

9. Discussion

This thesis has examined the nature of individual differences in approach to design practice, in terms of a practitioner's relationship with the medium with which they work, and its role in their practice. This enquiry has been situated within the context of developing future digital environments for creative practice.

It has used methods and instruments designed to elicit information on differences: between individuals, between theoretical positions, and between other phenomena. It has defined and explored the territory of research through reviews of the literature (both contextual and theoretical); a systematic analysis of literature to derive a comparative framework as the basis of empirical work; and empirical studies, mostly interviews, but also set tasks and observation.

It has drawn on literature on creative processes from other disciplines (writing and computer programming/epistemology) and the results of three empirical studies which examined in detail the creative practices of students and professional practitioners working with three-dimensional media, both material and digital, to demonstrate that important underlying differences exist between individual design practitioners, concerning their relationship with the medium with which they work, and its role in their practice.

It has argued that these differences are more significant than variation arising from each designer's personal style, unique experience, or working context; rather they represent wholly different approaches to design, elements of which relate to the nature and extent of a dialogue between practitioner and medium. However, it concludes that while aspects of these differences in approach can be mapped to a formal/concrete axis, this does not account for all the variation which can be observed.

This chapter places the research and its findings within their wider critical and practical context. It examines the findings from the different elements of the research, draws a number of conclusions about the nature of the relationship between practitioner and medium, and more particularly about differences between individuals concerning their relationships with the medium and its role in their practice, and proposes avenues for further investigation.

If the following discussion reflects the frustration occasionally experienced when trying to disentangle the different threads within this research, I hope it also illustrates the insight which can be gained from comparisons across different fields.

Critical and practical context of the research

Comparative disciplines

This research has drawn on three very different fields of practice in the development of its thesis: 3D material/digital design practice, writing, and programming. It has shown that, while the fields may be different, studies in each reveal a similar range in the underlying approaches taken by individual practitioners. Although writing and computer programming may at first appear to be quite different fields to 3D design practice, there are a number of reasons why they are appropriate for this comparative role. My research concerns the entire design-make process; I am interested in examining cases in which individuals undertake the whole process, partly because this is a situation in which individual differences in approach emerge. Writing and programming share a similar ‘design and make’ context. Writing in particular provides a good comparative discipline, because there are studies in both writing and design which propose not only similar models of the creative process and the relationship between practitioners and artefacts (or similar explanations of differences between individuals), but each has a range of similarly different models of the creative process. The diversity of commentary on differences in approach adds to the strength to the argument: if similar differences in approach appear in two disciplines, it adds weight to the probability that they will appear in a third. A comparison between descriptions of these differences in approach in diverse fields allows one to illuminate another, adding clarification, or highlighting aspects which may not be immediately obvious. Further use of this type of comparison is made later in this chapter to gain additional insights into the structure of relationships between the various dimensions of difference that can be observed in individuals’ practice.

Writing and computer programming are useful and appropriate fields for comparison for other reasons. Most people who read this thesis will have some experience of writing (whether as ‘planners’ or ‘discoverers’...), forming a point of common understanding. They are both disciplines in which the ‘planner’ approach has often been viewed and taught as the ‘right’ approach (particularly in computer programming). However, there are programmers such as Casey Reas who describes software as “a medium”, and “each programming language as a material with unique affordances and constraints” [Reas

2004]. Part of the motivation behind this research is to identify those aspects which should be considered in the design of the next generation of digital media, therefore the discussion of differences in another digital context is of interest.

Defining ‘difference’

Readers may respond to this thesis by saying, ‘of course people are different and do things differently’, but I would suggest that our ideas about individuality between design practitioners (or indeed any creative practitioners) are often rather undifferentiated. Some may relate more to personal style - the unique quality which makes it possible to recognise work as belonging to a particular practitioner - rather than to quite different approaches; in a class of student practitioners, for example, it quickly becomes possible for class members to identify each other’s work (the reader is referred to a discussion of the use of the term ‘style’ in Chapter 1, p. 9). Art and design education emphasises the importance of developing this individuality of expression – a unique ‘voice’. These notions of difference relate to Schön’s model of design, where he recognises the uniqueness of each individual’s practice, but the differences he discusses arise from the personal and situational context within which the practitioner is working - their unique ‘design world’ - rather than wholly different approaches to design, reflecting different relationships between individual design practitioners and the artefacts and media they work with within their creative practice.

Other readers may argue that, ‘of course we know there are differences’, citing comparisons between design and craft, between those who work analytically and those who work intuitively, between ‘thinking’ and ‘doing’ (like Hoban’s descriptions of Muskrat and Manny Rat in the *Prologue*). However, while people may agree that these different approaches exist, they may not have considered more deeply why people would use these different approaches, or what it actually is that causes them to be different. They may assume that the fundamental differences between these ways of working and knowing are embedded in the physical context of the real world. They may therefore confuse approach and context, and classify a practitioner as a ‘designer’ or ‘maker’ because of the type of work they’re doing, or the context in which they’re working. However, Chapter 6, *Concepts of dialogue in design*, illustrates that practitioners in quite different fields can also experience a close relationship with their medium, whether that medium be software or language. The Practitioner Interviews in Chapter 8 indicate that even between practitioners who appear to share a close relationship with the medium, this relationship may not be the same, as the role of the medium in their practice may be

different. An examination of approaches within the group of students working with physical media revealed the important distinction between those students who originally appeared to be what I would originally have termed ‘making’ – working directly with materials at the bench to create a piece – but who, as revealed through further discussion, were actually using materials more as a medium for design.

Most significantly, this research suggests that the relationship between practitioner and medium encompasses ways of working and knowing which can be dissociated from the material context of the real world, and brought into new spheres of practice.

Some studies discussed in Chapter 3, *Artefacts and the design process* explored the relationship between differences in designers’ processes and the quality of the outcome: this research makes no link between choice of approach and quality of output, but shares the stance of Turkle & Papert who observed that computer programs produced by bricoleur-style programmers could be just as elegantly structured as those produced by ‘conventional’ programmers, but that the process used to arrive at them was different.

“...the differences between planners and bricoleurs is not in quality of product, it is in the process of creating it.” [Turkle & Papert 1991]

This research has focused solely on differences between individuals regardless of gender. Although Turkle & Papert found that there may be some gender differences in preferred approach, these were not absolute:

“...the elements of each cluster [‘hard’ and ‘soft’] are not invariably associated with each other; still less are they invariably associated with gender. But in our observations of people learning to program we have found an association between gender and approach to programming. When people are free to explore programming without preconceptions about the ‘right’ way to do it, more women use soft approaches and more men hard approaches, although many men are alienated from the dominant engineering style and many women work creatively within it.” [Turkle & Papert 1991]

For this stage of research, my main interest has been in identifying individual differences that can be observed in groups of design practitioners, rather than linking these to gender. In the Artefact Study where all the participants were female, differences in approach could still be observed. In the Comparative Study, where one group was all female and the other was mixed, similar differences in approach could be observed within each group, and neither seemed to be skewed heavily in one direction. (Indeed, my expectation before these studies would have been that any skew would have been towards the ‘hard’ approach in the digital environment, and a ‘soft’ approach in the physical environment, resulting from the commonly perceived differences between the two environments.) The fact that differences in approach appeared within all-female contexts

might have certain implications in the broader context of this research. However, within the existing limitations of the analysis as regards the comparison of individual approaches, and as the gender ‘dimension’ within the data has not yet been explored, it is not possible to comment further at this stage.

Attitudes towards the digital as a medium

The broad contextual motivation for this research is to bring a deeper understanding of the working processes of creative practitioners to the development of future digital environments for creative practice. The research has revealed a number of attitudes towards the role of computer systems in creative practice.

While discussing her use of Alias’s industry standard 3D modelling and animation software, one of the students in the digital group in the Comparative Study, who had previously worked with physical media, commented:

“...you can't take a tea bag into Maya. It doesn't go in!”⁶⁴

This light-hearted remark encapsulates many reservations that practitioners may have about the digital as a medium: its immateriality, its intangibility, its distance from the real world. For those used to working in material practice, a dialogue with the digital medium might seem a remote possibility. It may be difficult to envisage using the same approaches to digital media as you would with material media, or appear that your range of approaches is more limited; yet interviews with practitioners working with different types of digital media show that while the processes and techniques may be different, their approach to the digital medium is in line with, and largely derives from, the approach they used with physical media. PractC, for example, now sees little difference in his ways of working between physical media and digital media.

PractB described how, in his experience, some practitioners come to computer systems within creative practice with an expectation of making the process easier, or to solve problems in their practice. Linked to this approach is a tendency to focus on the current perceived limitations of the technology in terms of comparing it to physical materials: the ‘won’t it be good when...’ scenario. He sees this viewpoint as problematic, as it precludes practitioners from exploring the possibilities inherent within the medium. This reflects the contrast between the view of the digital as a tool to simulate reality, or as a medium in its own right with unique properties to be explored. It also emphasises a point

⁶⁴ Digital student 1, interview 1

which will be familiar to those working with physical media, but may be less obvious to readers from other fields, that a medium may be used both as an abstraction/representation of another one, or for its own sake.

The spectrum of approaches which can be observed in the group of students working with digital media is similar to that visible in the group of students working with physical media, suggesting that although some students do not find the digital medium as intuitive as working with physical media it does afford a broad variety of ways of working. These may not be the *same* ways of working, but it is this aspect that is of particular interest; how ways of working and knowing can be dissociated from the material context of the real world, and brought into new spheres of practice.

Design processes and creativity

In the *Introduction*, I explained that this research is not concerned with what might be termed ‘design processes’ (e.g. the patterns of and relationships between analysis, synthesis and evaluation, or divergent and convergent thinking in a practitioner’s process), or ‘creative cognition’. Although these aspects may be an element of the individual differences in which I am interested, they are not the territory of this research.

This distinction may shed light on some observations that I had made in the Artefact Study: firstly, a number of students’ approaches changed depending on which exercise they were doing, particularly if they were recalling things from memory; secondly, while a number of students expressed preferences for ways of working in the various exercises within the study, these could not necessarily be correlated to preferences for ways of working in their design processes. One student moved from a more narrative approach to a brainstorming technique, while another moved from a narrative approach to making lists. Another student appeared to change approach quite markedly between the ‘responsive’ exercises and the design exercise in the Words study, because she ‘was designing’. There may be a number of reasons for this: for example in the ‘responsive’ exercises the students were being asked to use the different types of media to respond to something – an object, a person, a memory – whereas in the design exercise, they were creating something new.

These differences with an individual’s responses could be seen as contradicting my conclusion from the Practitioner Interviews that a practitioner’s approach is consistent across media, yet the two things are actually quite distinct: in the Practitioner Interviews, I was comparing the same activity in two different contexts, physical and digital; in the

example from the Artefact Study, I was examining different activities in the same context. In another case the student commented that she normally did use words to an extent in designing, but had not found in the Words design exercise that it had sparked off any ideas: this may have been because ‘words’ were playing a different role in the workshop context, or being used in isolation.

In the context of this research it is to be expected that practitioners will use media in different ways depending on what they are doing: using a computer system to design an object is quite different from using it as a medium, for example. In Sharples & Pemberton’s study of writers discussed in Chapter 6, *Concepts of dialogue in design* they frame the writing process as a sequence of steps (not necessarily linear) through different external symbolic representations which facilitate different cognitive processes. In the *Comparative study* (Chapter 7) it is apparent that students use different media for different stages of the process.

Even though the two observations are therefore not contradictory, it is worth emphasising that you can’t make assumptions that the way someone will use a medium in one type of activity will be the same way as in another type of activity. This does not preclude the fact that individuals may use different media for the same activity, or engage in entirely different activities, which is the concern of this research.

The Artefact Study does not provide enough evidence to make clear exactly what the relationship is between the ways in which an individual might use a medium for a particular activity, and how they might relate to it (e.g. in the Artefact Study where participants appeared to have a subjective or objective approach to the items they were responding to, or whether the physical materials were foregrounded or backgrounded in their responses). The comparative framework derived from the literature includes indicators which appear to address both aspects, such as a planned or emergent approach to work, and people’s ways of ‘seeing’ or relating to objects; however, it does not examine in detail the patterns of activities such as analysis/synthesis/evaluation that might normally be considered as ‘designing’.

It is therefore worth making the distinction in this research between the term ‘approach’, which concerns the practitioner’s relationship with the medium, as distinct from the term ‘process’, which concerns these different activities.

Summary of main conclusions

The characteristics of a medium are not absolute

The previous section suggested that an individual practitioner may use the same medium differently for different activities. This section proposes that the characteristics of a medium are tied even more closely to each individual practitioner.

One of the most important conclusions that can be drawn from this research is that the characteristics of a medium are not absolute, resulting from notional inherent properties, rather they are defined through a practitioner's relationship with the medium. (This is different to Brereton's observation that "the problem context derives what attributes of an object people notice and in which ways they try to use an object" [Brereton & McGarry 2000]: I'm claiming that for different people even in the same context, the characteristics of a medium would be different.) This conclusion is supported by findings from all four studies in this research.

In the Artefact Study, the range of artefacts that were produced by the group of students within each exercise suggests that individuals used the same 'type' of artefact quite differently. The apparent taking of a subjective or objective approach towards source objects, and the ways in which the material aspects of the medium seemed to be foregrounded for some students, also suggests that the characteristics of an object or medium which are important to one individual may be quite different to another.

While this is not as strong a position as saying that the characteristics of a medium are defined through a practitioner's relationship with it, Turkle & Papert bring this closer in their description of the different ways in which the students they studied related to the objects they worked with: 'hards' see them formally, as what they are for, while 'softs' see them concretely, as what they can do.

Similarly different approaches and ways of relating to the medium could be observed within the group of students in the Comparative Study who were all working with the same (albeit large and complex) digital medium. While some students viewed the medium as a means to an end, others engaged with the medium, and worked with the effects that arose through experimenting with what the medium could do. Similar differences can be observed in the different approaches to learning the software that could be observed within the group: those who preferred to learn what tools were for before using them, and those who played with the software to see what it could do. Although

the group of students working in the physical environment were using different media, processes and techniques, the approach of many students in exploring their chosen medium to develop a repertoire of processes and techniques, some quite different from ways in which the medium might conventionally be worked, also supports this premise.

