	0	1	1	2	2	1	1.37931
	Surprise	0	1	3	3	0	2	0	3	2	0	0	1	0	1	0	2	3	0	2	1	3	0	3	4	1	0	3	1	2	1.41379
	Trust	2	1	2	5	2	0	2	4	3	3	4	2	2	3	0	3	3	2	1	4	4	3	0	3	5	4	3	2	0	2.48276

	MALE RESULTS																																		
Emotive intensity	Aggressiveness	1	0	2	0	0	2	0	0	1	5	1	0	0	1	0	0	0	1	1	0	0	1	3	0	0	0	0	2	0	0	0	1	0	0.66667
	Anger	0	4	0	0	0	0	0	0	2	4	0	0	0	1	0	1	0	1	1	0	1	0	2	0	0	0	0	2	0	1	0	2	0	0.66667
	Anticipation	1	1	2	3	2	3	1	0	0	4	2	2	0	4	4	1	2	2	0	1	3	3	0	2	0	0	3	3	1	3	2	2	0	1.72727
	Awe	0	4	4	4	4	3	0	1	1	3	0	3	3	5	2	0	3	2	0	3	3	1	0	3	0	3	4	2	2	3	3	1	3	2.21212
	Contempt	0	3	0	4	0	1	0	2	0	2	2	1	0	1	1	2	0	0	0	0	2	1	0	0	0	0	0	1	0	4	2	2	0	0.93939
	Disapproval	0	0	0	0	0	1	0	0	2	5	1	0	1	1	1	1	3	2	0	0	1	2	0	0	0	0	0	1	0	0	2	2	1	0.81818
	Disgust	0	2	0	0	0	1	0	0	0	3	1	0	0	0	1	2	4	0	0	0	2	0	0	0	0	1	0	1	0	0	1	1	0	0.60606
	Fear	0	2	1	0	0	1	0	0	0	3	1	1	0	2	0	2	5	1	1	0	1	2	0	0	0	0	0	1	0	0	0	3	0	0.81818
	Joy	1	3	4	4	1	0	1	4	2	2	0	2	3	3	3	1	1	4	0	4	3	2	2	4	0	4	3	2	2	2	2	2	4	2.27273
	Love	0	4	2	3	0	1	0	2	1	1	1	3	3	2	4	0	3	2	0	4	4	3	1	3	0	3	2	2	1	3	1	1	1	1.84848
	Optimism	1	3	3	4	1	0	1	0	2	3	3	4	4	5	4	3	4	4	0	5	3	2	0	4	0	4	4	3	2	1	4	1	3	2.57576
	Remorse	0	2	1	0	0	1	0	0	0	3	1	1	1	0	0	0	4	1	0	0	3	2	0	0	0	0	0	1	0	0	0	2	1	0.72727
	Sadness	0	1	0	0	0	1	1	0	2	1	1	0	0	0	0	0	5	2	1	0	2	3	1	0	0	0	0	1	0	0	1	3	1	0.81818
	Submission	0	1	1	1	0	4	2	0	0	3	1	0	1	5	1	0	3	1	1	0	1	1	1	0	0	1	1	1	0	2	2	1	0	1.09091
	Surprise	1	2	3	2	2	2	1	1	0	3	1	4	1	3	2	1	4	3	0	3	3	0	0	1	0	3	4	3	2	1	0	1	1	1.75758
	Trust	2	2	5	3	0	3	3	3	2	5	1	2	2	5	4	3	4	3	0	5	5	4	0	4	0	3	3	2	1	4	5	3	4	2.87879

11.7.1 Study 3 results – raw data (visual preference, texture 1)

Visually prefer = 1

Visually don't prefer = 2

No visual preference = 3

VISUAL	TEXTURE 1	PLATE 1	
SURPRISE 30	**TRUST 60**	**FEAR 30**	**JOY 60**
1	1	2	3
2	1	2	2
1	3	3	2
3	1	2	2
2	1	3	1
1	1	2	2
3	1	2	1
1		3	
1			
3			
2			
1			
3			
3			
2			
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3			
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3			
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1			
3			
3			
1			
3			
1			
1			
1			
1			
2			
1			

VISUAL	TEXTURE 1	PLATE 2	
SURPRISE 45	**TRUST 45**	**FEAR 15**	**JOY 0**
1	1	2	1
1	1	2	2
3	1	2	2
3	1	2	2
2	3	2	1
1	1	1	2
2	1	1	1
3		2	
1			
3			
3			
2			
3			
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2			
3			
3			
1			
2			
1			
1			
1			
3			
2			
2			

VISUAL	TEXTURE 1	PLATE 3	
SURPRISE 60	**TRUST 30**	**FEAR 60**	**JOY 75**
2	2	2	2
2	2	2	2
1	1	2	1
3	3	2	2
2	1	2	2
1	1	2	2
2	2	2	1
2		2	
2			
2			
2			
3			
3			
2			
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3			
2			
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2			
2			
2			

VISUAL	TEXTURE 1	PLATE 4	
SURPRISE 0	**TRUST 75**	**FEAR 75**	**JOY 45**
1	1	2	3
2	1	2	2
3	1	3	1
3	2	2	2
2	1	2	1
1	1	2	1
1	1	2	1
1		1	
1			
1			
1			
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1			
3			
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1			
2			
1			

VISUAL	TEXTURE 1	PLATE 5	
SURPRISE 75	**TRUST 15**	**FEAR 0**	**JOY 15**
2	2	1	2
2	2	2	3
2	2	2	1
2	2	2	3
2	2	2	1
2	1	3	1
2	2	2	1
2		2	
2			
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2			
2			
2			
2			

VISUAL	TEXTURE 1	PLATE 6	
SURPRISE 15	**TRUST 0**	**FEAR 45**	**JOY 30**
3	2	2	2
2	1	2	2
3	2	2	1
2	1	2	2
2	3	2	1
2	1	1	2
1	1	2	1
1		2	
2			
1			
1			
3			
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3			
1			
2			
3			
3			
2			

11.7.2 Study 3 results – raw data (visual preference, texture 2)

VISUAL	TEXTURE 2	PLATE 1	
JOY 60	**SURPRISE 30**	**TRUST 60**	**FEAR 30**
2	3	1	2
1	1	2	1
2	1	1	1
2	1	2	2
2	1	3	2
2	1	1	1
2	1	1	1
2		3	
2			
2			
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1			
3			
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1			
3			
3			
1			
3			
1			
1			
1			
1			
2			
1			

VISUAL	TEXTURE 2	PLATE 2	
JOY 0	**SURPRISE 45**	**TRUST 45**	**FEAR 15**
2	3	2	1
2	2	2	3
1	2	1	2
2	3	2	1
1	3	2	1
1	1	2	1
2	1	1	1
2		2	
1			
2			
2			
2			
2			
1			
3			
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3			
3			
1			
2			
1			
1			
1			
3			
2			
2			

VISUAL	TEXTURE 2	PLATE 3	
JOY 75	SURPRISE 60	TRUST 30	FEAR 60
2	3	2	2
1	3	2	2
2	1	2	2
2	2	2	2
2	1	2	1
2	1	2	2
3	2	1	3
3		2	
2			
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2			
3			
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2			
2			
2			
2			

VISUAL	TEXTURE 2	PLATE 4	
JOY 45	SURPRISE 0	TRUST 75	FEAR 75
2	1	2	2
1	1	2	2
2	2	2	3
2	1	2	2
2	1	3	2
2	1	3	2
3	1	2	1
3		2	
2			
2			
2			
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2			
1			

VISUAL	TEXTURE 2	PLATE 5	
JOY 15	SURPRISE 75	TRUST 15	FEAR 0
2	2	2	2
2	2	2	3
1	2	1	2
1	2	2	2
2	2	1	3
1	1	2	2
1	2	2	2
1		3	
2			
3			
1			
1			
2			
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VISUAL	TEXTURE 2	PLATE 6	
JOY 30	SURPRISE 15	TRUST 0	FEAR 45
2	1	2	2
2	3	2	2
2	2	1	2
3	1	3	2
2	3	2	3
1	1	3	1
2	1	1	1
2		3	
2			
2			
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3			
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11.7.3 Study 3 results – raw data (visual preference, texture 3)

VISUAL	TEXTURE 3	PLATE 1	
FEAR 30	JOY 60	SURPRISE 30	TRUST 60
1	2	1	2
2	2	1	1
1	2	2	2
2	2	2	1
2	3	1	3
3	2	1	1
2	3	1	2
2		3	
1			
2			
2			
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3			
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VISUAL	TEXTURE 3	PLATE 2	
FEAR 15	JOY 0	SURPRISE 45	TRUST 45
2	2	1	2
1	3	1	3
1	1	2	2
1	1	3	1
2	2	1	3
2	2	1	1
2	1	1	2
1		3	
2			
1			
1			
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1			

VISUAL	TEXTURE 3	PLATE 3	
FEAR 60	JOY 75	SURPRISE 60	TRUST 30
2	2	1	2
1	2	1	1
2	2	2	1
2	2	2	2
2	2	1	3
2	1	3	2
3	1	1	3
3		3	
3			
3			
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VISUAL	TEXTURE 3	PLATE 4	
FEAR 75	JOY 45	SURPRISE 0	TRUST 75
1	1	2	2
3	1	3	2
1	2	3	1
1	2	3	1
2	3	3	1
2	1	1	2
1	2	1	2
1		1	
3			
1			
2			
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3			
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VISUAL	TEXTURE 3	PLATE 5	
FEAR 0	JOY 15	SURPRISE 75	TRUST 15
2	1	1	2
2	2	2	2
2	2	1	2
2	3	2	3
3	1	3	1
3	2	3	2
2	1	2	2
1		3	
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VISUAL	TEXTURE 3	PLATE 6	
FEAR 45	JOY 30	SURPRISE 15	TRUST 0
2	1	2	2
1	2	2	2
1	2	2	1
1	3	2	3
1	3	1	1
1	2	1	2
2	1	1	3
1		3	
2			
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3			

11.7.4 Study 3 results – raw data (visual preference, texture 4)

VISUAL	TEXTURE 4	PLATE 1	
TRUST 60	FEAR 30	JOY 60	SURPRISE 30
2	1	2	1
1	1	2	1
1	2	2	1
1	1	2	2
1	2	1	1
1	2	2	1
1	1	2	1
1		3	
1			
1			
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1			
3			
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VISUAL	TEXTURE 4	PLATE 2	
TRUST 45	FEAR 15	JOY 0	SURPRISE 45
2	1	3	2
2	1	1	2
2	1	2	1
1	2	3	2
2	3	1	1
1	2	3	2
1	1	2	3
1		2	
3			
3			
1			
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3			
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3			