From the descriptions of the working processes of the three practitioners interviewed (see Chapter 8), it becomes clear that a medium's characteristics cannot be derived from the medium in isolation, but are, and must be, defined in relationship to the practitioner. In these cases the 'conventional' characteristics of digital media are not necessarily those used or experienced by the practitioners: for example, geometric primitives in 3D modelling software are normally regarded as abstract entities, but PractC treats them like materials, albeit with mathematical rather than physical properties, manipulating them in a direct, spontaneous and intuitive way. This way of approaching the software is possible because he is not using the medium as a representation of 'real' objects, rather he is working with the qualities of the medium as they reveal themselves through exploration. This approach is similar for all three practitioners: they are questioning the medium, engaging with it - using the qualities it possesses as a medium, 'finding its edges', exploiting its limits, using unintended effects, rather than as a tool for simulating reality - each within the context of their own practice. This type of approach is not conventional, and results in the digital medium being used in ways other than for which it is intended, or beyond that for which it was 'designed'. The point that the characteristics of a medium must be defined in relationship to the practitioner is reinforced in that what one practitioner highlights as differences between the physical and digital media they are using may be quite different from another's experience. PractA's use of metaphors such as 'vocabulary' and 'palette' when describing her relationship with the medium, emphasises the close identification between some practitioners and the media they use.

Individuals relate in similar ways to different media

The previous two sections have proposed (a) that an individual practitioner may use the same medium differently for different activities, and (b) that a medium's characteristics are not absolute: they cannot be derived from the medium in isolation, but are, and must be, defined in relationship to the practitioner. This section argues that an individual practitioner will relate to/approach different media in similar ways.

The tentative findings from the Artefact Study, where differences observed within the collective data included a subjective or objective approach to objects, or where for some

students, materials in all the exercises seemed to be ‘foregrounded’ (i.e. whether the exercise used words, markmaking or materials), suggest that individuals may approach different ‘types’ of artefact or medium (1D/2D/3D) in similar ways. However, a direct and rigorous comparison between individuals’ approaches to the different media would require further analysis of this data. Although some students in this study expressed a preference for working with one type of medium over another, this does not preclude the fact that they may approach both media in the same way.

In the Comparative Study comments from some of the students working with the digital medium who had previously worked with a physical medium, also support the argument. One remarked that for him, although the medium was different, the “philosophy, the way of thinking” carries on. For another student who had been used to gathering physical objects for her work, although that wasn’t possible in the digital medium she found an alternative way of achieving a similar approach:

“...every single texture symbolised something, like the fact that she had a jumper on that had stripes that looked a bit like a fence, or barbed wire - she was divorced from reality... So, you know, I got it in there. But in a completely new different way, as in it wasn't the actual things, it was symbols of things, instead.”⁶⁵

In the Comparative Study some students in both groups expressed preferences for working in three dimensions as opposed to two, as this allowed them to more successfully express ideas they could already see clearly in their heads. One student described how,

“I have it all in my head and I'm not so good in doing a storyboard because, I have a picture of the cameras, I have a picture of the movements of the characters but, when I'm doing a storyboard I (find?) like limited in the 2D paper, so I prefer to take it to the 3D...”⁶⁶

However, this does not necessarily imply that individuals might relate in different ways to different media, particularly as in the cases above the two-dimensional medium was being used as a design medium, rather than the medium within which the work was being produced.

From the examination of the working processes of the three practitioners described in Chapter 8 it is clear that, in all cases, their approach to the medium in their digital practice is in line with, and largely derives from, the approach they used in the physical environment. This is not to imply that they use similar techniques and processes in both environments (the media are different, after all!), but that their overall approach to the

⁶⁵ Digital student 1, interview 3

⁶⁶ Digital student 4, interview 1

medium is consistent across both. As described above, all of them were questioning the medium, pushing its boundaries, ‘finding its edges’, and crucially, using the qualities it can possess as a medium, not as a tool for simulating reality.

While this is certainly true for the three practitioners that I interviewed for this study, for all those interviewed the materials played an important role in their practice and they had what could be classified as a ‘close’ relationship with the media they used (although the roles and relationships still differed in a number of respects). However, given that practitioners who see a medium as a tool to be used to achieve a particular end might tend to have a more objective approach to a medium in any case, it could be argued that their approach is less likely to change as a result of a change in medium. This is supported by a comment from one of the students in the Comparative Study about the software he was using:

“I see it as a tool like anything else. The way I look at a pencil and a bit of paper, they're just tools to produce something that's in my head, and I see the computer as the same”⁶⁷

It might be argued that the three practitioners interviewed have chosen media which can be approached in this way i.e. they might take a quite different approach with other media. Yet PractA’s description of her initial frustrations in getting to grips with the software she was using shows the struggle she went through to achieve this type of relationship with the medium, and would argue against the position that difficulties in using one approach with a particular medium would result in a change in approach. It could be true that practitioners see potential in some media that they wouldn’t see in others, but they might nevertheless approach them in the same way.

There are differences between individuals in the ways that they relate to the media with which they work

While the previous sections have focused on clarifying aspects of the relationship between a practitioner and the medium with which they work, this section discusses the differences in this relationship which can be observed between individual practitioners.

Initial enquiries concerning practitioners’ preferences for working in two or three dimensions to generate design ideas [Chapter 5] suggested more fundamental differences between individuals in their relationship with the medium with which they work, relating to their relationship to the medium and its role in their practice; in particular, they

⁶⁷ Digital student 10, interview 2

identified differences concerning a subjective or objective way of relating to objects; whether materials played a foreground or background role; and the extent to which a design was expressed in or derived through working with the medium.

Although little design literature has examined individual differences of this nature [Chapter 3], there exist studies of writers and student programmers which discuss variation in individual approach which resonated strongly with what I had observed in previous research, and with the tentative ideas emerging from these early enquiries. They discuss individual differences which can broadly be described in terms of the nature and extent of a dialogue between practitioner and medium [Chapter 6].

A systematic analysis of this literature suggested the formal/concrete axis as organising principle for differences in approach, across disciplines and different levels of practice [Chapter 7]. This analysis was used to derive an analytical framework based on the notion of ‘ideal types’: two distinct approaches – ‘hard’ and ‘soft’ - representing each end of a spectrum (see p. 130 and Table 6 p. 131 for more detailed descriptions of each approach). The framework is therefore two-dimensional, categorising individuals as one of (or neither i.e. somewhere on the spectrum between) two approaches, which are expressed through a number of different characteristics or ‘dimensions of difference’, where the internal coherence of each approach is reflected in the logical relationships between these dimensions of difference.

Taking this framework as the basis of enquiry, an investigation was made into whether similar differences in approach could be observed between two groups of student 3D practitioners, one working with physical media, one with digital media [Chapter 7]. A comparison between individuals across all aspects of their approach, using the framework, suggested that differences, broadly along the lines proposed, existed within each group, with a similar spread of approaches in both groups.

However, an examination of the collective variation within each group revealed relationships between different dimensions within certain individuals’ practice which were not consistent with the original framework. It identified differences within the *collective* variation along the lines of the framework: a preference for a planned or emergent approach; a preference for control, or a willingness to take risks; those who see the medium as a means to an end, and those for whom the means become the end; the extent to which the materials are chosen to suit a particular design, or whether the design is determined by the materials which are available; their different relationships with the

medium, including distance or closeness in relating to the artefacts they create and work with; those whose idea generation or development is done largely ‘internally’, or those who achieve it through external means. However, how these different dimensions logically related to one another within an *individual’s* approach did not appear to be completely described by the two-dimensional nature of the framework.

In particular it identified instances where an emergent approach did not equate to a ‘dialogue *with* the medium’, as inferred by the original framework; rather it could be described as a dialogue *through* the medium’ where the emergence relates to the conceptual idea or design, rather than an exploration of the properties of the medium.

Another related dimension which is not adequately explained by the original framework concerns the ‘choice of materials’. In the framework, this dimension broadly distinguished between whether the materials are chosen to suit the design, or whether the design is determined by what materials are available. On closer examination, further variation could be discerned within this spectrum, relating to at what level of process and how ‘material’ constraints arise. At a ‘practice’ level, some students worked within a *repertoire* of skills or processes, while others worked also within a *palette* of existing materials. At the level of the piece of work or artefact, some students built elements of a piece, then arranged and rearranged them to achieve the final form of the work. There were also cases where students were working with elements which had already been defined (like found objects), but which they had selected rather than defined themselves. For others, the piece largely emerged from working directly with the medium, and from what the medium can do. The main distinction appeared to be whether the ‘materials’ and elements were *defined* or *selected* by the student.

A further decoupling of dimensions arises from the observation that an ‘external’ approach did not necessarily equate to an emergent approach.

Without a more formal means of comparing the relationships between dimensions within each individual’s practice (see p. 171) it is not possible to determine, at this stage, whether these differences in approach simply represent different positions on the existing ‘hard’/‘soft’ spectrum, or indicate two wholly different spectra of approach, one at the level of representation, and one at the level of the artefact.

The interviews with practitioners [Chapter 8] also revealed differences between approaches which would be classed as similar in terms of the original framework. All three exhibit elements of the ‘soft’ approach: a focus on exploration or tacit aims rather

than explicit goals; an openness to unexpected possibilities; the importance of the medium in their practice and their approach to it - actively engaging with the medium, and using its inherent qualities, rather than using it to represent or simulate reality; exploiting unpredictability and unexpected effects; and using the medium in ways other than for which it is intended, or beyond that for which it was 'designed'; exploring the digital medium in very different ways from its conventional use; and what might normally be considered limitations actively contributing towards their developing practice. Yet a more detailed examination revealed distinct and significant differences between practitioners, concerning the role of the medium within each practitioner's practice.

PractA describes her relationship with the medium, and its role in her practice, using strong metaphors of language. Her approach to each medium she uses – questioning it, understanding it – is related to the idea of becoming familiar with it as a language: how it works, what its characteristics are, what you can do with it, what you can say with it. In PractB's work and practice, the medium's role appears to be to reflect back our ways of seeing, ways of thinking, ways of experiencing, to make us aware of our unconscious assumptions about the world. PractB's relationship with his chosen digital medium therefore appears to be qualitatively different from PractA's: PractA sees her relationship with the medium in terms of language, making it almost part of herself; PractB seems to relate to it as something 'other', a means of doing 'interesting things' and of 'rethinking the world'. The role of the medium in PractC's practice is again subtly different from PractA and PractB. PractA's relationship with the medium is one of language; PractB's one of challenging assumptions. But PractC is very definite that he 'doesn't have anything to say', he's not asking questions. Rather, he describes his process as speculative and disinterested, about "exploration and discovery". This defines the medium as 'other' rather more markedly than PractB. In his subjective explorations of the medium, with their emphasis on discovery rather than invention, realising rather than recognising, PractC sees himself not as looking for something specific, but responding to things he sees, not giving meaning through creating objects, but deriving meaning from the objects he finds and brings into being through his explorations.

PractA's process is closely related to her relationship with the medium: a tacit, organic approach, 'playing and pushing', in which the work evolves, guided by a sensibility, what she describes as a journey drive by a feeling. In PractB's practice the process seems to be less closely related to his relationship with the medium - there seems to be less explicit

focus on process, more on content, or ‘intent’ - but he does nevertheless have a process in which the medium is allowed to play a important role. Perhaps more than for either PractA or PractB, the medium plays an immediate and crucial part in PractC’s practice. This ‘otherness’ of the medium, together with his speculative, exploratory and responsive approach, defines the reciprocal relationship between him and the medium which is fundamental to his practice, and to the form of the work which is, in a sense, not created but ‘realised’: ‘wrestled into being’ through working with the medium.

Although there are similarities between these approaches, as described above, nevertheless they seem to be qualitatively different. Drawing comparisons between PractA and PractC in particular, this relates to whether the medium is closely identified with ‘self’, or viewed as ‘other’; whether the process is ‘purposeful’, where the work evolves through questions/enquiry driven by a tacit aim, or ‘disinterested’, where the work arises through speculative exploration and discovery through a reciprocal relationship with the medium; whether the process could be described as a dialogue *through* or *with* the medium.

These studies demonstrate that important underlying differences exist between individual design practitioners, concerning their relationship with the medium with which they work, and its role in their practice. However, while elements of these differences in approach are described by the original framework, with its formal/concrete axis, others are not.

Do the findings of the research support the thesis?

This section examines in more detail whether the findings of the research support the thesis:

that individual practitioners experience different relationships with the artefacts they create and work with in their processes, and that elements of these differences can be attributed to the nature and extent of a dialogue between designer and media

As discussed in the previous section, while the ‘dimensions of variation’ within the data are largely in agreement with those in the framework, the data diverges from the framework in terms of the ‘structure of variation’, i.e. how these dimensions relate to one another within an individual’s practice. (Although the analysis of the data presented here does not permit the formal connection between these dimensions within each individual’s practice to allow a rigorous comparison between individuals across all the ‘dimensions’

of their approach, an examination of selected dimensions with certain individuals' approach reveals aspects which diverge from the original framework.)

There appear to be two main ways in which the data diverge from the original framework: firstly, where individuals have both 'hard' and 'soft' elements in their approach (e.g. where a student appeared to have an 'external' approach, yet the form of the work was predetermined before it was made); and secondly, where the approaches as defined by the framework do not accommodate all the variation that can be observed.

Although Turkle & Papert categorised their 'hard' and 'soft' ideal types in terms of clusters in which an individual's style of organising work and their relationship with objects are closely related, this does not exclude the possibility of finding examples where they are not:

“Empirically, we sometimes find each aspect of soft mastery – bricolage as a style of organization and closeness to the object – without the presence of the other. In particular, one finds people who are planners but who enjoy a close relationship with concrete objects (and who experience computational objects this way).” [Turkle & Papert 1991]

In some cases, Turkle & Papert argue that this does not reflect the individual's underlying preference, rather it is an approach adopted to operate within a particular situation.

“But although closeness to objects favours contextual and associational styles of work, it does not exclude the possibility of using a hierarchical one. Planning is not always an expression of personal style. It can be acquired as a skill, sometimes because it is needed to get a job done, sometimes as a façade to hide rather than express individuality.” [Turkle & Papert 1991]

Turkle & Papert's description of such cases suggests a more fundamental adjustment than simply an automatic change in approach to suit whatever situation an individual is working in:

“Some bricoleurs respond to the dominant ethos of the computer culture by entering into an inauthentic relationship with the computer. This can lead to a paradoxical reaction: frustrated bricoleurs appear at first sight to be extremely rigid planners... When denied a chance to do their 'real thinking', they turn to rules that do not require them to think at all.” [Turkle & Papert 1990]

From the examination of the data presented here, it is not possible to state whether or not 'crossovers' between hard or soft approaches in this research are primarily the result of personal preference or 'imposed' choice. In the case of the student who appeared have an external approach (working with collage in the early stages of the process) yet predetermined the form of her work through storyboarding, although she commented that it is accepted practice,

“...everybody says you must have a storyboard, work and stick to your storyboard, so it has to be quite a rigid structure I imagine, that you need to get it down the line at the start, and try and stick to it...”⁶⁸

there was no strong sense that she was struggling against a process that was being imposed upon her:

“...I have to have it down in 2D, which sounds odd if you're working in 3D to have to have it down in 2D straight away but it's just the normal working practice. But I have seen people going straight to computer, which seems very odd for me... I can't imagine coming up with an idea and not being able to sit down with a paper and pen and take it as far as I can go before even approaching the computer.”⁶⁹

However, a closer examination of all the data would be required to say whether this was the norm, or the exception.

Examples where the framework does not accommodate all the variation that can be observed (particularly within the ‘soft’ approach) could be seen in both the Comparative Study and the Practitioner Interviews, and concerned the following aspects:

- *emergent approach*: differences relating to whether the emergence relates to the conceptual idea or design, or an exploration of the properties of the medium
- *choice of materials*: differences (both at the level of the process, and the level of the piece) relating to whether material constraints are *defined* (repertoire of techniques and processes; physical elements) or *selected* (palette of materials; components or materials) by the practitioner
- in terms of the overall role of the medium, whether it is viewed in terms of ‘self’ (e.g. language, vocabulary) or as ‘other’
- where the practitioner is working with the medium, whether this is guided by a tacit aim (‘a journey driven by a feeling’), or is exploratory and speculative

Some of these differences may be, or be similar to, dimensions that already exist within the framework, for example working with ideas or working with the medium; a focus on goals or discovery; acting upon or engaging with the medium. The difference here is that the relationship between them is not as defined in the original framework.

The main question is whether they simply represent different positions on the spectrum between the ‘hard’ and ‘soft’ approaches, as in Figure 70, or are indications of an entirely different relationship between various dimensions within the original framework (i.e. an alternative ‘structure of variation’ to its current two dimensional nature).

⁶⁸ Digital student 2, interview 1

⁶⁹ Digital student 2, interview 1

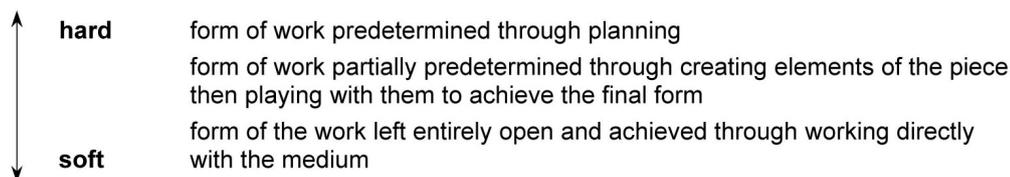


Figure 70: 'Hard' – 'Soft' spectrum

While the example above may solve the 'predetermined' dimension, it does not allow for a distinction between whether the emergence concerns the 'idea' (as would be the case with the predetermined elements) or the properties of the medium (the third case, above). In the Practitioner Interviews, the comparison of PractA and PractC's practice suggests that there may be alternative approaches within the third case in the above example.

A number of the observed divergences from the original framework can be placed in the relationship illustrated in Figure 71. It is quite possible that an individual might use elements from both columns in their work (for example one student in the S&J group used physical elements she had created as well as objects such as pearls, etc.), and another student who had a huge collection of materials from which she selected to use within her pieces, also was using a particular technique within her work; nevertheless it is likely that an individual might tend towards one or other of the columns.

	Relates to self / 'defined'	Relates to medium / 'selected'
Overall relationship to medium	as a 'language', identified with self	as 'other'
'Choice of materials' (material constraints) at process level	*'repertoire' of processes and techniques	*palette of materials
Partially defined elements	elements created by practitioner	components selected by practitioner
Working directly with the medium	using a 'language'	speculative exploration and discovery

* PractA's use of the term 'palette' is related more closely to the term 'repertoire' used in the discussion of the Comparative Study

Figure 71: self-medium

Although similar differences within the planned approach are not as obvious, there are aspects of certain individuals' approach which might be characterised in similar ways (see Figure 72).

	Relates to self / 'defined'	Relates to medium / 'selected'
Form of work predetermined	through drawing and sketching	through the use of collage, working with objects

Figure 72: Form of work

Rather than signifying an 'additional' dimension within both the 'hard' and 'soft' approach, these observations suggest that there may be a spectrum of approaches (similar in nature to the planned/emergent spectrum) which appear in each of these two different contexts. This would therefore support the idea of an entirely different relationship between the various dimensions within the original framework, as yet to be determined. One interpretation is that the two poles in the table above – 'relates to self' and 'relates to medium' – are actually a more accurate description of the 'internal' and 'external' dimension, or perhaps a separate but related element within it.

Without further analysis of the data, it is not profitable to speculate on what the actual structure of variation might be, or indeed whether within the entirety of the data these divergences might be less significant. However, they do suggest that the original two-dimensional structure of the framework is not adequate to explain all the differences in approach that can be observed within the data.

Regardless of whether the framework completely explains the diversity that can be observed within the data, it is clear from the findings of the various studies that individual differences in approach can be observed between individual practitioners; that aspects of these differences do concern a practitioner's relationship with the medium; and that elements of these differences can be attributed to the nature and extent of a dialogue with the medium. The studies therefore do support the original thesis:

that individual practitioners experience different relationships with the artefacts they create and work with in their processes, and that elements of these differences can be attributed to the nature and extent of a dialogue between designer and media

However, they also suggest that there may be additional elements which contribute to individual differences in approach, and that these and the variety of ways in which practitioners relate to the media with which they work require to be more fully explored.

Effectiveness of the research method chosen

The combination of theory-driven inquiry and the examination of themes which emerge from the data is one of the strengths of this research, and is in keeping with the overall

spirit of using the examination of difference as a means of inquiry. Rather than being viewed as a problem, the identification of a gap between these two elements is a positive basis for further research. The comparison between these two aspects of this research has allowed deeper insight into the phenomenon than would be achieved through each alone.

Much research tends to one of two different approaches: begin with a theory which is then tested by running experiments (while this approach allows you to test elements of the theory, it does not enable insights to emerge from the data); or take a purely emergent approach which focuses on themes that emerge from the data (and only later consider how it fits with the theory). Chapter 4, *Difference as a means of enquiry* describes how design research which takes the former approach, and which assumes that there is a single design method to be discovered, has been blind to individual differences in design practice. A combined approach, such as that adopted for this research, provides some safeguards against either extreme. Although the method used for this thesis is not entirely emergent, it nevertheless has many characteristics of a Grounded Theory approach: it uses the literature as data (developing the theoretical framework in Chapter 7); comparison within the data is fundamental to the process (as described in Chapter 4, *Difference as a means of enquiry*); and its ultimate aim is to find the theory which best fits the data.

In disciplines where a combined approach (examining what emerges from the data in opposition to the theory) is common practice it is quite normal to have a gap: when there are strong top-down and bottom-up elements to a body of research there are many reasons why the results from each won't match completely.

In this research there are at least three possible explanations as to why the data do not fit the framework: firstly, incorrect interpretation of the literature from which the framework was derived which, had it been interpreted correctly, would have fully explained the data (i.e. a structural problem); secondly, the difference in environment, i.e. 3D creative practice as opposed to writing or programming (i.e. an interdisciplinary difference); thirdly, the literature from which the model was derived does not provide an adequate explanation (i.e. a theoretical problem). The analysis reported here cannot make this decision. However, of the three explanations given above, an interdisciplinary difference is least likely. For this to be true, the framework succeeds in the other environments (writing, programming), but doesn't adequately explain this one. However, although the structure of variation seems not to be explained fully, the dimensions of variation that have so far emerged from the data are largely in line with those given in the conceptual

framework. Also, the ways in which the two diverge, while they may relate to the medium, could apply to any medium.

The contribution of this research to and implications of this research for a variety of audiences

This research has drawn on three very different fields of practice in the development of its thesis: 3D material/digital design practice, writing, and programming. It has shown that, while the fields may be different, studies in each reveal a similar range in the underlying approaches taken by individual practitioners. Further, it has made explicit a number of detailed ‘dimensions of difference’ which can be observed within these fields. (Although Turkle & Papert and Chandler discuss a number of ‘dimensions of difference’ within individual approach, these are not detailed explicitly in the papers reviewed for this research; the list of ‘indicators’ in Table 6 was derived from an examination of a number of publications by a variety of commentators.) However the broad comparative basis of this thesis has also revealed that the differences in approach identified in these different studies may not entirely explain the differences that can be observed between individual practitioners and their relationship with media. It has tentatively suggested an alternative explanation, and proposed that further research is necessary to address this variance.

Although this research has demonstrated the added insights that arise from the comparisons between these similar but different fields, this cross-disciplinary approach appears, certainly from the research reviewed for this thesis, to be the exception rather than the rule. Chandler does not discuss practice other than writing, although he, like Turkle & Papert, draws on Levi-Strauss’s concept of *bricolage*. Turkle & Papert’s concern is different approaches to knowledge and intellectual styles, focusing on programming as a particularly fruitful area of exploration given its cultural associations with ‘hard mastery’:

“... When we look at particular cases of individuals programming computers, we see a concrete and personal approach to materials that runs into conflict with established ways of doing things within the computer culture. The practice of computing provides support for a pluralism that is denied by its social construction.” [Turkle & Papert 1991]

Although Turkle & Papert make reference to musicians, writers and artists in examples, these are not discussed in any depth. Given their focus on an area where ‘hard’ mastery is the accepted canon, and their comment that “soft mastery has always had its place in

the discourse of the arts” [Turkle & Papert 1991], this is not unexpected. However, it should not be implied from this that approaches more similar to ‘hard’ mastery do not also occur in the arts.

One commentator who very deliberately draws links between writing and design is Sharples. In the second of his papers reviewed in Chapter 6, Writing as Creative Design [Sharples 1995], and in his subsequent book, How We Write, Writing as Creative Design [Sharples 1999], he discusses “the writer as a creative thinker and a designer of text”. Examining “how creativity occurs” and “the relationship between writers and their environment”, his focus is still mainly on cognitive aspects: the deliberate exploration and transformation of a writer’s conceptual space, and on processes of reflection (“the deliberate and cognitively demanding process of re-representing embedded processes and exploring cognitive structures”) and engagement (“the direct recording of conceptual associations”). Woodcock is also examining cross-disciplinary links in The Software Author as Designer [Woodcock 2005], looking at “programming as reflective practice” [School of Art and Design, Coventry University].

This research, with its focus across a range of elements of practice, therefore plays an important role in linking research in writing, programming and 3D design practice, and its findings have implications within a number of different areas. This research also offers a bridge between the ‘traditional’ design research community and the community of research into practice: those who both design and make. The examination of 3D practitioners reveals implications for the former, with its emphasis on design-by-drawing (see following section); and the research provides a more empirical view of the latter, a field which is largely characterised by practice-led enquiry.

Regarding theories of design, design research community

The findings from this research suggest that individual differences in approach do exist which are more fundamental than variation resulting from the personal and situational context of the designer, as described in Schön’s model of design as reflective practice; that the differences cannot adequately be explained by Louridas’ conclusion that they represent the same process but at different levels (metaphorical or literal), or by Sharples’ distinction of emphasis between different aspects of the same process (reflection or engagement). They support the view that wholly different approaches to design do exist, with several ‘dimensions of difference’ across different levels of practice, as proposed by Turkle & Papert; and further, as concluded by Chandler, that these are “not simply

different ways of describing the same experience: they represent quite different experiences reflecting basic orientations” [Chandler 1995].

This study has implications for researchers both in design and other fields, to be aware that individuals do vary in significant ways, and that there is not a single approach to design. Assuming there is one ideal approach to be discovered is to ignore important differences in the ways in which individuals approach work, and relate to the objects they work with. It should also be recognised that there is value in exploring not just ‘design’, but ‘design-make’ processes, as this is a good situation in which to observe individual differences in approach. Although an increasing number of practitioners are undertaking research, and aspects of this are being addressed in the context of practice, ‘traditional’ research into design processes has, to date, focused largely on the ‘design’ element.

Regarding creative practice

This research has a number of implications regarding creative practice: both for practitioners, but also for those looking at practice from the ‘outside’.

A common view of creative practice is that it is first and foremost about doing, rather than about analysing what is done. Involving as it does tacit ways of knowing, it can be imbued with an air of mystique. In comparison with computer programming, for example, it could be argued that in applied arts the primary product is the artefact: the ‘analysis’ may happen, but that is not what is delivered. In programming, in effect it is the analysis/underlying structure that is being delivered: the code is the vehicle by which this is achieved. However, this comparison is not as straightforward as it appears: a functional artefact embodies the decisions the practitioner has made about how best to deliver that functionality; a less functional artefact nevertheless embodies the considerations that have gone into its creation. (Indeed, the extent to which an artefact can embody and communicate knowledge is the subject of much debate around practice-based doctorates in Art & Design, and in conferences such as Research into Practice 2004, “What is the role of the artefact in art and design research?”.) Perhaps one difference between applied arts and programming is the extent to which the analysis or knowledge is made *explicit* in the final product. It may be true to say that practitioners are primarily concerned with doing, rather than with examining theories of how they do what they do. However it would be wrong to assume that practitioners do not consider their processes; this thesis contains examples of practitioners who have thought deeply about their practice.