VISUAL	TEXTURE 4	PLATE 3	
TRUST 30	**FEAR 60**	**JOY 75**	**SURPRISE 60**
2	1	2	1
1	2	2	3
1	2	2	3
2	2	2	3
2	3	2	3
2	1	2	1
2	2	2	3
1		2	
2			
2			
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VISUAL	TEXTURE 4	PLATE 4	
TRUST 75	**FEAR 75**	**JOY 45**	**SURPRISE 0**
3	1	2	1
1	2	2	1
1	2	1	1
3	3	2	1
2	1	2	1
2	1	3	3
1	1	2	3
1		3	
1			
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3			
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3			
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VISUAL	TEXTURE 4	PLATE 5	
TRUST 15	**FEAR 0**	**JOY 15**	**SURPRISE 75**
2	1	2	2
2	2	2	2
1	1	2	1
2	1	2	2
2	3	1	3
2	2	2	3
2	2	2	2
3		3	
2			
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VISUAL	TEXTURE 4	PLATE 6	
TRUST 0	**FEAR 45**	**JOY 30**	**SURPRISE 15**
3	1	2	2
2	1	2	2
1	2	2	1
2	2	2	2
1	1	3	2
3	1	3	2
2	3	2	2
1		3	
2			
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3			
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11.7.5 Study 3 results – raw data (tactile preference, texture 1)

TACTILE	TEXTURE 1	PLATE 1	
SURPRISE 30	TRUST 60	FEAR 30	JOY 60
2	3	2	3
2	2	2	2
2	3	2	2
2	2	2	2
2	1	2	1
2	2	2	2
2	2	2	3
2		1	
2			
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TACTILE	TEXTURE 1	PLATE 2	
SURPRISE 45	TRUST 45	FEAR 15	JOY 0
2	3	2	2
2	2	2	2
2	2	2	2
2	2	2	2
2	3	2	1
3	2	1	1
2	3	2	3
2		2	
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TACTILE	TEXTURE 1	PLATE 3	
SURPRISE 60	TRUST 30	FEAR 60	JOY 75
2	2	2	2
3	2	2	3
3	2	3	3
2	2	2	3
2	3	2	2
3	2	2	1
1	2	2	2
2		2	
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TACTILE	TEXTURE 1	PLATE 4	
SURPRISE 0	TRUST 75	FEAR 75	JOY 45
3	1	2	2
2	2	2	2
2	3	1	2
3	3	2	2
3	1	2	2
2	2	3	3
2	3	3	3
2		3	
3			
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TACTILE	TEXTURE 1	PLATE 5	
SURPRISE 75	TRUST 15	FEAR 0	JOY 15
3	1	2	2
2	2	2	1
3	2	2	1
2	2	2	2
2	2	2	2
2	2	2	2
3	1	2	2
2		2	
2			
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TACTILE	TEXTURE 1	PLATE 6	
SURPRISE 15	TRUST 0	FEAR 45	JOY 30
3	3	2	2
3	2	2	3
3	3	2	3
2	2	2	2
2	3	2	1
3	2	2	1
3	1	2	2
3		1	
2			
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11.7.6 Study 3 results – raw data (tactile preference, texture 2)

TACTILE	TEXTURE 2	PLATE 1	
JOY 60	SURPRISE 30	TRUST 60	FEAR 30
2	2	2	2
2	2	2	3
2	3	3	1
2	2	2	2
2	2	3	1
2	2	2	2
3	3	3	2
3		1	
2			
2			
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TACTILE	TEXTURE 2	PLATE 2	
JOY 0	SURPRISE 45	TRUST 45	FEAR 15
2	2	3	1
2	2	1	2
2	3	2	1
2	2	2	2
2	3	2	2
2	2	2	1
3	2	2	2
1		2	
3			
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TACTILE	TEXTURE 2	PLATE 3	
JOY 75	SURPRISE 60	TRUST 30	FEAR 60
2	2	2	2
2	2	3	2
2	2	2	1
2	2	2	2
2	2	2	1
2	1	2	3
1	3	3	2
2		2	
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TACTILE	TEXTURE 2	PLATE 4	
JOY 45	SURPRISE 0	TRUST 75	FEAR 75
2	3	3	1
2	3	2	3
1	3	3	2
2	3	2	2
2	3	2	2
2	3	2	2
2	3	3	2
3		2	
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TACTILE	TEXTURE 2	PLATE 5	
JOY 15	SURPRISE 75	TRUST 15	FEAR 0
2	2	2	2
2	2	3	3
2	2	2	1
2	2	2	2
2	2	2	2
2	1	2	2
1	1	2	2
2		2	
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TACTILE	TEXTURE 2	PLATE 6	
JOY 30	SURPRISE 15	TRUST 0	FEAR 45
2	3	3	3
2	3	3	2
1	3	3	2
2	3	3	2
2	3	2	1
2	2	2	1
1	1	3	2
2		2	
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11.7.7 Study 3 results – raw data (tactile preference, texture 3)

TACTILE	TEXTURE 3	PLATE 1	
FEAR 30	**JOY 60**	**SURPRISE 30**	**TRUST 60**
3	2	1	2
2	3	2	1
2	3	2	2
2	2	2	2
2	2	2	2
3	2	2	1
1	3	3	3
2		3	
3			
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TACTILE	TEXTURE 3	PLATE 2	
FEAR 15	**JOY 0**	**SURPRISE 45**	**TRUST 45**
3	2	2	1
3	3	1	3
1	3	2	3
2	3	2	3
2	2	2	1
3	2	2	2
2	2	2	2
2		3	
3			
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TACTILE	TEXTURE 3	PLATE 3	
FEAR 60	**JOY 75**	**SURPRISE 60**	**TRUST 30**
3	2	3	2
2	2	3	1
2	2	1	2
2	2	2	3
2	2	2	2
2	2	3	2
2	2	2	2
2		3	
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TACTILE	TEXTURE 3	PLATE 4	
FEAR 75	**JOY 45**	**SURPRISE 0**	**TRUST 75**
1	2	2	3
2	2	2	2
1	2	2	2
3	2	2	2
2	2	2	2
2	2	3	3
1	3	1	2
2		3	
3			
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TACTILE	TEXTURE 3	PLATE 5	
FEAR 0	JOY 15	SURPRISE 75	TRUST 15
2	2	2	2
2	2	2	1
2	2	2	2
2	3	2	2
2	2	3	2
1	1	2	2
2	1	2	2
3		2	
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TACTILE	TEXTURE 3	PLATE 6	
FEAR 45	JOY 30	SURPRISE 15	TRUST 0
2	2	2	3
2	2	2	2
2	3	2	2
2	2	2	2
3	2	3	2
3	1	3	2
3	3	3	3
2		3	
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11.7.1 Study 3 results – raw data (tactile preference, texture 4)

TACTILE	TEXTURE 4	PLATE 1	
TRUST 60	FEAR 30	JOY 60	SURPRISE 30
1	3	3	3
3	3	2	2
3	2	2	2
1	2	2	2
2	2	3	2
2	1	2	2
2	2	2	2
2		1	
2			
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TACTILE	TEXTURE 4	PLATE 2	
TRUST 45	FEAR 15	JOY 0	SURPRISE 45
3	2	2	2
2	2	1	2
1	3	2	2
2	3	3	2
2	3	3	2
2	2	3	2
2	2	3	2
1		1	
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TACTILE	TEXTURE 4	PLATE 3	
TRUST 30	**FEAR 60**	**JOY 75**	**SURPRISE 60**
3	2	2	1
2	2	2	3
1	2	2	3
2	3	2	2
2	2	3	2
2	2	2	2
1	2	2	2
2		3	
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TACTILE	TEXTURE 4	PLATE 4	
TRUST 75	**FEAR 75**	**JOY 45**	**SURPRISE 0**
3	2	2	1
2	2	2	2
3	3	2	1
1	1	2	2
2	3	2	2
3	2	2	2
2	3	2	3
3		1	
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TACTILE	TEXTURE 4	PLATE 5	
TRUST 15	**FEAR 0**	**JOY 15**	**SURPRISE 75**
2	2	2	3
2	3	1	2
1	3	2	3
2	2	2	2
2	2	2	1
2	2	3	2
2	2	2	3
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TACTILE	TEXTURE 4	PLATE 6	
TRUST 0	**FEAR 45**	**JOY 30**	**SURPRISE 15**
1	2	2	2
3	2	2	2
2	3	2	1
1	3	2	2
3	2	1	2
2	2	2	3
1	3	2	3
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Participant Information Sheet

Name of department: DMEM
Title of the study: *Visual and tactile examination of pattern and textured metal surfaces*

Introduction
This study will analyse the visual and tactile qualities of patterns and textured metal surfaces. I am investigating the emotive qualities of form generally and am using pattern and texture as a medium for this analysis. This study has four parts and can be completed in approximately 30 minutes.

What will you do in the project?

TASK 1:

Four patterns will be presented on a screen one after another. After viewing one pattern you will be required to fill in an assessment of your emotional interpretation of the pattern. The assessment is built from a list of key emotive terms. For each emotion, a scale of experienced intensity is provided – ***for each emotion, indicate the extent in which each is conveyed to you by the pattern***

TASK 2:

Four textured metal plates will be presented to you. After viewing one texture you will be required to fill in an assessment of your emotional interpretation of the texture. The assessment is built from a list of key emotive terms. For each emotion, a scale of experienced intensity is provided – ***for each emotion, indicate the extent in which each is conveyed to you by the texture design***

TASK 3:

You will be presented with two metal plates with textured surfaces. One plate will be a datum plate, the other will be a comparison plate. There are small differences in the production properties of each plate. Following a ***visual examination, you are asked to indicate if the comparison plate is preferred to the datum plate*** – a worksheet will be provided for your answers. The task will compare a total of 28 plates.

TASK 4:

You will be presented with two metal plates with textured surfaces. One plate will be a datum plate, the other will be a comparison plate. There are small differences in the production properties of each plate. Following a ***visual examination and a guided tactile interaction, you are asked to indicate if the comparison plate is preferred to the datum plate*** – a worksheet will be provided for your answers. The task will compare a total of 28 plates.

What happens to the information in the project?
Participants will remain anonymous. The information gathered will be used in interpretive human-centred-design models for enhancing product aesthetics and user interaction.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

Consent Form

Name of department: DMEM
Title of the study: *Visual and tactile examination of pattern and textured metal surfaces*

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences. If I exercise my right to withdraw and I don't want my data to be used, any data which have been collected from me will be destroyed.
- I understand that I can withdraw from the study any personal data (i.e. data which identify me personally) at any time.
- I understand that anonymised data (i.e. .data which do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project

(PRINT NAME):	
Signature of Participant:	Date:

11.8 Experiment matrix

		VARIANT		DEPENDANT VARIABLE				INVARIANT						
	TEST	Tool path angle	Geometry (design)	Tooling	Cutting forces	Feed rate	Part polishing quality	Material	Dimensions (RAW PLATE)	Equipment	Step over	Lubrication	Environment	Cutting speed
DESIGN 1 - JOY	1	Optimised	Positional (DATUM)	1 mm end mill (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	Optimised	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	2	0 degrees	3 mm radius	1 mm ball nose cutter (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	0.15 mm / 15 %	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	3	15 degrees												
	4	30 degrees												
	5	45 degrees												
	6	60 degrees												
	7	75 degrees												
	8	90 degrees												
DESIGN 2 - TRUST	9	Optimised	Positional (DATUM)	1 mm end mill (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	Optimised	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	10	0 degrees	3 mm radius	1 mm ball nose cutter (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	0.15 mm / 15 %	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	11	15 degrees												
	12	30 degrees												
	13	45 degrees												
	14	60 degrees												
	15	75 degrees												
	16	90 degrees												
DESIGN 3 - SUPRISE	17	Optimised	Positional (DATUM)	1 mm end mill (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	Optimised	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	18	0 degrees	3 mm radius	1 mm ball nose cutter (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	0.15 mm / 15 %	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	19	15 degrees												
	20	30 degrees												
	21	45 degrees												
	22	60 degrees												
	23	75 degrees												
	24	90 degrees												
DESIGN 4 - FEAR	25	Optimised	Positional (DATUM)	1 mm end mill (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	Optimised	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	26	0 degrees	3 mm radius	1 mm ball nose cutter (carbide coating)	Geometry and machine dependent	Geometry and machine dependent	Geometry and method dependent	Aluminium	120 X 84 X 5	Denford CNC engraver (Microrouter Pro)	0.15 mm / 15 %	Silicon based (Swantek Gold)	DMEM Labs	400 mm per minute
	27	15 degrees												
	28	30 degrees												
	29	45 degrees												
	30	60 degrees												
	31	75 degrees												
	32	90 degrees												
Total tests	32													

11.9 Expert interview consent form

Completed participant consent forms available on request

University of Strathclyde Glasgow

Participant Information Sheet

Name of department: DMEM
Title of the study: *Expert interview examining initial findings from EngD theoretical and practical work*

Introduction
This expert interview will examine the initial conclusions drawn from the EngD work conducted by the researcher Lewis Urquhart.

Your participation has been requested because of your expertise and experience in manufacturing, engineering, design, or a closely related discipline

What will you do in the interview?
The researcher will present a short summary of the theoretical and practical work undertaken for the researcher's doctoral thesis on linking visual and tactile preferences with specific manufacturing protocol in machining to the interviewee. Some data and other visuals will be presented to enhance the dissemination of the work.

The introductory presentation will last between 10-15 minutes.

The participant will then be asked several semi-structured questions about the work in an informal interview format and will be encouraged to freely discuss their thoughts on the questions raised. This will be to gain feedback about the work and explore some of the key findings and conclusions.

The interview will last between 30-45 minutes.

The full session should last between 40-60 minutes.

The interview will be audio-recorded.

The participant may indicate their unwillingness or inability to answer any question at any time in the process. They may also stop the interview process at any point, from hence forth the interview will be terminated and any data obtained to that point discarded.

What happens to the information in the project?
The information will be used as a form of validation in the conclusions of the researcher's doctoral thesis with full transcripts of the interview to be included in the appendices of the thesis.

Any IP sensitive content referred to can be omitted from the transcripts on request. The audio recording of the interview will not be shared with any party out-with the researcher and the interviewee.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

Consent Form

Name of department: DMEM
Title of the study: ***Expert interview examining initial findings from EngD theoretical and practical work***

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences. If I exercise my right to withdraw and I don't want my data to be used, any data which have been collected from me will be destroyed.
- I understand that I can withdraw from the study any personal data (i.e. data which identify me personally) at any time.
- I understand that anonymised data (i.e. .data which do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project

Please indicate below if you consent to be named in person within the thesis in the sections describing this interview. If an answer is not indicated, you will be kept anonymous by default:

YES / NO

(PRINT NAME):	
Signature of Participant:	Date:

11.10 Interview transcript – participant 1

11.10.1 Question 1

LU: How do you approach a manufacturing problem?

Okay. So I can, I can just talk to you about, uh, a typical project for me then. Yeah. So I, I deal a lot with, um, well, you spoke about it earlier, but I do a lot with, um, I get a part and I need to, put it into CAM, program the tool paths, and then output the CNC program.

Um, and, but it doesn't stop there. What I need to do then is go up to the machine and machine the parts and build the tools, um, get the parts out the door, but, um, quite often, uh, Yeah, there's quite a few things that need to be thought about. So, um, the project I'm working on at the moment, um, we got given the part, but maybe it could be a sort of holding problem as well, but, um, we have tooling in one center tooling in another center, so it needs to understand which tooling we had available, um, then that, that could help me to understand what tool paths to use when I'm selecting the part.

Um, But also you've got a list of tooling suppliers. They will all say that they can do the same thing. So you need to kind of understand, um, what best supplier to use, um, the person that had been able to give us the best outcome. So most recently my most recent problem was to cut aluminium part in a machine that doesn't have the coolant. So, um, that's a bit challenging because ideally you like to cut aluminium quite fast with optimal cooling and, um, you want to cool the part with coolant, but because we don't, this machine doesn't have coolant in it I needed to try find the best tooling to dry cut aluminium, and think of it the best, the best way to machine it. Or that. So not necessarily like machining strategy, you went through with changing the angle, but more, um, understanding how many they're supposed to do, maybe slowing down the feeds and speeds and stuff. Um, so that that's, um, quite typically what I need to do, um, today actually it's quite good we were talking about because today, we did machine the aluminium dry for the first time. Um, we did some things different to the tooling supplier. So he said to go straight to a 15mm depth of cut but we did a 5mm instead and actually when the technician, um, machined the part, I made sure he took videos for me and it sounded good, it looked good.

That's typically one thing that I would do, you know, on a daily basis, but also deal with, um, work holding as well. So, um, you know, when you've got a part and it's not a typical shape or wherever, it needs to think about how to hold this part, sometimes it can quite challenging. And you need to design fixtures and, um, as design, uh, affects your to, to make sure the part doesn't vibrate too much as it gets machined

LU: Yeah. So, so you're, so, so you think about there, the kind of logistical, whole, the kind of logistical kind of structures are in place to that will allow you to complete then job: what tooling you have, how is the part being held

I'll do whatever I can do in the center. There was a research project I'll go away and actually find the best thing for the part rather than machine and the part based on what I've got existing, I'll rather select things to machine it. Optimally. So you can go back and forth, but the research side of things is slightly different though process.

11.10.2 Question 2

LU: Yeah. Okay, cool. Um, well I think that, um, mostly covers question one. Um, thank you. So, I mean, we discussed, um, I mean, Like, uh, we discussed some of this stuff in the, in the presentation that I give you the start. And I mean, to kind of bring this into what we're talking about. I mean, do you do kind of qualitative experiential/ factors form a basis in your thinking about using advanced manufacturing technology. I mean, I know this may be a function of.... Like you might not deal with, these kinds of these kinds of things, but, um, I mean, have you, have you had any sort of experience in that, in that way of thinking before

So more, that you want to get a more quality part rather than, uh, rather than thinking about just getting something out the door. So, yeah, a lot of the time, um, when your machine for me, when I'm getting it more now with the composites machining, but you have to go into nitty-gritty of the difference between climbing cutting and conventional cussing. That's a qualitative thing. So you kind of decide, um, would it look better if you climb cut compared to conventional cut and actually with metal cutting, especially to climb cut. Um, so you start with thicker chip and end up with thinner. With composite cutting it's the opposite. So that's one thing that we have to think about more, a finer detail to make the experience better.

Um, also when we are looking at cutting, um, materials, you have to think about the relationship between the feeds and speeds. So sometimes they're doing it, um, selecting the feeds and speeds to get the, um, to get the part quicker and, you know, get, get through put quickly. But actually what we, I do work with is understanding the dynamic stability of the tools, and that helps you to understand how much the tool, um, vibrates.

And then you have to relate that to the feeds and speeds. Um, so you do some sort of, you tool some the tools beforehand. So we do, um, tap tests because you get a hammer an accelerometer on the tool. It lets you just hit the tool and they get frequency response function from the tooling. And from there you get a graph and you can find out where your stable cutting parameters are. So we select, we traditionally people will um, if they hear chapter, you know, when the hear squealing, they would slow the feeds and speeds down of the cutting tool, but actually with this type of technology, they're all going into this new advanced manufacturing technology. Um, You can actually find that you can eliminate chatter going faster, but you have to find the right is the that sweet spot in this graph. Um, so it's called a stability bubble. So it was actually quite a nice. Um, technology. So not many people know about it because they, they just think, oh, I'm just gonna slow down and cut the chatter out. So that's quite a nice technology.

LU: And in terms of, um, I mean, just, just, just, uh, kind of related question. I mean, there's this sort of quality you're thinking about in the part, I mean, does that, does that relate to aspects of, is that the sort of visual aesthetic quality there's the surface finish and that kind of thing.

Yeah. Cause when you get chatter, you get chatter lines. So you get the lines on the part. If you eliminate chatter using this sort of technology, you don't get the chatter lines. It's a smoother part – your surface finish can be better.

11.10.3 Question 3

LU: So you're making this link between process issues and poor finish or poor quality. Um, okay, cool. Good stuff. Um, okay, so, um, question three, and I think you may have touched on some of this stuff already in your last answer about, and given your experience and knowledge of CNC machining, do you feel the exploitation of the process that I was doing in my work and do you think it is useful moving forward? Or does they expand the framework of how the process is currently thought about; linking, linking this, this sort of, and sort of process control, these process control factors to these qualitative aspects of product experience?

Yeah, absolutely, you know, you talk about the visual experience and some people actually say that the patterns are nicer, visually nicer than that is something that is not just for, um, aesthetics, you know, it's not just, um, you know, the visual experience. Sometimes you need a better visual experience as well for surface quality, I mean the quality of the part itself. So, you know, the, the experiments that you went on and you got a better surface finish because you changed the angle, that would actually also result in, um, ib a machining process they would change. They would want a different surface finish for different reasons. So actually I knew you would know as well, some parts require a rougher surface. And some parts depending on what it is, the main, this is for, it will require a better surface finish. So it's really interesting what you did.

11.10.4 Question 4

LU: I suppose what's interesting is as well, as you just said that, you know, sometimes a kind of, I rougher surface, or what you might assume is poorer quality. That's maybe sometimes more desirable for your, for your user or for your client or whatever. And so, yeah. Okay, cool. And so you, so you feel that broadly speaking, it is a kind of useful exercise. Um, okay. Okay, cool. And, okay, very good. So, um, Question four, so thinking outside machine for a moment, do you think all our advanced processes say such as additive and could also benefit from this kind of conceptual expansion? So, so, you know, tying the, the, and the making processes much more closely in with the, and this perception stuff that I've been talking about.

Yeah, I think actually is more suitable for additive processes in a way, because the patterns that you have created, I think you've got less limitations when you're doing it in additive.