This research has shown that differences exist between design practitioners that are more fundamental than simply personal style, and represent very different approaches to practice (the reader is referred to a discussion of the use of the term ‘style’ in Chapter 1, p. 9). Further, it has demonstrated not just that there are differences, but provides an explanation of what these differences might be.

It has pointed out the pitfalls of assuming that these differences can be explained by comparisons between ‘design’ and ‘craft’. In particular it challenges any assumption that the fundamental differences between these ways of working and knowing are embedded in the material context of the real world: practitioners in quite different fields can also experience a close relationship with their medium, whether that medium be software or language; differences in approach exist that do not simply relate to working at the level of the representation or the medium; and even between practitioners who appear to share a close relationship with the medium, this relationship may not be the same, as the role of the medium in their practice may be different. It warns against confusing approach and context, and classifying a practitioner as a ‘designer’ or ‘maker’ solely by the context in which they’re working. It illustrates the spectrum of approaches used by those who design and make, and demonstrates that the conjecture I had made at the beginning of this enquiry - that the differences concerned whether work was ‘design-led’ or driven by an ‘exploration of techniques’ - is not sufficient to explain all the differences that could be observed. It stresses the importance of recognising the distinction between ‘making’ – working directly with materials at the bench to create a piece – and using materials as a medium for design. This last aspect illustrates a point which may be less evident to readers outwith the field of design, and which is amply demonstrated through this research, that a medium may be used as an abstraction/representation of another one, or for its own sake. This is true not just in the physical environment, but also in the digital, and is particularly evident in the Practitioner Interviews.

While this research has mainly concerned differences in the way individual practitioners relate to the medium with which they work, it also reveals other important aspects of the relationship between design practitioner and medium. It proposes that an individual practitioner may use the same medium differently for different activities. More importantly it concludes that the characteristics of a medium are not absolute, resulting from notional inherent properties, rather they are defined through a practitioner’s relationship with the medium. It demonstrates that an individual practitioner will relate to/approach different media in similar ways.

These findings support the position that creative practitioners have markedly different approaches to practice, and that when looking at ways of fostering creativity (or particularly when debating what ‘creativity’ is or how it can be understood) these differences should be recognised. It also has implications for educators in creative practice to acknowledge differences in approach, and the breadth of practice that needs supported (this may be particularly challenging in the digital environment). On a more personal level, if you’re a student who finds that the way design practice is taught doesn’t seem to ‘fit’, it doesn’t automatically mean that there is something wrong with *you*; it may be that an alternative approach would be more effective.

Regarding the application of digital technologies in design and creative practice

While some of the observations in the previous section may be familiar to those who practice, they may be less familiar, and therefore of more significance, to others exploring the ways in which digital technologies can be used within or as a medium for creative practice.

Many recent developments in digital technologies to support creative practice have focused on replicating and extending the ways in which creative practitioners currently work with materials, or in harnessing the potential benefits that can arise from combining the capabilities of computer systems with the traditional skills and working methods of artists and designers [Chapter 2]. Systems like these often reflect the belief that ‘hands-on’ access to materials is very important to makers/creative practitioners, and should be replicated when developing new digital environments for design.

One of the most striking aspects of the interviews with creative practitioners now working in digital media was that not being able to be physically ‘hands on’ with the medium, and not working with physical materials, appeared not to be a big drawback; moreover, as PractB commented, aiming to emulate that aspect of work when interacting with digital media is not without problems, both technical and philosophical. Other aspects, such as achieving a sense of ‘immersion’ characteristic of a maker’s relationship with their materials, were more important.

Also, many makers’ ‘hands-on’ interaction with physical media is mediated through tools: PractC, as a sculptor, is familiar with mechanical processes; for him, working with the software is, in a sense, a mechanical process. This is not to say that being able to work with their hands is not important to some practitioners, but to recognise that a number of factors may contribute to this perception including the ability to manipulate

things directly, the immediacy and responsiveness of the medium, the ‘physicality’ of objects, as well as the physical ‘hands-on’ interaction.

This research has also demonstrated the importance of taking into account the less ‘tangible’ aspects of the relationship: for example how a practitioner approaches the medium, and its role in their practice, particularly as the characteristics of a medium are defined in relation to each practitioner. The ways in which the three practitioners interviewed approach their digital medium is in line with, and largely derives from, the approach they used with physical media. However, this does not imply that the way to design new digital systems for the use of creative practitioners is to replicate existing techniques and ways of working with materials. These practitioners’ approach to the medium was to question it, engage with it, use the qualities it possesses as a medium, ‘find its edges’, exploit its limits, and take advantage of unpredictability and unexpected effects. A valuable lesson here is that practitioners, particularly those using the digital as a medium rather than as a tool for simulation, will use the medium in whatever way they see fit; this may result in the medium being used in ways other than for which it was intended, or beyond that for which it was ‘designed’.

This does not mean that the ways in which we interact with computer systems could not be improved; a number of practitioners and students interviewed during this research commented on aspects of the software interface which they found frustrating. But while the goal of designing interfaces to make them more intuitive for creative practitioners (and indeed all users) may be commendable, it is not merely a matter of replicating the ways in which creative practitioners currently work with materials: the role of the medium in one individual’s practice may be quite different than in another’s; individual practitioners will approach and use a digital medium in different ways; and what one practitioner may find frustrating about working with a medium may be someone else’s creative springboard.

This research illustrates that digital media afford a broad variety of ways of working. These may not be the *same* ways of working, but it is this aspect that is of particular interest: how ways of working and knowing can be dissociated from the material context of the real world, and brought into new spheres of practice. It also emphasises that the digital is not just a tool with which to simulate reality, it is a medium in its own right with unique properties to be explored.

At a philosophical level, approached with the desire to simulate reality through representation, or through devising systems whereby it is possible to work with digital media in the same ways as we can with physical media, a digital medium embodies our assumptions about the how we see, experience and relate to the world. When its inherent qualities and limitations are explored and exploited, it has the potential to reveal our assumptions about the world, and to allow us to rethink our experience of and relationship with the world.

Regarding programming

There may be readers with a background in computing science who would equate the different approaches discussed in this thesis to the ‘top-down’/‘bottom-up’ distinction in approaches to programming. However I believe that this does not adequately describe the range of approaches used by the practitioners studied within this research. If the differences did equate to the top-down/bottom-up distinction, a bottom-up approach would equate to an emergent approach. However, the results from the studies suggest that there are two quite different types of emergent approach, relating to whether the emergence relates to the conceptual idea or design, or an exploration of the properties of the medium. This suggests either that the top-down/bottom-up dichotomy is not applicable in this case, or that it does not in itself adequately describe the range of programming approaches.

The main distinction that Turkle & Papert appear to make is between ‘structured’ programming and bricolage. The terms they use when describing the former include planning, black-boxing, rule- and plan-oriented, abstraction, logic, hierarchy, analytic, divide-and-conquer, modular solutions, dissect problem, assembled from sections/parts, specification in advance, clear plan defined in abstract terms. These are in contrast to bricolage, “a style of organising work that invites descriptions such as negotiational rather than planned in advance, what Warren McCulloch describes as ‘heterarchical’ rather than hierarchical” [Turkle & Papert 1990]. However, although Turkle & Papert use the phrase ‘top-down’ in some of their examples of the formal or hard approach, it cannot be assumed that the differences which they discuss between planners and bricoleurs equate to the ‘top-down/bottom-up’ dichotomy. I don’t believe that the ‘soft’ approach which Turkle & Papert describe directly equates to a ‘bottom-up’ approach.

There are commentators from within programming who propose a wider spectrum of approaches than the ‘top-down’/‘bottom-up’ dichotomy. Rebecca Mancy describes three

‘modes of programming’: top-down, bottom up and ‘interactive’ [Mancy 2004]. She distinguishes between a ‘bottom-up’ approach, where elements of a program are built before considering the final structure, and an ‘interactive’ approach, where you “build a simplified version of the problem, and then work on extending it”. In a deeper analysis of these approaches, she proposes that there are three “modes of creation”: top down, bottom up (‘from parts’), and “from simpler”, and has examined them in reference to another dimension, “precise desired outcome” v “loose or no desired outcome”.

When examining the intersection of these dimensions, the approach above, “from simpler” can in turn be defined as “*interactive*” in the case of a ‘precise desired outcome’: “Take a simplified version of the problem, create a fully-working version of this simplified problem and then build on it”, and as “*growing*” in the case of a ‘loose or no desired outcome’: “Start with something, and build on it, see where it goes”.

In Mancy’s discussion, she comments that the ‘interactive’ approach she discussed correlates well with Turkle & Papert’s description of Anne, who ‘sculpts’ her program:

“Anne does not write her program in “sections” that are assembled into a product. She makes a simple working program and shapes it gradually by successive modifications... Each step is a small modification to a working program that she has in hand. If a change does not work, she undoes it with another small change. She “sculpts.” At each stage of the process she has a fully working program, not a part but a version of the final product” [Turkle & Papert 1990]

Mancy has therefore identified another dimension - ‘mode of creation’ – distinct from her dimension of ‘precise desired outcome’ v. ‘loose or no desired outcome’ (similar to what I would term ‘planned’ or ‘emergent’).

Mancy’s analysis of different approaches within programming appears partly to correlate to the differences I had observed in an emergent approach: in one there is the sense of predefining elements, then building something from them; in the other there is a strong sense of ‘growing’ the piece of work. However, my interpretation effectively amalgamates Mancy’s ‘modes of creation’ within the ‘planned v. emergent’ dimension. I had also proposed that this dimension works alongside a separate dimension (see Figures 71 & 72): ‘relates to self’, where an emergent approach can be viewed as a dialogue *through* medium; and ‘relates to medium’, where the emergent approach can be viewed as a dialogue *with* medium.

Sutherland & Hoyles describe a number of ‘dimensions’ of difference which they observed in the ways in which children approached programming projects [Sutherland & Hoyles 1988]. One of the main differences they observed was between whether the

children worked with well-defined goals (a “well worked-out and preplanned overall structure and global product”) or loosely defined goals (“build up their goal whilst interacting with the computer”). Within those who had well-defined goals, they identified further differences: top-down and bottom-up approaches to *planning*. This implies that a bottom-up approach does not necessarily equate to implementing or making the final product, but is rather a different approach to planning it. The following description given by Sutherland & Hoyles may serve as illustration:

“George and Asim are two of our case study pupils. Throughout their first year of learning Logo they always chose for themselves well defined picture goals. They preplanned their work very carefully, usually away from the computer. Their planning took the form of drawing out their design on graph paper, writing a linear series of commands and splitting these into sub-procedures only when this was imposed by the storage restrictions of the machine... They never worked in an experimental way with sub-procedures and did not come to appreciate the intrinsic nature of turtle geometry; that is that the same ‘shape’ in a different position of orientation can be defined by the same procedure. This absence of ‘hands on’ exploratory activity was detrimental to their understanding of the ideas of structured programming.”

This approach, while sharing some aspects of Turkle & Papert’s ‘hard’ mastery, is quite different in others. While the pupils certainly preplanned their work before executing it on the computer, there appears to be little in the way of abstraction, in the way of dissecting the problem, or working with modular solutions.

Across these dimensions of well-defined and loosely-defined goals, and top-down or bottom-up planning, Sutherland & Hoyles also observed differences between the ways in which children chose to interact with the computer: their “mode of computer interaction”. This was either ‘hands-on’, dealing with the programming interface directly, or more distanced:

“Throughout the Logo Maths Project we occasionally gave the case study pupils, either individually or in pairs, the same well-defined task and we observed differences in programming style between the girls and the boys. These differences cannot be adequately described by reference to the dimension of top-down planner and bottom-up planner but are more to do with mode of computer interaction. In fact one boy and one girl, Asim and Sally, both tended to be top-down planners whereas George and Janet both tended to be bottom-up planners. In contrast to Asim, though, Sally always wanted to work initially in direct mode. Her behaviour masked the fact that she nearly always started a project with a clear top-down plan... Sally and Asim both made top-down plans but, whereas Sally tested all the modules of her top-down plan and then used these to build up the row of decreasing squares before defining the final superprocedure, Asim defined a superprocedure straight away in the editor. He then had considerable debugging problems because he had not attended to state and interface details in his square module. Similarly, when Sally and Janet were working together on a well-defined task, they consistently worked in a way which involved testing individual modules and building these into the final product before defining the

superprocedure. The fact that they did not start the project by defining the superprocedure did not mean that they did not have a top-down plan of the problem solution. When given the same task Sally and Janet, unlike George and Asim, used ‘hands on’ activity as a way of getting into the problem. Once involved in the problem, they took time off to discuss their global plan, whereas George and Asim discussed their global plan before typing any commands into the computer. There is the danger that superficial observation could lead to the conclusion that Sally and Janet were not planning. Our evidence suggests that they did plan when working to well-defined goals but the nature of their interaction with the computer was different from the boys. They used interaction with the computer to get started and to engage on the problem...”

There are two possible interpretations of Sutherland & Hoyle’s descriptions of these differences in approach. First, that they represent two different ‘dimensions’ of variation: one relating to goals (a spectrum from well-defined goals, incorporating top-down planning and bottom-up planning, to loosely defined goals); the other to the mode of interacting with the computer (direct/hands-on v. distanced). The first dimension has some similarities to my ‘planned v. emergent’ dimension, although their definition of ‘bottom-up planner’ is not the same as my ‘predefined elements’, which is more like Mancy’s ‘bottom up’ categorisation. (Sutherland & Hoyle’s description of George and Asim’s ‘bottom up planning’ is different from Mancy’s intersection of bottom-up and ‘well-defined goals’: ‘defining the elements then worrying about how they are put together’, which has partial similarities to some elements of Sally’s approach (above), whom they describe as a top-down planner, working in direct mode.) The second, ‘mode of interaction’, although similar, does not appear to be the same as my ‘relates to self/relates to medium’ dimension, although it is significant that they define it as a separate dimension working alongside others, rather than an element of another dimension.

Alternatively, although Sutherland & Hoyle don’t mention a ‘bottom-up’ approach to loosely defined goals, it may be that ‘top-down/bottom-up’ is a separate dimension, distinct from well-defined/loosely defined goals (see Figure 73).

well-defined goals	top-down	‘hands-on’/direct
loosely defined goals	bottom-up	distanced

Figure 73: Three dimensions

In the context of my own research, I had thought that the top-down/bottom-up distinction, as I had originally interpreted it, could relate entirely to the organisation of work (the planned/emergent dimension) and say very little about the practitioner’s relationship to the objects of work, or the role of the medium (be it written language, programming

language, or physical medium) in their practice (the ‘express/engage’ and ‘internal/external’ dimensions). While this may be true, Mancy’s and Sutherland & Hoyles’ observations would suggest that, while the top-down/bottom-up dimension might relate to the organisation of work, it does not necessarily equate directly to my ‘planned/emergent’ dimension.

Regarding writing

Further comparisons with the field of writing allow useful parallels to be drawn and insights to be obtained in the search for relationships between the different dimensions.

Function of writing and role of language

Britton et al [Britton, Burgess et al. 1975] developed a framework for classifying writing, based on studies of the writing of students in secondary school, across disciplines, and spanning first to final year. Finding the existing classifications of writing too limiting, they were concerned with developing a

“...means of classifying writings according to the nature of the task and the nature of the demands made upon the writer; and, as far as possible, a way of classifying that is both systematic and illuminating in the light it sheds upon the writing process itself”

They also wanted a framework which could accommodate both the writing of mature writers, and the development of writing abilities.

Their major concerns were the aspects of *process* and *function* in writing. Their ‘function categories’ are of particular interest here: “These are an attempt to provide a framework within which to ask or answer the question ‘Why are you writing?’ in a specifically limited way”. ‘Function’ here is defined in terms of the relationship between the writer and the reader, and largely relates to the role of language.

Mature writing can be classified into three function categories: Transactional, Expressive and Poetic. These categories are seen as a spectrum, with Expressive in the centre, and Transactional and Poetic at the extremes. (Within this framework, learner writers begin as Expressive: “...in developmental terms, the Expressive is a kind of matrix from which differentiated forms of mature writing are developed.”)

Transactional language is “language to get things done”, writing as a means to an end; the language is transparent. *Expressive* language is language “close to self”, “revealing the speaker, verbalizing his consciousness”. *Poetic* language is writing as an end in itself, which “uses language as an art medium”; “a piece of poetic writing is a verbal construct,

an ‘object’ made out of language”; the language is used concretely, “the phonic, syntactic, lexical and semantic aspects of the utterance itself are the objects of attention, by the writer and the reader”.

Although Britton et al. are discussing functions of writing rather than types of writers, their distinctions between ‘function categories’ resonate in many respects with the axes and dimensions of difference discussed in this thesis. Table 10, adapted from [Britton, Burgess et al. 1975], contrasts characteristics of the two polar extremes of the spectrum.

Transactional	Poetic
The writing is an immediate means to an end outside itself.	The writing is an immediate end in itself, and not a means: it is a verbal artifact, a construct.
The form it takes, the way it is organized, is dictated primarily by the desire to achieve that end efficiently.	The arrangement <i>is</i> the construct: the way items are formally disposed is an inseparable part of the meaning of the piece.
Attention to the forms of the language is incidental to understanding, and will often be minimal.	Attention to the forms of the language is an essential part of the reader’s response

Table 10: Contrasting the extremes: Transactional and Poetic (adapted from [Britton, Burgess et al. 1975])

These have strong similarities to a number dimensions of difference in the framework described in Chapter 7, *Comparative study*, such as:

- medium as a means to an end/means separate from end v. medium is end in itself
- form and content separate v. form and content developed together
- medium is used transparently v. medium is used concretely

In Table 11 I have placed characteristics of the functions in another relationship, illustrating aspects of the shift from the focus on self and fewer ‘external’ demands of the *Expressive* function to, on one hand the focus on writing as a means to an end and the demands of the task of the *Transactional* function, and on the other the focus on writing as an end in itself, language as a medium, and the demands of the construct of the *Poetic* function.

Transactional	Expressive	Poetic
focus on topic, content	focus on self	focus on medium
demands of task	freer from outside demands (<i>but demands from self?</i>)	demands of construct
language as a means to an end	language as exploration, as “thinking aloud on paper”	language as an end itself; for its own sake

Table 11: Some characteristics of the Function Categories

Looked at this way, the differences between these functions have strong similarities to the differences that could be discerned between Practitioners A, B and C in Chapter 8. In particular, these different ‘function categories’ would appear to accommodate the difference between PractA’s identification with the medium as part of self, and process as ‘a journey driven by a feeling’ (*Expressive*), PractB’s with the medium as ‘other’ and a means of ‘rethinking the world’ (*Transactional*) and PractC’s with it as ‘other’, deriving meaning from the objects he finds and brings into being (*Poetic*). (Whether the focus on topic, self or medium is a dimension in itself, or results from the interaction between other dimensions, is yet to be determined.) These function categories may also provide another way of classifying the types of response to objects of students in the Artefact Study (my original types were Descriptive, Responsive or Generative).

Writing strategies

In The Act of Writing Chandler, as well as proposing two main orientations to writing – ‘planner’ and ‘discoverer’ - describes four different writing ‘strategies’ which writers would recognise as their methods of composition: Architectural strategy; Bricklaying strategy; Oil Painting strategy; and Water-colour strategy [Chandler 1995]. These were based both on a review of accounts of writers’ processes in literature, and a survey of academic writers.

In How We Write: Writing as Creative Design Sharples also discusses writing strategies, based on studies by van Waes and Wyllie [Sharples 1999]. van Waes developed a classification based on the cluster analysis of data collected from a number of writing episodes, resulting in five strategies: Initial Planners; Average Writers; Fragmentary First-phase Writers; Second-phase Writers; and Non-stop Writers. Wyllie’s study was

based on writers' accounts of their practice; she used a taxonomy based on Chandler's (Watercolourist; Architect; Bricklayer; Oil Painter) but with the addition of one more category, Sketcher. Sharples draws parallels between these and the five categories developed by van Waes (see table 8.1 in [Sharples 1999]).

These writing strategies largely concern the relationships between what Sharples describes as the main activities of writing: planning ("generate notes and plans"); revising ("annotate and edit text, notes or plans"); and composing ("generate text").

The strategies are not strict subdivisions of the 'Planner' and 'Discoverer' dimensions, although, for example, those who used the Architectural strategy (which Chandler describes as "plan-write-edit") tended to be Planners, in that the form of the work was preplanned, and they tended not to think of writing as a form of thinking. The Oil Painting strategy is closest to the Discoverer, with what Chandler describes as "minimal planning, maximum revision", and "a strong tendency to write to understand better what they wrote". Chandler appears to include two types of writer in this category; those who could be described as working from the 'bottom up', and those who start off with a whole and work into it:

"... I evolve a paper out of the mist. It comes in pieces, each piece being smoothed a bit as it comes along. And so it isn't a linear thing starting at the beginning and going to the end, but rather clusters'. Another reported 'writing it several times until I see how I'm going to convey crystallize, and then sort of letting the paper flow... I write the paper and let it come as it comes... My first draft is an enormous, lengthy, amorphous mass... I found myself crossing out... I do a tremendous amount of pruning'..."

Writers using the Water-colour strategy (those who van Waes called 'Non-stop Writers') aim "to produce a complete version at the first attempt, with minimal revision". Wyllie has classed Watercolourists as 'mental planners', but Chandler seems to include two types of writer in this category: those who "refer to complete texts being formed in the mind after a long period of mental 'incubation' or 'germination'", and those who describe their writing as "unpremeditated'... 'dictated' by an inner voice". (In terms of orientation (Planner/Discoverer) these two types, while appearing to have similar strategies, would be polar opposites.)

Those who use the Bricklayer strategy refine the text as they go. Chandler quotes one writer:

"I have to get every paragraph as nearly right as possible before I go onto the next paragraph. I'm somewhat like a bricklayer; I build very slowly, not adding a new row until I feel that the foundation is solid enough to hold up the house."

Wyllie classes Bricklayers as Planner/Discoverer (as opposed to Discoverer/Planner), although Chandler reports that “they tended not to be Discoverers” – “They usually had a clear idea of what they wanted to say and strongly disagreed that thinking would be difficult without writing”.

Wyllie’s addition of the Sketcher category to Chandler’s four (in her terms Discoverer/Planner and what van Waes classified as Average Writer, in the sense that “this strategy combines aspects of all the other profiles, with close to average values for each of the variables”), includes those writers who start with a rough plan, who sometimes work sequentially but sometimes not, and who revise a lot. Her description suggests that the plan is not detailed, and can also be revised in the light of the form of the work that is emerging.

In How We Write: Writing as Creative Design, Sharples observes that there are different levels of planning in writing as compared to, for example, architectural design in which a complete specification of the item in question has to be produced. In terms of the research reported in this thesis, where the model is ‘design and make’, there can also be more flexibility in terms of planning the work, as we have seen.

Differences between the various writing strategies described above include:

- the extent, level of detail, and flexibility of preplanning
- whether the text is produced sequentially, or whether it is produced in sections which are then put together
- the extent, level and timing of revision
- whether activities are performed internally or externally
- whether the writer views the work primarily at the level of the text, or at the level of the structure
- whether the writing is focused to the writer (writing to think) or towards the reader
- the extent of recursion in the process.

Some writers may use a variety of strategies, while others may have a strong preference for one; Chandler discusses the relationship between choices of strategy in [Chandler 1995]. Further examination of the differences between writing strategies can therefore add insight into the interaction between the various dimensions of difference between individual approaches to writing. It suggests a more complex structure of variation, along similar dimensions to those discussed previously.

The examination of the writing strategies above suggests that they concern the pattern of relationships between the main activities of writing and their manifestation, resulting from the interaction between the orientation of the writer, their preferred style of organising work, their relationship with the medium and its role in their practice, and the task at hand.

Relationship between ‘dimensions of difference’

Without further analysis of the data, and given the many dimensions of difference identified in the conceptual framework derived from the literature [Chapter 7], it is not profitable to speculate further at this point as to the exact relationships between the various ‘dimensions of difference’ within the data. However, what is suggested by the above discussion (and from the observations made by Turkle & Papert discussed earlier in this chapter) is that individual approaches may result from different combinations of orientation towards practice (goals/discovery), preferred style of organising work (preplanned/emergent), way of relating to the medium (close/distant), role of the medium (a means to an end/an end in itself), and mode of thinking (formal & abstract/intuitive & concrete). Each of these broader dimensions of variation are included in the original framework, but this suggests that the interplay between them may result in a more complex structure of variation than the two-dimensional structure of the original framework with its ‘formal/concrete’ axis.

As becomes clear from this discussion, the examination of differences in approach to creating artefacts, whether they be three-dimensional objects (physical or digital), computer programs or writing, is a non-trivial exercise, dealing with many interdependent dimensions of variation. However, it also illustrates the insights that can arise from comparisons between and within disciplines.

Recommendations for future systems to support creative practice

Above, I outlined limitations of replicating existing techniques and ways of working with materials when designing new digital systems for the use of creative practitioners. However, if this is not the right approach, what could be the alternatives? That is a question which must properly be left for the next stage of this research, although certain observations can be made, and possible areas of enquiry sketched out.

An examination of diversity in design practice has revealed fundamental differences in the relationships between individual design practitioners and the artefacts they create and

work with in their design processes. While it has not yet been able to provide a fully coherent explanation of these differences, it has identified a number of dimensions in which the approaches differ, broadly relating to the ‘hard’ and ‘soft’ approaches identified in the original conceptual framework. It has also identified a number of different elements of working with physical materials which, though important, do not all rely on working in a ‘physical’ environment: the ability to manipulate things directly, the immediacy and responsiveness of the medium, the ‘physicality’ of objects, as well as the physical ‘hands-on’ interaction. This research has therefore demonstrated that the relationship between design practitioners and the artefacts they work with encompasses important ways of working and knowing that are not embodied in the material context of the real world, which should be acknowledged and could be harnessed in the development of new ways of working in future digital environments.

It is inaccurate to claim that most existing computer systems for 3D design and modelling only suit those with a ‘hard’ approach: this research has shown a variety of examples where practitioners and students who display elements of a ‘soft’ approach have successfully used complex 3D modelling software. Although some found that the hierarchical system of menus and abstract style of interface engendered a distance from the medium, for others this did not seem to be a problem. While some carefully planned their work before starting in the software, others found it possible to interact with it directly and create their work through a dialogue with the medium. This underlines the argument that the characteristics of a medium are not absolute, rather they are defined in relation to the practitioner. Yet a number of participants did say that they felt the style of interacting with the software was at odds to those whose experience of working with materials was very different. This being the case, is it therefore possible to design systems which take advantage of the particular differences in approach that have been observed?

I believe that the key to making real differences in the way in which computer systems can support creative practice is to consciously focus on those “ways of working and knowing that are not embodied in the material context of the real world”, in a sense abstracting or subverting them from their embodiment in the contexts in which they have been examined here: it is all too easy, even when thinking along these lines, to fall back into the ‘material’ trap, or to approach the problem in terms of making modifications within the way existing 3D computer graphics software, for example, is designed.

Indeed, it soon becomes evident that achieving such change is non-trivial, particularly as the characteristics of a medium are defined in relation to the practitioner. Perhaps there are actually two questions here: how can we improve digital systems for those who want to use them as tools in different areas of practice; and can we create digital environments which enable new ways of exploring ‘the digital’ as a medium?

One way to proceed is again to examine the work of researchers in different fields who have taken similar approaches. Ackermann and Strohecker used the distinction between planners and bricoleurs in the design of their PatternMagix Construction Kit software, “a game-like software construction kit” with a “*constructive-dialogic* style of interaction [which] supports learning through playful exploration” [Ackermann & Strohecker 2001]

“Users play in a world of colourful tiles and geometric operations, from which they forge mosaic-like patterns. Interactions are modelled as a conversation between the player and the system. The dialogic turn-taking manifests as spatial changes in the display of constructions and system states.”