So you have to have a plate, you can have more exotic patters, that's the process. So you could actually go through more different emotions. Um, so I actually additive is more suited to this, but then again, sometimes with additive you sometime get the same surface finish. And what you want from yours is to get different finished. So you might end up needing to do some post-processing on those additive surfaces, but if you're satisfied with the surface, it's just about the patterns. So your just comparing the patterns rather than the finish or the angles. – there a compromise

LU: Yeah, exactly. And then do you think there's a, and some of kind of related point and do you think there's a kind of link or a kind of process link to this in some ways between like, say something like machining and something like additive, which both, say like FDM, additive manufacturing process, like, and comparing it to machining. They both use these sort of nozzles, nozzle type shapes, like structures that sort of go around and it's are, um, *they kind of like, they kind of use maps of lines to sort of, to, to sort of create this art, create their structures and they sort of use these sort of patterns. Um, function. So like, in, in my example, there sort of a pattern upon a pattern. And so there's like a pattern of the making process and then a pattern that's created in the form. But do you think there's a link between additive and machining? Or do you think it's a bit more sort of complicated and that. Because I mean the way I, the way I see it as like machining is almost an inversion of additive, so machining comes in and subtracts material, but you know, it subtracts material and it's are incrementally in a way. It will map out the process and then sort of go and complete it, um, and sort of similarly, and are inversely like additive will you know, it'll map out the process and build up material. The way I see it, there's almost kind of inverse symmetry and process.*

Because the bead that was done is like the inverse. When you mentioned FDM then I had to change my line of thought when you said that, but yeah, you're right then as an inverse, um, sort of relationship with the thing about additively, a limited to the bead size as well. Where as in machining, you can change that scallop.

11.10.5 Question 5

LU: So perhaps there's a bit more controlling and machining and some, some ways. Um, okay, very good. Um, okay. Um, question five. So do you believe better control and understanding of key parameters relating to experiential facets of a manufactured part would be useful to industrial clients. Or do you think users of products could benefit from being aware of manufacturing processes in this way? So if, you know, to give an example, so if like, if I provided you with some object, say some, some artifact, some product; would it be useful or interesting, um, or even, you know, even perhaps just sort of, you know, fun if, if you could see the way it was made sort of implicit within the object and that's kind of what I'm getting at with this question.

So I'm trying to think of an industry need. So I was thinking laptops. You have a laptop and you have a certain pattern on that laptop, it will make people feel a different emotion. The joy one I was thinking like, you know, the controller from my machines, um, the CNC machines, you know, if it was in a certain way, maybe it will inspire the technicians. So maybe have more of a, not joy, but more of a, uh, sort of excitement one or, you know, something like that. I was thinking that could be quite cool.

Um, I don't know if I'm answering it correctly. Cause you just said by understanding how the manufacturing process of that. So, um, I don't think, you know, machine tool manufacturers...that process of chasing these surfaces will be too exotic for them. You know what I mean? Because they're used to creating parts of a certain standard and you know, you're used to putting different parts into their machines, their controllers are the things that they think the most straightforward things. They wouldn't like put too much detail into what the pattern or whatever they have on the surface.

LU: I suppose for, um, yeah, I suppose, just to add a bit of a few more specifics to the question. I suppose what I'm asking is that, so take my patterns as an example. And so like I explored. Like, there's the sort of differentials that you can, that you can do with process control. And so I also had like the rastering angle and I gave a sort of slightly, a slight difference in the different parts. And as you, as you would see them, and, but also it does something else. Actually, it actually brings a kind of awareness to the to the user, *to the onlooker of like how the part was actually made. So like, you can, you can see the actual, you can see the cuts of the tool, you know, you might not necessarily be like, uh, familiar with machining, but like you, you you'd be aware that this thing was made through like the extraction of material in one way or another. So, I mean, that's kind of what I'm. Yeah, well, I'm wondering if that sort of understanding would be, uh, would be useful for people.*

So I think it was the way I answered the first question or the second one. Personally. I would like to know. But you know, not everyone cares.

I always look at things wonder how they were made. I, I do think about things like that but not everyone necessarily does. Let's see. 40% of users are totally would what to know.

LU: Yeah. Well, fair enough. Um, but yeah, I suppose like, uh, like part of the reason I was like, eh, exploring that was because like now in our, in our sort of modern, in our modern technologized society, um, there's like the, the way, like in the past, you could like, and. Like in the past, you you'd have maybe like small products that you would use on a daily basis. And each one would be like each one would have all these traces of how it was made in various ways. So would have this unique, uh, mark of the, of the maker. Um, and like, no, no, that sort of thing has kind of almost gone from the world whereby ..like you still get it a little bit. In ceramics and sort of handmade, handmade objects and so on. But like, I guess what I'm trying to try to do to some extent is try to maybe bring, bring back, somewhat, bring some of that thinking into, um, into our more kind of advanced manufacturing, uh, You know, are more advanced manufacturing kind of, kind of thinking. So could, could that sort of crafty kind of older world type, type way of thinking about making things, inform how we, how we make things and you know, how we make things know and we're using modern, advanced techniques.

I love that thought process and I think that would be useful in STEM activities.

So a good way to promote engineering to the younger audience so they become more aware of understanding how the things are made. So yeah, I actually have kind of changed my thinking because actually something that people don't, but as you're right, and some people will look at, they look at, um, you know, sewing, all that kind of stuff.

You get TV programs...baking and all that kind of stuff. Yeah, it could be, it could be that you, you, you make it a thing that the people get to know how to make metal parts, you know, make this type of thing. People could definitely benefit from it..it’s just how do you start the ball rolling?

11.10.6 Question 6

LU: Okay. Cool. Very good. Um, okay, so, uh, question six. Um, do you think some of the ideas for presented here have limitations, and so could these approaches, or could this way of thinking about say machining. Um, could it impede, could it impedes the practice or machining in any ways in particular that, that you can think of? I mean, actually trying to bring in and so say like, say I wanted to change the angle of the cut as a way of enhancing sort of the aesthetic or the, or the visual dimension. Would that way of thinking and about the process of machining, do you think that would impede the *machine practice, do you think it would reduce efficiency or anything like that? Or would there be some kind of, would there be any kind of cultural problems?*

When it comes to actual, um, technical side of things, I just wonder, like you have like a part and you had a curve surface, for example, and you only had a three-axis machine. If you needed to do a five axis move.. technically the machine cannot do that..to create that aesthetic with that tool path. But, um, otherwise I don't think it will change the culture side of things. People usually just get stuff and then they get told the types of machining processes that they need to follow. And actually they will follow them as long as they've got the capabilities in their machines.

LU: So culturally in general, like a machinist would be like, happy to perform this, this kind of crazy, this crazy operation, if they were...

yeah, that's, that's a good way. But then, so when I was talking to you about tap test, the new technology. Um, and people are dubious, sceptical of it, and they are only won over if you prove it to them.

So this is slightly different and read that this is actually the final outcome. You're telling them the final outcome is going to be good for the user. So they have to machine it anyway, whereas, um, the way that you've said, because that's definitely like, um, what has, what this like tap test, you know, we have to prove that technology to them. So there are limitations, and obviously you've got these old-school people will probably will, maybe think, oh, this is not going to make a difference. If you have the scallop height here, you have that surface finish there, they'll be like, but they're drawing will state they have to have it that way. So they will have to, you know what I mean? So it will, it will be stated on the drawing. It needs to be done that way.

11.10.7 Question 7

LU: Yeah. Sure. Okay. Very good. Um, so, uh, question seven. Um, do you think the integration of these, these methods, these ways of thinking about advanced production could be integrated then to technical control systems? So what I mean by that, do you think, like, say you have, like, you have like a software, like edge cam, right? Could you imagine like a, a distinct function in the edge cam whereby the software could tell you that this, this kind of cutting path with how I have an interesting, tactile sensation, for users interacting with it, it would have an interesting aesthetic or visual dimension?

It could be done! Um, so obviously I use NX and even just introduced a new function, which is trochoidal. So traditionally trochoidal, it was like full circle, going round, cutting incrementally. Whereas they figured out, it’s coming back and cutting slowly, but it's not actually cutting anything. So they've changed that tool path. So it was literally just doing a moon shape cut directly. And doing another bit. So they've changed it. So this is an example, but there can be, there's a function. Um, the settings that can see, um, scallop height, or, you know, how many step overs, so they could have one that says if you want it to be more, um, if you want the mood to be a certain way, you click there, it will just automatically know what that the scallop height would be at that point. So I think it can be done… it’s just will

LU: And it's just, um, well, yeah, I mean, that's the kind of interesting, the interesting thing whereby you have like all these, like… All these software are they are in completely *reasonable ways in, in the sense that they're designed for soft process efficiency and, and designed to like give the and machinist or, um, the G code.. give good, good control over, over what they're doing, but like, it does tend to defer to like, basically what the software creators imagined to be the most efficient way of doing things. Right. And that's been, that's been generated from like years of experience and machining and, and traditional ways of sort of doing things. But I guess it's like interesting to maybe, you know, as, you know, as you suggested you can maybe challenge that and say like, well, if you do it this way, the software could suggest to you this way, it will give you a, a different perceptual quality*

The functionality is there. Like you're saying, it's just, um, yeah...

11.10.8 Question 8

LU: Yeah. Um, okay. Very good. And, and, yeah, so, I mean, we've kind of touched on this before, but do you think industry engineering specialists cause feasibly apply to this new thinking to manufacturing problems. I mean, this is kind of, um, I suppose quite a general question, but, um, yeah. Do you think, do you think it could be, could be done?

Yeah. Yeah. And I said, that's another thing you have to have a good enough argument to say that these things will, um, you know, bring out these emotions, you know? But I think it could be done especially in industries selling things like laptops and things where people do have a bit more of a...they use all the time. They want to, um, have certain types of, um, features from them. So I think it can be it's just, again, I, I easily you can promote it and how well you word it to these specialists.

But yeah, I think is very interesting. I, yeah, I think it's a very interesting concept. If it can be done, it'd great be get them on board as well. You just have to, I guess you have to go to the right people, you know, research departments and all these places, you know, start off with people like us, you know, NMIS who engage with companies and stuff. But yeh I think it's possible, I think it's feasible.

LU: When there's a will there is a way!

11.11 Interview transcript – participant 2

11.11.1 Question 1

LU: Okay. No worries. Um, okay. So, um, the first question is mostly about yourself and your expertise. So, I mean, could you describe briefly your experience to what we might call advanced manufacturing technology, but I suppose, you know, we can limit it to what you might understand. There's more advanced manufacturing technology and, and for you, how is a manufacturing problem initially thought through if you're presented with one?

I guess the approach that we take is somewhat different to standard processes that were, that are quite common place, such as your Ashby's on are and Pugh's and kind of systematic generation of concepts that are envisioned of such towards creating, uh, what would have been, uh, typically quite a limited school in terms of geometry and form being achievable with certain manufacturing technologies, whether that's machining, casting or otherwise, and purely because of the design freedoms enabled by additive manufacturing. And I guess that, that the thing that's perhaps misunderstood about and design for AM, is you did not have complete design freedom, but also from technology to technology, there are limitations.