(Selected quotations and the figures in this section are taken from the PatternMagix presentation included on [Arnowitz, Dykstra-Erickson et al. 2001].) The PatternMagix program allows the player to “select elements to build colourful tiles, and experiment with geometric transformations by rotating an element or reflecting it around the x- or y-axis” (Figure 74). Once a tile has been created, it can be added to the ‘library’ of tiles for use as an element in further operations.

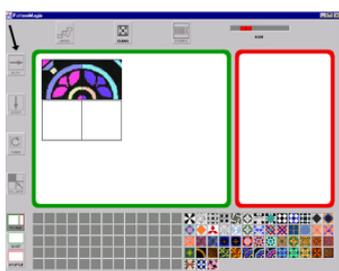


Figure 74



Figure 75

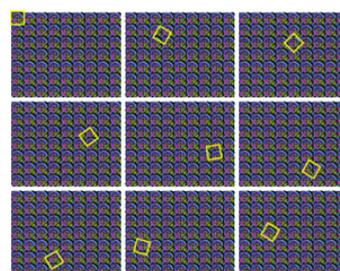


Figure 76

Reproduced by kind permission of E. Ackermann & C. Strohecker. For further details on PatternMagix see <http://www.carolstrohecker.info/ProjectPages/patternmagix.html> (Last accessed 25 September 2006)

When the tile is completed, the system generates a pattern by replicating the tile (Figure 75). A floating frame then appears, which moves slowly and randomly across the pattern (Figure 76). The user can select this frame and move, scale and rotate it to outline a particular piece of the pattern; alternatively, they can leave it to float at random, outlining possibilities for new tiles, and selecting the frame when a fragment appeals. In either case, once the desired pattern is in the frame, a ‘snip’ facility copies it into the library for future use (Figure 77).

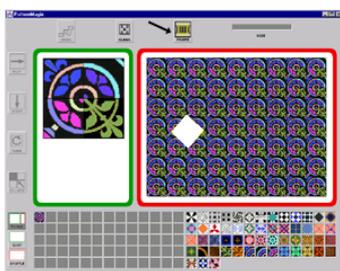


Figure 77



Figure 78



Figure 79

Reproduced by kind permission of E. Ackermann & C. Strohecker.

The program is designed to support two different types of interaction: direct manipulation, which is more akin to a monologue by the user, and automatic, in which the system plays a more active role. The first of these has two modes: ‘Draw’⁷⁰, in which the player can create freehand “decorations” for the tiles; and ‘Quilt’, in which the tiles in the library can be dragged onto the working area, and a selection made from the resulting pattern to form a new pattern (Figure 78).

The automatic style of interaction also has different modes: ‘Shuffle’ (see Figure 79) and ‘Kaleid’⁷¹:

“In the two automatic modes... the activation area expands to its maximum width, and the system automatically generates variations of user-crafted patterns. The player relinquishes control temporarily but can contemplate the evolving transformations and use them as inspiration for further constructions.”

The different modes within the PatternMagix system

“...enable varying degrees of control in the dialog with the system. Manual modes maximize the player's constructive capability, automatic modes maximize the system's contribution, and the basic Tiling mode offers a balance between the two.”

Thus the software supports two quite different ‘conversational’ models: ‘monologue’ and ‘dialogue’ within the one system.

Where next?

The following discussion represents very preliminary speculation on possible avenues of exploration.

Choice of materials

One dimension on which individuals differed concerned whether the materials are chosen to suit the design, or whether the design is determined by what materials are available.

⁷⁰ At the time of publication at CHI2001, the ‘Draw’ mode had not been implemented.

⁷¹ At the time of publication at CHI2001, the ‘Kaleid’ mode had not been implemented.

On closer examination, further variation could be discerned within this spectrum, relating to at what level of process and how ‘material’ constraints arise: either *defined* (repertoire of techniques and processes; physical elements) or *selected* (palette of materials; components or materials) in the case of the students in the Comparative Study.

3D modelling software packages offer primitives: a basic set of predefined forms such as cube, sphere, etc, which prevent you having to build every model from scratch. However this does not have the same connotations as the notion of a ‘palette’ of materials which have been collected. As it is more difficult (certainly in 3D software) to collect the equivalent of found material objects (although it is possible, for example, to import pictures, textures, 3D models from libraries) perhaps future systems could provide the ability to generate primitives in new ways, or to provide other ways of instantiating objects.

However there are already alternative approaches to using primitives in Maya (other than starting models from scratch): one of the students in the Comparative Study used drawings via a graphics tablet to give her a starting point in the digital environment:

“...I don't tend to use primitives as much as I tend to use drawings, to start off any kind of- ... 'Cause I feel like I have more control over it, I suppose. I feel like it's more mine by having the drawing first. Definitely control, I think, and that's just familiarity, I guess.”⁷²

But perhaps this still sits within the constraints of existing paradigms: do we need to take the idea further? Should we provide a digital ‘rummaging room’ where you could collect things that you liked for use later? Could it store all different kinds of digital ‘things’ that could be used in unexpected ways?

Ways of seeing

One of the truly different characteristics of ‘the digital’ is that it can take many forms, and digital objects could be manipulated in all kinds of ways. One of the characteristics of the *bricoleur* approach is to use things other than for which they have been designed; to see things in terms of ‘what they can do’ as opposed to ‘what they are for’. From this viewpoint, you could exploit the notion that something can be seen as a tool or a medium, or that one medium can be used as an abstraction for another. How could an abstraction be used as a medium? Could you use sound as the basis of generating 3D objects?

⁷² Digital student 5, interview 1

Different ways of introducing change into the situation

Within the data two different types of ‘emergent’ approaches could be observed: one related to working directly with the medium, and an exploration of its properties; the other related to the conceptual idea or design.

One of the differences between these two approaches concerns ways of introducing change into the situation. In the first case, the *medium* effects the change by reacting to what you do to it, possibly in unexpected ways; I have equated this to a dialogue *with* the medium, where the set of possibilities is undefined (as far as you’re concerned). In the second case, *you* effect the change through arranging and rearranging elements (it is a conscious change that is being made, even though you can’t foresee the exact outcome). I have equated this to a dialogue *through* the medium, where in a sense you define the set of possibilities, or at least control the change of possibilities.

In the second case, one approach might be to make it easier to rearrange elements within a digital environment (in most cases digital models have, or at least tend, to be very tightly specified). In the first case, one approach might be to increase the possibility of happy accidents or unexpected effects (although that could be seen as a contradiction in terms!). Another might be to create a positively active medium, rather than a passive or reactive medium; or provide the ability to change the activeness/reactiveness of the medium.

Exploring possibilities

What might a truly digital ‘workshop’ be? What kinds of tools would you want? Many different ways of instantiating things? Many different ways of introducing change? Ways of creating your own tools or your own media?

In terms of the variety of disciplines discussed in this thesis, one possibility might be to create a true 3D environment for writing poetry: instantiating words through speech (or writing) as objects with sound or other ‘physical’ attributes; move them around as physical objects in 3D space; combine and manipulate them; set them in motion through the environment to take paths of their own...

Areas for future research

There are two main directions in which the research undertaken for this thesis could usefully be extended: firstly, towards a greater understanding of individual difference

between design practitioners; and secondly, towards the development of new digital environments for creative practice.

One of the limitations of the empirical studies within this research is that while they identified differences in approach that could be observed along certain dimensions, within the various groups, they lacked the formal connection between these dimensions within an individual's practice to allow a rigorous comparison between individuals across all the 'dimensions' of their approach. This is especially significant in the Artefact and Comparative studies, where although interesting differences can be observed, it is not yet possible to accurately distinguish the number of broadly different types of approach (i.e. whether there are two (as in the original framework), four, etc.).

This could be improved in two main aspects: extending the analysis of the collective variation within the groups (i.e. undertaking a more detailed analysis of the various dimensions of difference, as the existing analysis was relatively broad); and examining the connections and correlations between these to understand the relationships between the dimensions within individuals' processes (the structure of variation). This would allow a more rigorous comparison between the emerging structure of variation and the original framework, and therefore a proper assessment of how well the conceptual framework derived from the theoretical review fits the data.

Another area of enquiry that could usefully be pursued is a deeper investigation into parallels and differences between the three fields discussed in this thesis: 3D design, programming, and writing. Comparisons of the similarities and differences between these fields provided useful insights into individuals' approaches. The examination of other fields, such as music, would also be beneficial.

The second principal area for further research is the development of new digital environments for creative practice based on the premise, proposed and discussed briefly above, of focusing on those 'ways of working and knowing that are not embodied in the material context of the real world'. Building such systems would not only allow the exploration and testing of various 'fledgling' ideas, it would also provide additional means of examining and testing what the essential characteristics are of various 'dimensions of difference'.

Both of these areas – developing a greater understanding of individual difference between design practitioners, and developing of new digital environments for creative practice – would benefit from the introduction of additional methods of investigation, such as

different instruments for comparing individuals across a range of dimensions of variation, and more focused experimental studies based around techniques such as design games discussed by Schön [Schön 1992] and Habraken & Gross [Habraken & Gross 1987a; Habraken & Gross 1987b]. These have the advantage of dealing with similar underlying approaches as are encountered in design practice, without being mini 'normal' design projects artificially constrained for the purposes of experimentation. While these may not have been appropriate for this first stage of the research, they would be certainly be suitable for the more focused enquiry required for these second stages.

Conclusions

This examination of differences in approach has demonstrated an underlying commonality between disciplines including 3D design practice, writing and computer programming as regards how practitioners work, and their relationships with the medium they work in, on or through. It reveals important aspects of working and knowing that are not embedded in the material context of practice, which should be acknowledged by theory, and could be harnessed practically in the development of future digital environments for creative practice.

Finally, it is important to stress that while this research identifies a number of important differences which could be observed between individuals, it represents only an initial examination of the collective variation within the overall data, which has uncovered a complexity which this thesis has just begun to address.

10. Critique

The previous chapters have described the motivation behind this investigation, and introduced the different elements of the research, and their purpose and role in exploring and defining the territory of the enquiry, resulting in its thesis:

that individual practitioners experience different relationships with the artefacts they create and work with in their processes, and that elements of these differences can be attributed to the nature and extent of a dialogue between designer and media

They have proposed a conceptual framework by which to describe and within which to examine this diversity in design practice: in essence a model of ‘the nature and extent of a dialogue’ which embodied the thesis. They have described two studies of practitioners designed to both test and illuminate this conceptual framework. They concluded that, while the findings of these studies broadly support this conceptual framework, it could not completely explain the diversity that can be observed between individual design practitioners in terms of their relationship with the artefacts and media they use in their design processes, and suggested possible reasons for these discrepancies.

The previous chapter, *Discussion*, placed this research and its findings within their wider critical and practical context. It examined the collective results from all the studies and drew a number of conclusions, describing how they are supported or challenged by the different elements of this research. It assessed whether the findings of the research support the thesis, in particular how well the conceptual model of dialogue which I had derived to explain this diversity in design practice matches the differences observed in this research. It briefly assessed the effectiveness of the method(s) chosen, in terms of the different elements of the chosen approach, and how they worked together. Finally, it assessed the contribution of this research to and implications of this research for a variety of audiences, and proposed a number of areas for further research.

While these previous chapters have dealt largely with the subject of the enquiry, this chapter presents a short critique of the research, relating to the theoretical stance of the work and the method chosen. (The emphasis in this chapter is on whether the supposed benefits of the method were realised in practice, and their impact on the research; the theoretical basis of this research, and the reasons for choosing the method have already been discussed in previous chapters, therefore I do not propose to deal with them in detail

here.) This chapter aims to assess the ‘structural rigour’ of the research, examining the strengths and weaknesses of the method and its implementation, to enable the reader to assess not only the strength of the argument, but its weight.

Weaknesses

There are three main limitations of the research undertaken for this thesis: the extent of analysis of the data undertaken to date; the limited range of instruments used in the empirical work; and a lack of external validation of the analysis.

Extent of analysis undertaken

While the existing analysis of the data has identified a number of dimensions within the collective variation of the data, it has not yet been able to define the structure of variation i.e. how these differences relate to one another within an individual’s practice. It has questioned the ‘two-dimensional’ structure of variation embodied in the original conceptual framework, but it has not yet been able to propose any firm alternatives.

The main reason for this is that while the empirical studies within this research identified differences in approach that could be observed along certain dimensions, they lacked the formal connection between these dimensions within an individual’s practice to allow a rigorous comparison between individuals across all the ‘dimensions’ of their approach. The original analytical framework designed for the Comparative Study (which eventually formed stage 1 of the analysis of that set of data) incorporated this link between dimensions and structure of variation; however, due to limitations in its implementation⁷³, these could not be fully taken advantage of. (In any case, the subsequent stages of that study suggested that the original ‘two-dimensional’ structure of variation could not explain all the differences that could be observed.)

Another limitation of the analysis arose largely from the additional time required to undertake the ‘emergent’ phase of the Comparative Study, in comparison to coding the data against the analytical framework as in the original design. Although three sets of interviews were carried out in the Comparative Study, the main analysis of the data was based largely on the original set, with updates from later interviews as appropriate. However, there was little investigation undertaken of changes over time (apart from in

⁷³ These are discussed in Chapter 7, *Comparative study*

cases where distinct changes occurred, or were remarked on) and their impact on the results has yet to be fully explored. Again, an analytical framework would have provided an initial means of examining this aspect, but for the reasons given above, this was neither possible nor ultimately appropriate.

It could be argued that this study was over-ambitious in its expectation of the extent of analysis possible within the period available. However, it should be remembered that the study was designed to use the analysis schedule, and the emergent form of the analysis was an adaptation made to address problems arising from its implementation.

Despite these drawbacks, I am satisfied that the chosen instruments have gathered data relevant to the overall thesis, and to the various ‘questions’ asked in each individual study. The data is in a suitable format for future examination. Further analysis of this data, using existing methods to undertake a more detailed analysis of the collective variation within the groups, and new instruments to examine the connections and correlations between the different dimensions, will enable a clearer understanding of the relationships between the dimensions within individuals’ processes (the structure of variation) to emerge.

Range of instruments used in empirical work

Another criticism which could be levelled at the research is that the empirical work is based largely on one technique: interviews with participants.