So as much as we talk about design for additive manufacturing, and in all reality, we are typically following a design 'for' manufacture, based on the technology we are working with. In this approach. And as I say, we, we, we take a different view, what we have typically gone through and where we work within a design space then identify an additive manufacturing technology, a material that we're going to work with begin to generate using computer software, optimized solutions, and then working between the optimized solution and our own engineering knowledge

So things like and manufacturability as to say pre and post processing, but then I guess some of the emotional factors. Such as aesthetics and perceived factor safety, which I think quite an important one, typically speaking, but the algorithms that the software output very organic and people are almost hard wired, not necessarily trust organic looking shapes in an engineering-based environment. So we're working to kind of tweak what the computer outputs and to satisfy not only engineering factor of safety, but as I say, human led perceived factors, which often means that we are arriving on the very, very, very kind of unique solutions. And I guess that's part of the beauty of it is a solutions that otherwise wouldn't necessarily have be realized via just human and the engineering kind of working. And, and I guess that the other aspect to do that is also when you begin, to consider and generative design, which vary slightly from the standard optimization techniques.

So we go through, because it might employ 1, 3, 4, 5 definite optimization techniques. When does its arrives with, a set of solutions that have all meet and satisfy the engineering challenge. And I guess that's where it then uses a little bit of computer, uh, computer learning and shortlist based on what you select

LU: I suppose I'd like to limit the discussion a little bit. And I mean, it's all very interesting, but I mean, I think can, you know what you're talking about there, I suppose it's kind of designed solutions and but, I mean, I guess why I'm asking is if you're presented with, and *obviously you touched on this earlier about, if you're present, say you're presented with something, you know, a client says to you, I want you to make this and, you know, and using some additive process, like how, like, so you got, you got the part and CAD or whatever; how do you then take that into the actual fabrication phases? How do you think about it?*

Um, so, uh, I guess we went back to, and based on our own knowledge to understand which manufacturing process probably would be the right one for it, uh, we, we go through a concept generation stage where we consider a few different ones.

And I guess this is where I'm saying that we do design for manufacturer for each of these, but, um, with regards to CAD and or even a sketch, we actually worked backwards first before going forward. So we, we strip it back and look at the available design space; what material is this? What are some standards, et cetera.

Also the primary interfaces, loading points and faces. And this is where we let the software generate a solution. And that's as I say all driven by algorithms, et cetera. And then from there we pull it back on a scale of say optimization back to something that is somewhat more recognizable. But it's still beyond where a standard engineer would be able to, to get to.

LU: So it's a marriage between, um, engineering thinking and, and computation.

And you could argue you're going to, what was that again? The internet monkey theory yeah. Eventually somebody could arrive at that solution; but that's clearly not feasible and that's why we let the computer do its thing.

But then we read it back into something that satisfies the concerns we have. So qualification and certification is like big thing we need to consider. So that's a big driver, so we might tweak something and put say small artifacts on it as a reference point for measuring that has no function other than that.

11.11.2 Question 2

LU: Alright, cool. Very good. Um, we'll move on and I'll try and go through that. Try and go through the questions a little bit quicker and, okay, cool. Um, so question two. And so are you alluded to this a little bit? Do qualitative experiential factors form a basis ib you're thinking about using advanced manufacturing technology. So just to clarify, I mean, the, and, you know, uh, is there, do you think about these facts are such as I've said aesthetics and, you know, tactile response and so on when, when you're, you know, forming and, you know, when, when you're, when you're trying to manufacture something and yeah. Do, did you consider these aspects and in our general, in the general sense, or are they, or does it depend very much on the, um, on what you're dealing with?

So, um, I think the perceived factor of safety; you've probably got two levels or two or three levels from that.

One is the and customers when you're proposing a set design, you need their buy in. But if it's going to be a component or product that either people interact with or can see, then I guess that in terms of thinking about this as like a radar diagram behind your drivers weigh more heavily, if people will...Well, I guess if it's more like, uh, under the hood style component where people wouldn't see it when you interact with it, I guess that it's lights are one of the consideration. People will influence the design less. That's why I would in that respect.

LU: Yeah. Okay. So you think that. It depends on the kind of context of, of use, I suppose. And if it's, if it's concealed and not seen that it's less relevant to think about.

Yeah. If, if it was something that, uh, people were going to interact with a great deal, and I would say there'd be a great emphasis placed aesthetics perceived safety, tactile interaction.

And, and I guess, and this is where it's actually a, quite an interesting thing within additive manufacturing, especially when you consider technologies like the material jetting, because we have the ability play with shore hardness, surface roughness, transparency and weight, which means that something that you can choose to be in that manufacturing process really steps outside the whole realm of what is typically achievable. I guess the nearest comparable thing for a standard manufacturing process would be your kind of high density polymers that are used for injection molding, where people use high density polymers and coat them in metallic finishes, and it has that kind of weight to the look; it look metallic but is a polymer…

11.11.3 Question 3

LU: Sure. Okay. Very good. Um, all right, we'll move on to that question. Um, so I, I know you're, uh, an additive guy, but, um, I know you've got some experience and knowledge of seeing the CNC machining as well. Um, so given your, uh, experience on their knowledge of CNC machine, do you feel the exploration that I presented to you of the, you know, that this exploration of the process is useful and could they, or does it expand the framework of how the process is currently thoughts about?

Yeah, I mean, absolutely. It's just probably quite a left field application on my first evaluation ..but commercial products like golf putters, the machine finish has a huge bearing. And I guess there's, there's two aspects to it. One is the, aesthetics; golfers like to show off their equipment. But rather than a perceived factor of safety with these things. And, uh, I can have another term would be perceived performance. And obviously it's all psychological and driven by marketing, but a lot of manufacturers will lead you to believe that a certain type of finish, whether that is the actual milling pattern using offset fly cutters actually gives a performance enhancement to clubs. But in all reality, it's pure, purely marketing it's psychological

LU: But nonetheless, nonetheless, a real effect. Yeah.

I mean, absolutely. And yeah, that's just one example, but if you could start to talk about. Uh, more precious of personal products, maybe save something like watches. And I think this would have a huge bearing on the perceived value of these products. Um, being able to explore both the visual aesthetics and the tactile result and for how people interact with these products.

11.11.4 Question 4

LU: Yeah. Okay. Very good. And cool. So we'll move on. And so, I mean, this is more kind of your end of things. And, and I guess, uh, you've spoken about some of this stuff in the previous questions, but, and do you think like additive manufacturing could also benefit *from, from this kind of conceptual expansions? If you take like the work I've done in machining, where I've tried to serve, you know, takeoff, takeoff feature and property of the process, right. And then sort of experiment with it in terms of trying to, there is very it to get at, to explore how these variations could generate specific at properties for human user experience. And do you think something like additive could also benefit from a conceptual expansion of that kind? I mean, obviously there, there, there would be, so are structural differences and different assumptions you'd have to make, but, and I just, you know, what are your thoughts on, on that?*

Yeah, so I would say the biggest driver behind the generation of parts is... Additive manufacturing will create, um, isotropic properties both at a kind of crystallized level, as well as, uh, a, uh, a larger level in terms of the, that the actual patterns created as it is built in a linear process. And therefore trying to come away from anisotropic and trying to work towards isotropic properties, uh, people such as, yeah, eh, Swedish company, I've tried to do this and they have a process called 'islands'...it's like a wave from just going from one state to the other layer that may break it down in to little cubes. And these are what they refer to as islands it's to challenge the heating and cooling. And it does actually end up with quite an aesthetically satisfying look to it, and which is interesting.

And the other thing is recently there's a software company, I'm trying to remember the exact terminology 'play pocket' yeh. So remember that. So when we typically build things, we would take the Zed axis and slice that into equal layers and equal uniform layers. And that would be planar building. Recently, they started to look at non-planar... where you can build on curved surfaces, but not only can it do that perpendicular to said curved surfaces or angled surfaces.

What it also achieves is you can actually build and overhangs without the need for support structure underneath. So if you think about something like a T like this, you need to have support structure under this part and under this part here, otherwise it has nothing to hold it. They start to build out a 45 degree angle, that allows that to consolidate together that support structure. These new build angles that are non-planar actually have very interesting and final forms to them and structure. And there's been a lot of interest, especially from the furniture manufacturing world and, a Dutch company have been using it to manufacture chair...they've chosen to, again, a non-planar route because the flowing aesthetic which aligns to their design needs and aesthetic output

LU: Yeah. That's interesting, actually. Yeah. I mean, that's, that's sort of like indicates that there is like, uh, there's a sort of, kind of hidden realm, I suppose, in the, in thinking about the process and a different way, whereby you unlock like a new, um, yeah. A new area of aesthetics I hadn't previously been explored.

And so I guess in the consumer non-safety critical world, this is, uh, a big thing. And, um, I think there's definitely a big emerging area for additive manufacturing and in commercial, perhaps not engineering realm. Yeah. I would say that the, with developments that are enabled by this body of work I actually do have tangible outputs in the engineering world.

So as I mentioned, features, so a forged component that might have a flowing surface on it, being able to build on top of that surface it, you do need to do that in a non-planar way, and as well as a remanufacture. When we do remanufacture, we would machine down, be it with wall angles, 45 degrees to a flat surface and build from there and then machine finish.

But if you could, uh, machine conforming, so, uh, with respect to the surface, your building on and the build conforming as well. And there would time and energy saving and material saving. And you might end up with more isotropic material underlying structure, as you are adding features to remanufacture, most likely they will have grain flow to them. And you would want to match that with what you built.

LU: Yeah. Yeah. I mean, I see a kind of parallel process or I kind of parallelism or a kind of inverted parallelism between like some additive processes, like say like FDM and, and um, machining itself. So like machine comes in and subtracts material using, uh, you know, using a kind of tool path strategy. Right. And then the FDM will come and using a sort of similar to if I strategy, but I then material and Sr similar are in there. I kind of mirror image. They're like mirror images of each other. So I think like some of what you're saying, I mean, obviously will work in all cases, but some of what you're saying could apply like in the, in the sort of inverse in that kind of machine in context

Yeah, I mean, it's combinable with, uh, the digitization of machining. It went from being a manual, three axes point of manufacturer to three plus one, four plus one, full five axis six... Now you've been seeing some seven axis applications of the machining. So the geometries you can achieve with that are obviously the vast, I guess, where is goes in terms of complexity of achievable geometry would be the use of things like lollipop cutters, where you've got a larger, a larger heads than connecting parts to the actual drill bit that when you did that down into, uh, a cavity, you can then tilt that I'm actually machine around corners. So you can create out forms, which I guess is somewhat comparable to additive manufacturing, creating dissolvable square structures for some these impossible overhangs.

11.11.5 Question 5

LU: Um, okay, cool. Right. We're going to move on and they're good. So, and yeah, I mean, I guess what we've been discussing, and a lot of this is sort of process control and so on this, this questions is about that. I mean, do you, do you believe better control and understanding of key parameters relating to experiential facets of say manufacturing a part, would be, we'd be useful to industry clients and by extension, do you think users of products could benefit from being aware of the manufacturing processes in this way? So what I mean by that, do you think it, and so, I mean, to sort of explain this a little bit better or to give an analogy and when you buy a handcrafted piece of pottery, there is like, uh, there's sort of this implicit and, uh, quality to the, to the, to the artifact that, and. Derives from being made by the human hand where this sort of interaction between the hand and the material. So I guess what I'm wondering is what you think of, and you're having control of this processes and in these ways of it have not allow us to like serve and bad, these kinds of traces of, of process, or like produce parts and certain ways that couldn't be done by any other method. And so do you think that's a useful property for industrial clients to explore? And indeed you think that's an interesting and useful thing that could benefit users as well?