I have explained earlier in the thesis why I believe that interviews (as opposed to examining working processes ‘in action’, or examining the artefacts produced) were the most appropriate technique for this stage of research: partly because of the nature of the data I wanted to collect⁷⁴; and partly because of the limitations introduced by an experimental approach⁷⁵.

The aspects of practice with which I am concerned in this research involve people’s experiences, perceptions, opinions, and emotions, as well as accounts of their own process. The artefacts they create and work with are integral to this process, but cannot represent the whole process, and therefore an approach which only uses an analysis of artefacts to gain insight into each individual’s approach was unsuited to this enquiry. In

⁷⁴ See Chapter 7, *Comparative study* and Chapter 8, *Practitioner interviews*

⁷⁵ See Chapter 4, *Difference as a means of enquiry*, and Chapter 9, *Discussion*

the Practitioner Interviews, for example, I was interested in how each practitioner viewed the digital medium, how they engaged with it, and how their material practice related to their digital practice. I was also keen to identify insights they had obtained into their own practice in moving from material to digital, and the differences they highlighted between the two working environments. A lot of important information was gleaned from the different ways in which participants described their processes, and their relationship with the medium. In the Practitioner Interviews, for example, the subtleties of the differences in the role of the medium within their practice emerged from the language each practitioner used when describing their work.

However, while the interview was the major instrument used in this research, different methods were used to analyse the interview data, and it was not the sole technique used in the research.

While the Practitioner Interviews and Comparative Study did not examine any artefacts (other than incidentally during interviews), the analysis of the Artefact Study was largely based around an examination of artefacts produced by the participants in a situation which, while it was not a formal experiment or an artificially constrained design project, did involve the production of work. This study revealed some of the difficulties in using artefacts themselves as a basis for analysis; however examining the differences between artefacts opened up a new thread of enquiry, as it revealed differences *within* as opposed to *between* artefact types⁷⁶. At the time of the study I had not anticipated that an examination of the artefacts would represent a comparatively large part of the analysis; on reflection, the techniques used for this element of the research were rather informal. It was, however, very much an exploratory study; a more formal approach of this type would certainly be considered in future research, using more rigorous methods of examining physical artefacts.

Now that the parameters for this research have been more clearly defined, it would benefit from the introduction of additional methods of investigation, such as different instruments for comparing individuals across a range of dimensions of variation, and more focused studies based around techniques such as design games⁷⁷. While these may not have been appropriate for this first stage of the research, they would be certainly be suitable for the more focused enquiry required for these further stages.

⁷⁶ See Chapter 5, *Artefact study*

⁷⁷ See Chapter 9, *Discussion*

Lack of external validation of the analysis of the data

Further criticism which could be levelled at this research is that for each study, the analysis of the data has been subjective on the part of the researcher, whether against a ‘framework’ derived from other commentators, or emergent from the interview data or artefacts.

In the Comparative Study it had been the original intention to have additional external coding of the interviews using the analytical framework. However, difficulties were experienced in the application of this framework (relating to the definition of the categories)⁷⁸ which would have made its use by other researchers less valuable. This is exacerbated by the fact that the original two-dimensional structure of the framework now appears to be in doubt. At this exploratory stage of the research the value of this type of validation might therefore have been limited. It is probable that a revised framework, in which the categories were more closely defined using the results from this first stage of the research, would form the basis of future analysis of the data, particularly in relation to examining the structure of variation; it is expected that this would be subject to external validation.

In this research, these drawbacks have been mitigated to an extent by the range of studies which comprise the research. In the Comparative Study, for example, the conceptual framework was derived from a rigorous examination of commentators from other disciplines, and provides an external reference against which to compare the findings from the groups under investigation.

In conclusion, I am satisfied that the method chosen was appropriate for this stage of the research, and that the main drawback has been the extent to which the method has as yet been implemented. This could be improved through further analysis of the data, in conjunction with a suite of complementary studies using different instruments as suggested above.

Strengths

The main strength of this research is the breadth of elements which contribute to its findings. This includes the broad foundation of the theoretical basis of the research; the

⁷⁸ See Chapter 7, *Comparative study*

variety within the overall design of the research; and the benefits that arise from using difference as a means of enquiry.

Broad foundation of theoretical position (different disciplines)

The benefits of a broad foundation to the theoretical basis of the work have been discussed in Chapter 4, *Difference as a means of enquiry*, and Chapter 9, *Discussion*. These benefits relate to the additional weight of argument that arises from there being similar differences in approach within different disciplines, and the clarification and additional insights that can be gained from comparing these ‘similarly different’ approaches from quite different fields.

In this research, writing in particular has provided a useful comparative discipline. There are studies in writing and design which propose not only similar models of the creative process and the relationship between practitioners and artefacts (or similar explanations of differences between individuals), but each has a range of similarly different models of the creative process (with the exception that there had not appeared to be an equivalent in design of that proposed in writing by Chandler, which provided a route in to this enquiry).

The first benefit, therefore, of this broad theoretical stance was in providing an initial focus for the research: the differences that Chandler and Turkle & Papert identified resonated very strongly with things I’d observed in my previous research, and had been exploring further in the early stages of the research for this thesis, but there did not appear to be any existing models in the design literature that accommodated the types of individual difference with which I was concerned.

It has also provided, through the conceptual framework derived from these commentaries, a strong external element of comparison within the research, which has countered somewhat the current lack of external validation within the research, as discussed above.

Comparison within these other disciplines has also added clarity in areas where, although people may appear at first to be referring to similar differences, they are in fact not.

Chapter 9, *Discussion*, describes why I concluded that the top-down/bottom-up distinction does not equate to the planner/bricoleur distinction, and illustrates how an examination of why these are not in fact the same provides insight into other possible ‘dimensions of difference’.

Variety within overall design of research

Although it could be argued that the variety of instruments used on this research was small (as discussed above), nevertheless the range of areas within which these instruments were used was broad.

The research contains both theoretical and empirical elements. It has involved a range of participants with different ‘profiles’: students and practitioners; students working in physical or digital environments; practitioners with experience in both physical and digital media, who use different digital (and physical) media. Although interviews were the main instrument of data collection, the research has also involved more empirical techniques (Artefact Study). It has examined a number of different phenomena: models of the creative process from different disciplines or theoretical viewpoints; physical artefacts; and people’s creative processes and their relationship with the media they work with (through interview data). Interviews have ranged from following a fairly detailed schedule in the Comparative Study, to being more open-ended in the Practitioner Interviews. The research overall has combined ‘predefined’ and ‘emergent’ elements, as discussed in the previous chapter, and it is worth emphasising that the gaps between these two elements form a fruitful area for further research.

This variety within the design of the research has contributed to its strength as support for the thesis has come from these different quarters, thus broadening the basis on which the thesis is grounded.

Using difference as a means of enquiry

This research has confirmed the benefits of using difference as a means of enquiry, in its three guises: the comparative framework; the comparison of the individual against the collective (*difference*); and the added insight from comparing phenomena which are similar-but-different (*distance*). Although these have been identified separately, as they address different phenomena, in practice they operate closely together.

Individual against collective variation (difference)

The primary method used in this research has been the examination of an individual against the collective variation that can be observed within a group. This involved exploring, through comparison between all the individuals in a group, the ‘dimensions of difference’ within that group to determine the collective variation against which an

individual could be viewed. This research has included a range of individual/collective comparisons: between artefacts; between theoretical positions; and between practitioners, through interview accounts of their own practice.

In theory, this approach has a number of benefits: as the ‘dimensions of difference’ emerge from the data, it provides a route in to exploring a situation where there may be little previous knowledge; it can identify dimensions along which individuals may differ, particularly in regard to aspects which may not have been expected; and most importantly it can identify aspects of interest which may not be apparent from looking at one individual’s practice. Previous chapters have largely described how these benefits have been realised within the individual studies, and I therefore do not propose to discuss them in detail here. The following examples illustrate particular benefits which have resulted from this approach.

In the Artefact Study the collective examination of the artefacts revealed what appeared to be significant differences along a completely different ‘dimension’ to what I’d been originally been exploring but which actually aligned with the eventual direction of enquiry of the thesis.

In the Comparative Study, despite problems implementing the analytical framework, the analysis of the data using this emergent technique identified a large number of dimensions of variation, the most relevant of which have been discussed in this stage of the research (by ‘relevant’, I mean those dimensions pertaining most closely to the subject of this initial stage of the research). It also highlighted the importance of differentiating the variety of ways in which students use the media with which they work. This was particularly noticeable within the group of students working with physical media, and revealed the important distinction between those students who originally appeared to be what I would have termed ‘making’ – working directly with materials at the bench to create a piece – but who, as revealed through further discussion, were actually using materials more as a medium for design.

In the Practitioner Interviews comparisons between practitioners who had what at first appeared to be quite similar approaches, in terms of the original analytical framework, revealed distinct and significant differences relating to the role of the medium in each practitioner’s practice.

Comparisons of this nature led to one of the most important conclusions that can be drawn from this research: that the characteristics of a medium are not absolute, resulting

from notional inherent properties, rather they are defined through a practitioner's relationship with the medium.

Comparison between similar-but-different (distance)

The principle behind this approach is that insight can be obtained by comparing 'similar but different' phenomena. It is based on Chandler's observation in The Act of Writing, where he states:

"To become aware of the ways in which we engage with a medium we need to distance ourselves from it: to look with other eyes, to feel with other hands and so on; making the medium more visible or tangible." [Chandler 1995]

Within this research this principle has been used to inform comparisons between individuals, between environments, and between disciplines (as described in the previous section). It underpinned the theoretical review; it was a major component of the design of the Comparative Study; and it formed the basis of the Practitioner Interviews, comparing approaches between material and digital environments within each practitioner's approach.

In the Comparative Study, the comparison between groups working in the physical and digital environments added rigour to the collective variation emerging from the data. This arose not only from there being similar dimensions of difference within each group, but from the particular insights which arose from the differences between the two environments: one example is where the digital acted as a 'prism', separating the different aspects of 'working with physical materials' into constituent parts (being able to manipulate things directly, immediacy and responsiveness of medium, the physicality of objects, and physical 'hands-on' interaction). The comparison between groups also revealed that an external approach does not equate to an emergent approach, nor does it necessarily equate to an inability to visualise objects in one's 'mind's eye'.

In the Practitioner Interviews it showed that, in all cases, the practitioner's approach to the medium in their digital practice was in line with, and largely derives from, the approach they used in the physical environment. It also revealed the degree to which elements of their practice have, or have not been transferred between media (as distinct from their actual approach, which was broadly consistent across media). Perhaps the most striking aspect of this is that not being able to be physically 'hands on' with the medium, nor working with physical materials, doesn't appear to be a big drawback.

Finally, this principle applied throughout the research challenges any assumption that the fundamental differences between the different ways of working and knowing explored in this thesis are embedded in the material context of the real world: practitioners in quite different fields can also experience a close relationship with their medium, whether that medium be software, language, or 3D computer graphics.

Comparative framework

Chapter 4, *Difference as a means of enquiry* proposes the benefits of using comparative frameworks in this type of research: they add rigour to comparisons made between individual items (whether personal approaches or physical objects) by providing a context within which to make the comparison, and providing a means of placing different factors in relationship to one another.

The benefits that have arisen from using this approach to address the theoretical aspects of this research have been discussed above. It produced a robust comparative framework: a rigorous framework to provide strong basis for comparison between disciplines, and to understand how models from other fields might apply in design; and a complete framework which can also accommodate the broader range of studies included in the literature review.

In the Comparative Study, the implementation of the original analytical framework was problematic, and the ‘emergent’ analysis of the data does not yet permit the formal connection between dimensions within each individual’s practice to allow a rigorous comparison between individuals across all the ‘dimensions’ of their approach. Although these problems have meant that the role of the comparative framework has been less than envisaged, nevertheless the principle of examining the ways in which dimensions interact within certain individuals’ approach still applies, and has revealed a number of important ways in which the data diverged from the original conceptual framework.

The principal example of this was in the Comparative Study, where it became clear that an emergent approach did not equate to a ‘dialogue *with* the medium’, but might also be observed as a dialogue with oneself *through* the medium. In this case the differences relate to whether the emergence relates to the conceptual idea or design, or an exploration of the properties of the medium.

Summary

It could be argued that this comparative approach might spiral endlessly, that the framework might be split into tiny fragments, with no visible underlying structure. I don't believe this to be the case: although the research has identified cases of differences between what originally might have been similar approaches, dimensions relating to these 'additional' differences often already exist within the framework; it is the ways in which these dimensions combine within an individual's approach which result in the differences that are observed. This is one of the areas for further research proposed in Chapter 9,

Discussion.

In conclusion

Although the research described in this thesis has certain limitations, it has provided a substantial foundation from which to proceed. As a first stage of research in this area it has mapped out a territory, both theoretical and practical, within which subsequent investigations can be focused. It has examined the phenomenon in both students and experienced practitioners; and in both material and digital environments. It has extended research into three-dimensional practice. This thesis has identified ways in which the findings may impact on a variety of audiences, and it has proposed directions in which further research could usefully be pursued.

11. Conclusions

With due reference to the points made in the previous chapter, this research has demonstrated that important underlying differences exist between individual design practitioners which are more significant than variation arising from each designer's personal style, unique experience, or working context; rather they represent wholly different approaches to design. Further, it has demonstrated that these differences in approach are consistent across media, and concern each practitioner's relationship with the medium with which he/she works, and its role in his/her practice.

A review of literature from other disciplines, including writing and computer programming, revealed differences in approach which could be characterised by two 'ideal types': clusters of attributes observable across different levels of practice, divided broadly along a 'formal'/'concrete' axis. At one end of the spectrum the 'hard' or formal approach is characterised by explicit goals achieved through planning and working with representations. The medium is viewed as a tool to achieve a predetermined end. Risk is minimised, and mistakes viewed as problems. The relationship with objects is objective, formal and distanced, with an approach to thinking characterised by analysis, abstraction and reasoning in terms of rules. At the other extreme, the 'soft' situated, relational approach is characterised by tacit aims which allow the form of the work to emerge through engagement with the medium. The medium is viewed as interlocutor, with unexpected events viewed as part of the process of negotiation. The relationship with objects is subjective, concrete and situated, with a contextual approach to thinking characterised by transparency and a mastery of details, and concrete, bodily and intuitive forms of reasoning.