Talking purely about machining??

LU: Well, I wouldn't necessarily say so because I think you can, um, you can, you can achieve your, you can see some of the things with additive manufacturing to. I see mail or the types of process, but let's take out to the machining, like, so machining, you see, like you, you know, you see traces of the, of the, of the tool as it moves through the material. Sure. But also, and I said, if you see certain traces of the, of the process as well. And so I guess what I'm wondering is if you accentuated these, these qualities in some way or another or played with them in certain waysUm, I mean, do you think that's an aspect that needs to be explored further? And so our professional engineering circles, and when do you think there's all material benefit for that are users?

I would say if a, um, in a consumer point of view, yes. For an engineering point of view, no. Uh, the drivers aren't there for that. It's too much to do with I'd applied resource efficiency, um, to be a concern about for the consumer, but the absolutely. Yes. So again, they can have products that we highlight. Putters, watches, these sorts of things, absolutely. And, um, I think for, for machining, I think for the world of meta-information to do with how something was manufactured is, is something that's perhaps an app you could have, I dunno, a QR code or a welcome box or something that comes with your watch...where you can scan all code, go to their website and you might be able to see how that particular watch or how that watch company manufactures things do that. And I think we're moving towards more of an appreciation for, I guess, digital craft. Would you call it?

LU: Yeah, exactly. I mean, exactly. This, this sort of bringing that, you know, bringing the skill and knowledge and, and eh, yeah. That sort of subjective artisinal qualities that you see in and sort of handmade objects. Yeah. Could you, could you bring that into the sort of digital end of things I guess is a question, which I think which I met very much thinking as I kind of. And area are least the very, the very most I kind of emerging and area.

And so, so that would be my answer for CNC machining. The answer for additive would be somewhat different because you can start to work the world of customization with additive and more readily than you could in a machine, for instance, cochlea implants, hearing aids; that is now being run off of scan data. And then people are using technologies like vat polymerization. So it will exactly match your ear canal. Now very much on the functional end of the scale in the just personalization for fun ..BMW on their mini range. You can pick different finishes, as well as putting your name and other things on a particular component. They've isolated the wing mirror and that's enabled by additive manufacturing, you fill out a few of these things. And, uh, when your car is being manufactured, that gets 3d printed on the side and then brought along into the assembly. And so I think in that sense AM enables personalization of products.

I guess, you know, kind of functional end of the scale as well. We a little bit of did this, at the university, Dr. Crisler, where we were looking at actually quite mundane products, um, uh, uh, elderly and disabled people as used like zimmer frames. And what we did was we actually worked off an impression mold that they took by squeezing something. We 3d scaned that, and then we 3d printed those as the handles better grip. We also spoke to them about stuff like function and aesthetics. And the one thing that was highlighted in that was, and often these people would need to use these things in the evening or late at night, low light or the dark. So actually what we really need to do is 3d printed in a high visibility glow in the dark material. So these people could find these things. Others just wanted a ‘nice blue colour’

I know this is obviously talking more about material options rather than the, um, manufacturing process, but I guess it's intrinsically linked to an extent.

11.11.6 Question 6

LU: Yeah. Okay. Very good. Um, next question. And so, yeah, just cast your mind back to some of the things I was talking about in the presentation, the start, I mean, do you think on some of what we've been talking about here? I mean, do you think these ideas have limitations?

I guess probably a clear split between engineering and consumer products. And I think from a, from an engineering perspective, the industry wouldn’t be interested in this and less you're approaching that really high end. So starting to think about like say hyper cars, things like that are really performance driven, but still have some aesthetics linked to them. And they're more interested in buy to fly ratio, so, and minimal amounts of material as well as its resource efficiency. So build as quick build as, as possible, but using the least amount of cutters.. the tooling can be expensive. So a lot of machining strategies are driven by reducing wear.

Form a commercial point of view, resource would become another consideration as this will add cost and some may not think that that cost is balanced by the increase in value.

LU: Yeah. Yeah. I think, I mean like, like this kind of co I would say that like seven play, there was sort of two cultures. If you like, whereby there's this kind of culture of now you said this culture of kind of efficiency and I'm making sure your, uh, your processes is, is done like the most effective way possible. And your, the, your material uses and. You know, the most efficient possible at blah, blah, blah. And also like there's this other culture of sort of things I'm kind of talking about where, and you, you make sort of sacrifices I that, uh, that functional end to achieve and more interesting things out of the experiential end. And so there is this trade-off sure, but I guess what I'm trying to do with this work is sort of challenge. They challenged that assumption, that like challenge that assumption that the most efficient or most optimized method is, is just by default the best.. and say like, you can actually get interesting insights and positive and value from doing things differently that are unlike the Orthodox in technical terms.

Yeah. Uh, I think the perfect example is why I cited with them. The remanufacturing.. the feature addition work that.. actually all the softwares that are out there aren't necessarily fit for purpose for what we are trying to do some to be used going, then the more designed design aesthetic light approach to, uh, to us via software that's actually come up with quite an eloquent solution for what is actually an engineering problem. So I would say, yeah, and yeah, I think any opportunity to think outside the box a little is going to be useful for creating unexpected innovations.

11.11.7 Question 7

LU: Yeah. Okay. Very good. Um, yeah. And this, I mean, you sort of touched on this just there, but, um, do you think like an integration or kind of articulation of these messages of thinking about advanced production could be integrated into technical control systems like cam? So, I mean, you, you're alluded to the fact there that you find some of the *software that you use not quite fit for purpose in terms of what you, what you want to explore. And so perhaps you could, um, talk about that a bit more.*

Yeah. So I think probably some of the best examples from this are probably driven…I guess the whole optimization ones…there's a lot of biomimicry that has been adopted from that. And I think it's safe to say that everyone think biomimicry is quite outside the box thinking for engineers. And the evolutionary algorithms and the generic algorithms that have had huge and lasting affects of design for additive and advanced tool-paths.

And, uh, yeah, uh, are, are hugely beneficial and probably more so in like the field of robotics, a studied, um, lots of different animals and humans and especially humans, not necessarily just analyze somebody's walking up and down but analyzing people dancing… this is then taken into how these robots move… If you relate this back to cam, how robotic arms work and move, they've found more efficient ways to maneuver these, especially when they're working together in systems. Like, so here at San Bruno, like robotics, robotic welding, as well as car painting… but the shortest distance between two points isn't necessarily a straight line.

So, yeah, I would say I would, I would kind of relate some of what your discussion discussing here and your work into that category of, yeah, actually, we need to think about the curves rather than the straight lines between the points to actually come up with more optimized solutions.

LU: Yeah. But even like, let's say you didn't want him to say optimize your, your, your, your solution or your process. And I mean, why, I guess what I'm wondering is if you had like a cam system that would allow you to that, that not only integrated or allows you to see like different tool strategies, right. So like cam software will allow you to do that already. Right. But what it doesn't show you is how the cam strategies might link to and perceptual properties such as… You know, emotional response or tactile response and that kind of thing. I personally think that would be useful and as a, as an option, or to be added to the cam architecture as a kind of conceptual expansion.. would you agree with that?

Yeah, absolutely.

I think coming something, but we sort of review, let's just be simple pocket. We need to highlight a pocket feature in CAM software, you get options for the machining strategies. Um, what, what would be interesting is not only where it tells you recommended feeds and speeds and the resultant cutting time, but actually to then be able to hover over a surface and pops up, uh, an image of what does this cutting pattern produce. And I think that could be influential in the decision making process primarily for consumer based products. But especially when you're talking about high-end or high value engineering along the lines of super cars, these kinds of applications, it would make a big difference in what they choose to do.

11.11.8 Question 8

LU: Yeah. Okay. Very good. Um, so let's is a, uh, final question. And so do you think industry engineering specialists could feasibly apply this kind of new thinking to manufacturing problems? I mean, this is, this kind of is a bit more of a general question, *but, um, yeah. Do you think there's scope to bring that conceptual expansion to a wider audience of industry and engineering specialists?*

In short: yeh. Though, I think you'd need to evidence or demonstrate why it is useful

LU: Okay. So you think there's, there's, there's scope for it by we'd need to be there need to be, have a convincing sort of case.

11.12 University Ethics Forms

Note: all participant concept forms are available on request

Ethics Committee -
Code of Practice on Investigations on Human Beings

When implementing a staff or student project which involves 'investigation on human beings' it is important to note that the university has a code of practice governing the implementation and conduct of such investigations. This 'code of practice was developed by the 'Ethics Advisory Committee' and approved by the university court on 5th May 2000. The code governs all investigations on human beings including class teaching experiments and demonstrations, student projects and research investigations which fall within the scope of the code. The 'Departmental Research Committee' will act as the 'Departmental Ethics Committee', and can approve most routine, non-invasive investigations.

It is the responsibility of the supervisor to make the student aware of relevant guidelines and ensure that they are observed. The supervisor is also responsible for submitting details of proposed investigations for approval where necessary.

The following contains 2 checklists to aid the implementation of this practice:

(i) The first is to identify cases which require to be approved by the University Ethics Advisory Committee. If any of the boxes are marked in checklist (i) the investigation must be submitted to the university committee for approval.

(ii) The second is to ensure correct procedure is adhered to in any 'routine or non-invasive' investigation i.e. those which are readily approved by the 'Department Ethics Committee' (in essence the checklist represents a summary of Section 6 of the Code of Practice on Investigations on Human Beings.)

These checklists should not be viewed as a substitute for the original document and thus all supervisors should be familiar with the code before utilising these in staff/student research projects. The checklists are designed to ensure that the staff/students are immediately aware of the implications of the guidelines to their investigation. Furthermore, they act as departmental records of staff/student conduct in investigations on humans.

As 'Ethics Advisory Committee' approval of a protocol can take up to 4 weeks (longer for very specific requests), where research is likely to include an element of 'investigations on humans', an analysis of expected procedures should be carried out at as early a stage as possible.

In addition to the university regulations, investigations of a Physiological, Sociological and Biological nature must conform to additional 'codes of practice' set out by relevant professional bodies - in such cases the secretary of the ethics advisory board can supply copies of these statements.

(i) Supervisor and Student Ethics Checklist

Project Title: Emotive content of pattern and textured surfaces (study 2)

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be from a design or engineering background with age ranges from 20-35. Recruitment will mostly be focused on DMEM students and staff of appropriate backgrounds

Does the investigation involve any of the following (mark as appropriate):

1)	Harm, discomfort, physical or psychological risk (esp. pregnant women, elderly, the young).	yes☐	no☒
2)	Participants whose ability to give voluntary consent is limited (cognitively impaired, prisoners, persons with chronic physical or mental conditions).	yes☐	no☒
3)	Invasive techniques (DNA testing, collection of body fluids/tissue).	yes☐	no☒
4)	Extensive degree or duration of exercise or physical exertion.	yes☐	no☒
5)	Manipulation of human responses (cognitive or affective) which may involve stress or anxiety.	yes☐	no☒
6)	Administration of drugs, liquid/food additives.	yes☐	no☒
7)	Deception of the participants which might cause distress or effect their willingness to participate in the research.	yes☐	no☒
8)	The collection of highly personal, intimate, private or confidential information.	yes☐	no☒
9)	Payment to the participants (other than travel/time costs).	yes☐	no☒

If the answer to <u>any</u> of the above questions is yes you <u>must</u> submit a protocol to the 'Ethics Advisory Committee' unless previous consent has been granted for practising the 'generic' procedure involved. The protocol for such submissions to the 'Ethics Advisory Committee' can be found in Appendix A of the 'Code of Practice on Investigations of Humans Beings'.

Supervisors Signature(s)

........Andrew Wodehouse............... Date ...15/02/17.........

........A Wodehouse...................... Date ....

Students/Researchers Signature(s)

.........Lewis Urquhart..................... Date ...15/02/17.........

.... Date ....

(ii) Checklist for Department Approved Investigations

Mark all boxes when you have read, understand and, where appropriate, will adhere to the guidelines - also note the documentation required relative to your investigation:

N.B Investigators must acknowledge, understand and adhere to all of the points on this checklist.

Project Title: Emotive content of pattern (study 1)

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be from a design or engineering background with age ranges from 20-35. Recruitment will mostly be focused on DMEM students and staff of appropriate backgrounds

Investigation Content:

This is an aesthetic study looking at how aesthetics elements, such as geometry and composition, affect the emotional interpretation of Form and how emotions are represented through Form. There will be two tasks during the study.

1) Participants will be asked to observe a series of decorative patterns, shown in monochrome on a computer monitor. There will be 16 different patterns and each will be shown for a maximum of 90 seconds. A worksheet with emotive terms (e.g ("joy", "anger") will be provided with a corresponding Likkert scale for each participant to fill in the "perceived intensity" of each emotive term related to each pattern.
2) Participants will be given a worksheet with two dot points and an emotive term (e.g ("joy", "anger"). The participants will be tasked with freely drawing a line from one point to the other to represent the emotion as they see fit

It is the supervisor's responsibility to make students aware of these guidelines and the students to provide the supervisor with the required documentation from affected investigation components. Signed copies should be maintained by the supervisor and student(s) for departmental records.

☒ **Consent**. Obtain informed consent of all volunteers. A consent form must be signed by all volunteers.

☒ **Protection**. Protect all volunteers from possible harm and preserve their rights. No investigation should involve significant risks to mental or physical well-being of its participants.

☒ **Inducement**. Provide no financial inducement nor other coercion (actual or implied) to persuade people to take part in the investigation.

☒ **Withdrawal.** Volunteers must be free to withdraw at any stage, without giving reason.

☒ **Termination.** The investigation should stop immediately if volunteers report any problems (physical, mental or otherwise) during it. The problems must be reported to the appropriate ethics committee.

☒ **Recruitment.** Volunteer recruitment should wherever possible be via letter, notice (or orally - if through a group approach). However, random street or doorstep surveys are acceptable.

☒ **Staff Participation.** The motives for staff/students to participate as a volunteer in an investigation should be taken into special consideration i.e. neither declining nor agreeing to participate in an investigation should affect academic assessment in anyway.

☒ **Special Consideration**. Special consideration should be given to the young, adults with any cognitive disabilities or learning difficulties and to all persons who live in or are connected to an institutional environment (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Pregnancy.** Women of child bearing age must not be recruited for any investigation which could be harmful to fertility/pregnancy (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Selection.** Submissions based on the investigation should include details of the basis for volunteer selection i.e. questionnaires and/or other measures in the selection process.

☒ **Justification.** Investigators must justify the number/type of subjects chosen for each study.

☒ **Confidentiality.** Confidentiality and privacy must be maintained. Any waiver of confidentiality should be justified and consent must be given, in writing, by the volunteer(s). In addition, the investigator must comply with Data Protection Legislation.

☒ **Informing Volunteers.** Each volunteer must be provided with an information sheet providing full relevant details of the nature, object and duration of the proposed investigation and a contact for further queries (whom is independent of the investigation normally the secretary of the ethics advisory committee).

☒ **Deception.** There shall be no deception that might affect a person's willingness to participate in an investigation nor about the risks involved.

☒ **Unusual Symptoms.** Volunteers will be encouraged to note any unusual or unexpected symptoms arising during the investigation. These should be reported to the appropriate ethics committee

☒ **Location**. Places where investigations take place should be appropriate to the type and risk factor of study undertaken. Further, the ethics committee are entitled to carry out spot checks.

☒ **Records.** Full records of all procedures carried out should be maintained in an appropriate form. A register of all volunteers should be taken and a note of the population/sample from which they were drawn.

☒ **Queries.** Post investigation queries from a participant should be directed to an appropriate professional (supervisor, head of department etc.).

☒ **Insurance.** It is the responsibility for the applicant to seek extended insurance if the investigation scope falls out-with the University's Public Liability Policy (in such cases the investigator should refer to **Appendix B** of the original 'code of practice' document).

Additional general guidelines exist for biological, psychological and sociological investigations - in such cases refer to **Sections 6.2 and 6.3** of the original 'code of practice' document.

Additional general guidelines exist for biological, psychological and sociological investigations - in such cases refer to **Sections 6.2 and 6.3** of the original 'code of practice' document.

Supervisors Signature(s)

......Andrew Wodehouse.................. Date ......15/02/17......

........A. W........................ Date ....

Students/Researchers Signature(s)

......Lewis Urquhart........................ Date ......15/02/17.....

.... Date ....

Ethics Committee -
Code of Practice on Investigations on Human Beings

When implementing a staff or student project which involves 'investigation on human beings' it is important to note that the university has a code of practice governing the implementation and conduct of such investigations. This 'code of practice was developed by the 'Ethics Advisory Committee' and approved by the university court on 5th May 2000. The code governs all investigations on human beings including class teaching experiments and demonstrations, student projects and research investigations which fall within the scope of the code. The 'Departmental Research Committee' will act as the 'Departmental Ethics Committee', and can approve most routine, non-invasive investigations.

It is the responsibility of the supervisor to make the student aware of relevant guidelines and ensure that they are observed. The supervisor is also responsible for submitting details of proposed investigations for approval where necessary.

The following contains 2 checklists to aid the implementation of this practice:

(i) The first is to identify cases which require to be approved by the University Ethics Advisory Committee. If any of the boxes are marked in checklist (i) the investigation must be submitted to the university committee for approval.

(ii) The second is to ensure correct procedure is adhered to in any 'routine or non-invasive' investigation i.e. those which are readily approved by the 'Department Ethics Committee' (in essence the checklist represents a summary of Section 6 of the Code of Practice on Investigations on Human Beings.)

These checklists should not be viewed as a substitute for the original document and thus all supervisors should be familiar with the code before utilising these in staff/student research projects. The checklists are designed to ensure that the staff/students are immediately aware of the implications of the guidelines to their investigation. Furthermore, they act as departmental records of staff/student conduct in investigations on humans.

As 'Ethics Advisory Committee' approval of a protocol can take up to 4 weeks (longer for very specific requests), where research is likely to include an element of 'investigations on humans', an analysis of expected procedures should be carried out at as early a stage as possible.

In addition to the university regulations, investigations of a Physiological, Sociological and Biological nature must conform to additional 'codes of practice' set out by relevant professional bodies - in such cases the secretary of the ethics advisory board can supply copies of these statements.

(i) Supervisor and Student Ethics Checklist

Project Title: Emotive content of pattern (study 1)

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be from a design or engineering background with age ranges from 20-35. Recruitment will mostly be focused on DMEM students and staff of appropriate backgrounds

Does the investigation involve any of the following (mark as appropriate):

1)	Harm, discomfort, physical or psychological risk (esp. pregnant women, elderly, the young).	yes☐ no☒
2)	Participants whose ability to give voluntary consent is limited (cognitively impaired, prisoners, persons with chronic physical or mental conditions).	yes☐ no☒
3)	Invasive techniques (DNA testing, collection of body fluids/tissue).	yes☐ no☒
4)	Extensive degree or duration of exercise or physical exertion.	yes☐ no☒
5)	Manipulation of human responses (cognitive or affective) which may involve stress or anxiety.	yes☐ no☒
6)	Administration of drugs, liquid/food additives.	yes☐ no☒
7)	Deception of the participants which might cause distress or effect their willingness to participate in the research.	yes☐ no☒
8)	The collection of highly personal, intimate, private or confidential information.	yes☐ no☒
9)	Payment to the participants (other than travel/time costs).	yes☐ no☒

If the answer to <u>any</u> of the above questions is yes you <u>must</u> submit a protocol to the 'Ethics Advisory Committee' unless previous consent has been granted for practising the 'generic' procedure involved. The protocol for such submissions to the 'Ethics Advisory Committee' can be found in Appendix A of the 'Code of Practice on Investigations of Humans Beings'.

Supervisors Signature(s)

.........Andrew Wodehouse.............. Date ...15/10/18.........

.........A Wdh......................... Date ....

Students/Researchers Signature(s)

.........Lewis Urquhart.................... Date ...15/10/18.........

.........Lewis Urquhart........... Date ....

(ii) Checklist for Department Approved Investigations

Mark all boxes when you have read, understand and, where appropriate, will adhere to the guidelines - also note the documentation required relative to your investigation:

N.B Investigators must acknowledge, understand and adhere to all of the points on this checklist.

Project Title: Emotive content of pattern and textured surfaces (study 2)

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be from a design or engineering background with age ranges from 20-35. Recruitment will mostly be focused on DMEM students and staff of appropriate backgrounds

Investigation Content:

This is an aesthetic study looking at how aesthetics elements, such as geometry, texture and composition, affect the emotional interpretation of Form. There will be four tasks during the study.

1) Participants will be shown a series of four bespoke pattern designs. A worksheet with emotive terms (e.g ("joy", "anger") will be provided with a corresponding Likkert scale for each participant to fill in the "perceived intensity" of each emotive term related to each pattern.
2) Participants will be shown four small textured aluminium plates. A worksheet with emotive terms (e.g ("joy", "anger") will be provided with a corresponding Likkert scale for each participant to fill in the "perceived intensity" of each emotive term related to each pattern.
3) Participants will be given a set of textured aluminium plates (28 in total). Each plate will be visually compared with a datum plate and tested for preference. A worksheet will be provided for participants to indicate preference between the plates
4) Participants will be given a set of textured aluminium plates (28 in total). Each plate will be interacted with through a short, guided tactile interaction, compared with a datum plate and tested for preference. A worksheet will be provided for participants to indicate preference between the plates. There is no risk of harm during the interaction and hand sanitation will be provided for the participant for before and after the plate interactions

It is the supervisor's responsibility to make students aware of these guidelines and the students to provide the supervisor with the required documentation from affected investigation components. Signed copies should be maintained by the supervisor and student(s) for departmental records.

☒ **Consent**. Obtain informed consent of all volunteers. A consent form <u>must</u> be signed by all volunteers.

☒ **Protection**. Protect all volunteers from possible harm and preserve their rights. <u>No</u> investigation should involve significant risks to mental or physical well-being of its participants.

☒ **Inducement**. Provide no financial inducement nor other coercion (actual or implied) to persuade people to take part in the investigation.

☒ **Withdrawal.** Volunteers must be free to withdraw at any stage, without giving reason.

☒ **Termination.** The investigation should stop immediately if volunteers report any problems (physical, mental or otherwise) during it. The problems must be reported to the appropriate ethics committee.

☒ **Recruitment.** Volunteer recruitment should wherever possible be via letter, notice (or orally - if through a group approach). However, random street or doorstep surveys are acceptable.

☒ **Staff Participation.** The motives for staff/students to participate as a volunteer in an investigation should be taken into special consideration i.e. neither declining nor agreeing to participate in an investigation should affect academic assessment in anyway.

☒ **Special Consideration**. Special consideration should be given to the young, adults with any cognitive disabilities or learning difficulties and to all persons who live in or are connected to an institutional environment (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Pregnancy.** Women of child bearing age must not be recruited for any investigation which could be harmful to fertility/pregnancy (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Selection.** Submissions based on the investigation should include details of the basis for volunteer selection i.e. questionnaires and/or other measures in the selection process.

☒ **Justification.** Investigators must justify the number/type of subjects chosen for each study.

☒ **Confidentiality.** Confidentiality and privacy must be maintained. Any waiver of confidentiality should be justified and consent must be given, in writing, by the volunteer(s). In addition, the investigator must comply with Data Protection Legislation.

☒ **Informing Volunteers.** Each volunteer must be provided with an information sheet providing full relevant details of the nature, object and duration of the proposed investigation and a contact for further queries (whom is independent of the investigation normally the secretary of the ethics advisory committee).

☒ **Deception.** There shall be no deception that might affect a person's willingness to participate in an investigation nor about the risks involved.

☒ **Unusual Symptoms.** Volunteers will be encouraged to note any unusual or unexpected symptoms arising during the investigation. These should be reported to the appropriate ethics committee

☒ **Location**. Places where investigations take place should be appropriate to the type and risk factor of study undertaken. Further, the ethics committee are entitled to carry out spot checks.

☒ **Records.** Full records of all procedures carried out should be maintained in an appropriate form. A register of all volunteers should be taken and a note of the population/sample from which they were drawn.

☒ **Queries.** Post investigation queries from a participant should be directed to an appropriate professional (supervisor, head of department etc.).

☒ **Insurance.** It is the responsibility for the applicant to seek extended insurance if the investigation scope falls out-with the University's Public Liability Policy (in such cases the investigator should refer to **Appendix B** of the original 'code of practice' document).

Supervisors Signature(s)

......Andrew Wodehouse................ Date ......15/10/18.......

......A. Wodehouse...................... Date ....

Students/Researchers Signature(s)

......Lewis Urquhart........................ Date ......15/10/18.....

......L. Urquhart............................ Date ....

Ethics Committee -
Code of Practice on Investigations on Human Beings

When implementing a staff or student project which involves 'investigation on human beings' it is important to note that the university has a code of practice governing the implementation and conduct of such investigations. This 'code of practice was developed by the 'Ethics Advisory Committee' and approved by the university court on 5th May 2000. The code governs all investigations on human beings including class teaching experiments and demonstrations, student projects and research investigations which fall within the scope of the code. The 'Departmental Research Committee' will act as the 'Departmental Ethics Committee', and can approve most routine, non-invasive investigations.

It is the responsibility of the supervisor to make the student aware of relevant guidelines and ensure that they are observed. The supervisor is also responsible for submitting details of proposed investigations for approval where necessary.

The following contains 2 checklists to aid the implementation of this practice:

(i) The first is to identify cases which require to be approved by the University Ethics Advisory Committee. If any of the boxes are marked in checklist (i) the investigation must be submitted to the university committee for approval.

(ii) The second is to ensure correct procedure is adhered to in any 'routine or non-invasive' investigation i.e. those which are readily approved by the 'Department Ethics Committee' (in essence the checklist represents a summary of Section 6 of the Code of Practice on Investigations on Human Beings.)

These checklists should not be viewed as a substitute for the original document and thus all supervisors should be familiar with the code before utilising these in staff/student research projects. The checklists are designed to ensure that the staff/students are immediately aware of the implications of the guidelines to their investigation. Furthermore, they act as departmental records of staff/student conduct in investigations on humans.

As 'Ethics Advisory Committee' approval of a protocol can take up to 4 weeks (longer for very specific requests), where research is likely to include an element of 'investigations on humans', an analysis of expected procedures should be carried out at as early a stage as possible.

In addition to the university regulations, investigations of a Physiological, Sociological and Biological nature must conform to additional 'codes of practice' set out by relevant professional bodies - in such cases the secretary of the ethics advisory board can supply copies of these statements.

(i) Supervisor and Student Ethics Checklist

Project Title: Expert interview reviewing findings of doctoral research studies

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be interviewed in a semi-structured fashion following a presentation that describes the theoretical and practical work of the researcher. They will be asked 8 questions related to the work and asked to give their opinions and insights. Each participant is considered an "expert" in the field of manufacturing engineering and/or design. The study will involve 2 participants in total interviewed separately. Each session will last no longer than 60 minutes. Any IP sensitive material will be redacted on request. Participants will remain anonymous by default unless permission is granted for their identification within the reporting. Participants will sign consent forms outlining the interview process and data management before participating.

Does the investigation involve any of the following (mark as appropriate):

1)	Harm, discomfort, physical or psychological risk (esp. pregnant women, elderly, the young).	yes☐	no☒
2)	Participants whose ability to give voluntary consent is limited (cognitively impaired, prisoners, persons with chronic physical or mental conditions).	yes☐	no☒
3)	Invasive techniques (DNA testing, collection of body fluids/tissue).	yes☐	no☒
4)	Extensive degree or duration of exercise or physical exertion.	yes☐	no☒
5)	Manipulation of human responses (cognitive or affective) which may involve stress or anxiety.	yes☐	no☒
6)	Administration of drugs, liquid/food additives.	yes☐	no☒
7)	Deception of the participants which might cause distress or effect their willingness to participate in the research.	yes☐	no☒
8)	The collection of highly personal, intimate, private or confidential information.	yes☐	no☒
9)	Payment to the participants (other than travel/time costs).	yes☐	no☒

If the answer to <u>any</u> of the above questions is yes you <u>must</u> submit a protocol to the 'Ethics Advisory Committee' unless previous consent has been granted for practising the 'generic' procedure involved. The protocol for such submissions to the 'Ethics Advisory Committee' can be found in Appendix A of the 'Code of Practice on Investigations of Humans Beings'.

Supervisors Signature(s)

………Andrew Wodehouse..…………. Date …03/11/21………

…………………… ……………………. Date …03/11/21………

Students/Researchers Signature(s)

………Lewis Urquhart………………… Date …03/11/21………

………………………………………….. Date …03/11/21………

(ii) Checklist for Department Approved Investigations

Mark all boxes when you have read, understand and, where appropriate, will adhere to the guidelines - also note the documentation required relative to your investigation:

N.B Investigators must acknowledge, understand and adhere to all of the points on this checklist.

Project Title: Emotive content of pattern (study 1)

Participants (staff/students carrying out investigation): EngD Student Lewis Urquhart will carry out in the investigation. Participants will be from a design or engineering background with age ranges from 20-35. Recruitment will mostly be focused on DMEM students and staff of appropriate backgrounds

Investigation Content:

This is an aesthetic study looking at how aesthetics elements, such as geometry and composition, affect the emotional interpretation of Form and how emotions are represented through Form. There will be two tasks during the study.

1) Participants will be asked to observe a series of decorative patterns, shown in monochrome on a computer monitor. There will be 16 different patterns and each will be shown for a maximum of 90 seconds. A worksheet with emotive terms (e.g ("joy", "anger") will be provided with a corresponding Likkert scale for each participant to fill in the "perceived intensity" of each emotive term related to each pattern.
2) Participants will be given a worksheet with two dot points and an emotive term (e.g ("joy", "anger"). The participants will be tasked with freely drawing a line from one point to the other to represent the emotion as they see fit

It is the supervisor's responsibility to make students aware of these guidelines and the students to provide the supervisor with the required documentation from affected investigation components. Signed copies should be maintained by the supervisor and student(s) for departmental records.

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☒ **Withdrawal.** Volunteers must be free to withdraw at any stage, without giving reason.

☒ **Termination.** The investigation should stop <u>immediately</u> if volunteers report any problems (physical, mental or otherwise) during it. The problems must be reported to the appropriate ethics committee.

☒ **Recruitment.** Volunteer recruitment should wherever possible be via letter, notice (or orally - if through a group approach). However, random street or doorstep surveys are acceptable.

☒ **Staff Participation.** The motives for staff/students to participate as a volunteer in an investigation should be taken into special consideration i.e. neither declining nor agreeing to participate in an investigation should affect academic assessment in anyway.

☒ **Special Consideration**. Special consideration should be given to the young, adults with any cognitive disabilities or learning difficulties and to all persons who live in or are connected to an institutional environment (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Pregnancy.** Women of child bearing age must not be recruited for any investigation which could be harmful to fertility/pregnancy (in such cases the investigator should refer to **Appendix C** of the 'code of practice on investigations on human beings').

☒ **Selection.** Submissions based on the investigation should include details of the basis for volunteer selection i.e. questionnaires and/or other measures in the selection process.

☒ **Justification.** Investigators must justify the number/type of subjects chosen for each study.

☒ **Confidentiality.** Confidentiality and privacy must be maintained. Any waiver of confidentiality should be justified and consent must be given, in writing, by the volunteer(s). In addition, the investigator must comply with Data Protection Legislation.

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☒ **Queries.** Post investigation queries from a participant should be directed to an appropriate professional (supervisor, head of department etc.).

☒ **Insurance.** It is the responsibility for the applicant to seek extended insurance if the investigation scope falls out-with the University's Public Liability Policy (in such cases the investigator should refer to **Appendix B** of the original 'code of practice' document).

Additional general guidelines exist for biological, psychological and sociological investigations - in such cases refer to **Sections 6.2 and 6.3** of the original 'code of practice' document.

Supervisors Signature(s)

……Andrew Wodehouse…………… Date …03/11/21…….

…… A. Wodehouse. ……………………………………. Date …03/11/21………

Students/Researchers Signature(s)

……Lewis Urquhart………………… Date …03/11/21……..

………………………………………… Date …03/11/21………

11.13 Copyright statement

Signed:

Date: 25/05/2022