A detailed investigation of the creative practices of students and professional practitioners working with three-dimensional media, both material and digital, revealed that differences in approach along these lines could be observed in design practice, demonstrating an underlying commonality between the disciplines of 3D design practice, writing and computer programming. However, discrepancies between the data and my categorisation in terms of these two different approaches derived from the literature suggest that differences in approach exist over and above those that can be mapped directly to the formal/concrete axis. For example, there appear to be two different types

of emergent approach: one related to a conceptual idea or design, the other an exploration of the properties of the medium. There is also the suggestion of an underlying difference running parallel to a number of other dimensions, concerning whether the work is developed through reference to 'self', or to the medium.

Although the underlying dimensions along which these approaches differ have yet to be fully determined, this examination of differences in approach reveals important aspects of working and knowing that are not embedded in the material context of practice. It also emphasises that the characteristics of a medium are not absolute, resulting from notional inherent properties, rather they are defined through a practitioner's relationship with the medium. These findings suggest an alternative approach to developing future digital environments for creative practice: to consciously focus on those different 'ways of working and knowing' described above (separate from their embodiment in the contexts in which they have been examined here), rather than on replicating or enhancing aspects of material practice.

Appendix A: List of publications arising from this dissertation

Below is a list of publications arising from the research undertaken for this thesis (for completeness, the following list includes published journal and conference papers, and also papers presented at conferences and seminars where the proceedings were made available to attendees or on the web, but not published in official proceedings).

McLundie, M. (2001) Towards digital design environments. Position paper to CHI '01 Workshop on Tools, Conceptual Frameworks, and Empirical Studies for Early Stages of Design, 1 April 2001, Seattle, Washington, USA
(http://depts.washington.edu/dmgwksp/design_wksp.html)

McLundie, M. (2001) "Towards Digital Design Environments: Crossing the Borders." Proceedings of CADE 2001, Digital Creativity: Crossing the Border, 10-12 April, 2001, Glasgow, Scotland, The Glasgow School of Art Press.

McLundie, M. (2001) Design in a Digital Environment? Paper to research seminar on The Role of Haptics in Art and Design Research, 19 May 2001, University of Central England, (unpublished).

McLundie, M. (2001) "Building on diversity: crafting a paradigm for digital design environments." Digital Creativity 2001, **12**(2): 109-111. Swets & Zeitlinger.

McLundie, M. (2002) "A Guide to Haptics Applications in the Digital Realm", Research Issues in Art, Design and Media, Issue 2, Spring 2002, Research Training Initiative, Birmingham Institute of Art and Design, University of Central England. (This online journal ISSN 1474-2365 can be viewed at <http://www.biad.uce.ac.uk/research/riadm>)

McLundie, M. (2004) "Talking Digital: exploring diversity in practitioners' relationships with digital artefacts." Proceedings of PixelRaiders 2, 6-8 April 2004, Sheffield Hallam University

Appendix B: Visualisation and interaction in 3D

This appendix provides a brief introduction to some of the technologies and principles involved in creating, visualising and interacting with digital models in three dimensions. This is an area where technologies are continually and rapidly advancing: this appendix does not aim to provide a comprehensive review or a comparative evaluation of the different technologies and current technical solutions; rather it aims to introduce this area to the reader who is not familiar with the technologies, techniques and principles involved.

3D visualisation

A variety of techniques exist which allow a user to ‘see’ a virtual model in three dimensions, and methods of displaying virtual 3D models in true physical space are increasingly viable. A selection of these techniques is discussed below. These range from fully immersive stereoscopic systems, where images for each eye are displayed on goggles worn by the user, ‘immersing’ them in the virtual environment, to volumetric and holographic systems, where the model is displayed in true 3D space, allowing the user to work with the digital model in the physical environment.

Stereoscopic

Stereoscopic displays take advantage of the principles of binocular vision by projecting a pair of images, one for each eye, that when combined by the brain produce the illusion of seeing a three-dimensional image.

In fully immersive systems the user is provided with a separate display for each eye (via goggles, for example), ‘immersing’ the user in the virtual environment: they can see only what is displayed to each eye. While head tracking allows the user to move easily around the model, the user’s whole environment must be generated virtually, including representations of the user’s hand in the case of interactive systems.

In semi-immersive systems, a stereo pair of images is projected onto a display. This display is viewed through glasses which restrict each eye to receiving a single image, producing the three-dimensional effect (there are a number of different techniques which can be used to achieve this, but the underlying principle is the same). Unlike fully immersive systems, objects in the physical environment can still be seen, e.g. the user’s

own hand interacting with the virtual model. Different types of display devices exist, varying both in configuration and size.

Multiple-screen stereoscopic displays range from CAVE systems, such as the Immersive Room (Figure 80) [Fakespace Systems], which are the size of small rooms, and where walls, floor and ceiling can all be used as display surfaces, to small, desktop displays such as the ‘Cubby’ developed at the ID-StudioLab (Figure 83) [Djajadiningrat, Overbeeke et al. 2001]. Single screen devices range from large wall displays such as the PowerWall™ PRO (Figure 82) [Fakespace Systems] to displays integrated into laptop computers. Bespoke displays can be configured to even larger sizes, within the technical limitations of the current technology. Flat, table-sized displays which can be tilted to different angles are among the most popular: the M1 Desk (Figure 81) [Fakespace Systems] is an example of this type. The most common systems for ‘true’ 3D visualisation in current use are based on semi-immersive stereoscopic displays.



Figure 80: Immersive Room
Image courtesy of Fakespace Systems Inc.



Figure 81: M1 Desk
Image courtesy of Fakespace Systems Inc.



Figure 82: PowerWall™ PRO
Image courtesy of Fakespace Systems Inc.

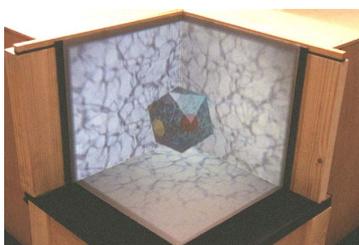


Figure 83: The Cubby desktop 3D display. Tom Djajadiningrat; reproduced by kind permission of ID-StudioLab, Delft University of Technology

Autostereoscopic

Autostereoscopic displays work on a similar principle to stereoscopic displays, but require no special goggles or glasses to view. Unlike a stereoscopic display where the viewer has a single image mechanically displayed to each eye, in an autostereoscopic display a series of images is projected into adjoining ‘windows’ in space, and the viewer is putting their eyes into the field of display: effectively the series of images ‘fan out’ like rays from the screen in which the viewer is free to move, and where each eye receives a different view. In lower specification displays (i.e. fewer ‘rays’ in the fan) the point where the eye moves between images can be quite noticeable, the viewing range is limited, and it can be awkward for more than one or two people to view the image simultaneously. In higher specification displays with many more ‘rays’ in the fan, such as the HoloVizio range [Holografika], the eyes move more smoothly between images, enhancing the perception of three-dimensionality.

Small and medium-sized autostereoscopic displays are now available commercially, both stand-alone like the HoloVizio range (Figure 84) [Holografika], and integrated into notebook computers such as the Actius RD3D (Figure 85) [Sharp Systems of America]. Larger displays are now beginning to emerge from research labs: Opticality Corporation recently developed a prototype 180 inch autostereoscopic wall display for the National Museum of Emerging Science and Innovation in Japan which is on display at the 2005 World Exposition in Aichi, Japan [Opticality Corporation].



Figure 84: HoloVizio 128W
Reproduced by kind permission of Holografika



Figure 85: Actius RD3D
Reproduced by kind permission of Sharp Systems of America

Volumetric

All displays based on stereoscopic principles are fixed focus, and therefore cannot provide proper depth cues: the eyes cannot converge or change focus within the virtual

scene, as happens when viewing real objects. Volumetric display systems construct an image in three-dimensional space, within a physical volume. A number of volumetric imaging techniques exist, although many are still under development.

The FELIX 3D-Display (Figure 86) [Langhans, Bezecky et al. 2002] uses a swept volume method, with lasers illuminating points on a rapidly rotating display surface. This surface moves at a speed that renders it invisible to the viewer, leaving only the three-dimensional image visible. This image can be viewed simultaneously by many viewers and from almost any angle. Normal variable focus and depth perception apply, but as the image is displayed within a volume, it cannot support co-incident interaction with the user's hand, or haptic devices; researchers are exploring the unique requirements for interacting with this type of display [Balakrishnan, Fitzmaurice et al. 2001].

Displays of this type are now commercially available: the Perspecta Spatial 3D System is a desktop volumetric 10" diameter display with full colour (Figure 87) [Actuality Systems].



Figure 86: FELIX 3D Display
Reproduced with kind permission of Knut Langhans



Figure 87: Perspecta Spatial 3D System
Image courtesy of Actuality Systems, Inc.
Bedford, MA USA (copyright 2004,
David Shopper)

Holographic

Holograms can display true 3D high quality images which provide all the depth cues used by the human visual system, including depth of field which allows variable focus. While the viewing volume has limits, multiple users can view the image simultaneously.

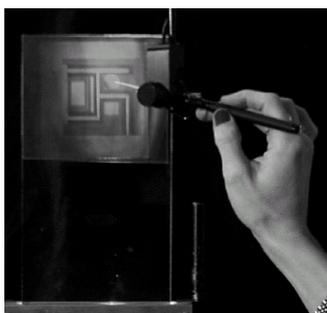


Figure 88: Edge-illuminated block haptic hologram
Reproduced by kind permission of Webb Chappell

A number of research groups including the Spatial Imaging Group at MIT (Figure 88) are developing techniques for producing computer generated holograms, where the holographic image is generated from a digital model, rather than being a copy of a physical object, as is the case with normal holograms [Plesniak & Pappu 1998; Plesniak & Pappu 1998; Plesniak, Pappu et al. 2003].

‘Immersive’

Other systems have been developed which, although not true 3D displays, give a sense of 3D perception without the need for special glasses or goggles. Examples include the VisionStation® and VisionDome® series of hemi-spherical displays (Figures 89 & 90) [Elumens]. Images, predistorted so that they display correctly, are projected onto the concave or hemispherical screen. In this viewing volume the image is displayed in its spatially correct position with reference to the viewer, producing enhanced depth perception. However, as the image is not truly perceived in space, co-incident interaction using haptic devices is not possible.



Figure 89: VisionStation
Elumens Corporation

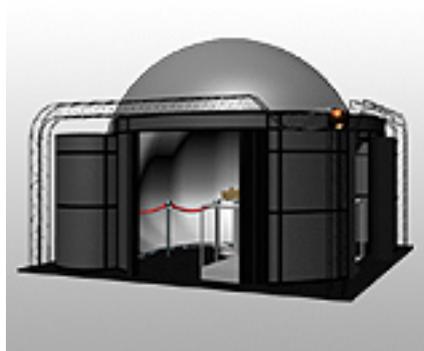


Figure 90: VisionDome V5
Elumens Corporation

Gesture interaction

A variety of techniques provide the ability to interact with digital systems via hand gesture.

Gloves

The simplest devices which use ‘gesture’ are, in effect, selection devices with a greater repertoire. In the Pinch® Glove (Fig. 91) a range of ‘pinch’ gestures between different fingers and the thumb can be recognised and used to correspond to a series of instructions, for example [Fakespace Systems].

The CyberGlove® is a tethered, multi-sensored glove that can sense the position and movement of the fingers and wrist (Figure 92) [Immersion]. It can be used with software to provide gesture control of systems (via up to 254 individual gestures), and when combined with a tracking device to determine the hand’s position in space, it can be used to manipulate virtual objects.



Figure 91: Pinch® Glove
Image courtesy of Fakespace Systems Inc.



Figure 92: CyberGlove®
Reproduced by permission of Immersion Corporation, Copyright © 2005 Immersion Corporation. All rights reserved.

3D gesture in space

In the above devices, the term ‘gesture’ relates to postures or shapes of the hand i.e. the relative positions of the fingers, for example. Other devices, such as 3motion™ being developed by researchers at the Digital Design Studio, Glasgow School of Art, contain sensors which track the trajectory of the device in space (Figures 93 & 94) [Payne, Keir et al. 2005]. This allows the user to make physical gestures in 3D space, which can be used either as commands to control software, through recognition of particular gestures, or as natural movements such as a ‘golf swing’ in a computer game.



Figure 93: 3motion™
Reproduced by kind permission of Digital
Design Studio, Glasgow School of Art



Gesture control is intuitive & can make
gaming more fun and accessible

Figure 94: 3motion™
Reproduced by kind permission of Digital
Design Studio, Glasgow School of Art

Haptic interaction

Haptic devices allow the user to experience a sensation of touch and physical properties when interacting with virtual materials. The term ‘haptic interaction’ is used to describe two different things: the tactile sensation of the skin touching a surface; and the resistance or force feedback experienced when you push against a material. It is most frequently used to allude to the latter, as the capability of most devices currently available is limited in conveying a true tactile sensation of a surface. Force feedback haptic devices exert force in response to a user’s action, at the point of action. They enable active ‘two-way’ interaction with virtual objects, where action and perception are brought together. There are a range of haptic devices available, including mice and joysticks such as those used with computer games, and specialist devices such as those designed for simulating laparoscopic surgery. Those reviewed below have been selected because they can be used not only to interact intuitively with virtual models, but to interact directly with such models in 3D space, providing co-incident interaction between hand and eye. (A wide range of haptic devices, both research and commercial, can be viewed on The Haptic Community Web Site [The Haptic Community Web Site].)

Single point force feedback

The PHANTOM® range of desktop haptic devices provide single point, 3D force-feedback to the user via a stylus (or thimble) attached to a moveable arm (Figure 95)

[SensAble Technologies Inc.]. The position of the stylus point/fingertip is tracked, and resistive force is applied to it when the device comes into ‘contact’ with the virtual model, providing accurate, ground-referenced force feedback. The extent of the arm determines the working volume.

A number of models are available to suit different user requirements; SensAble recently introduced the PHANTOM® Omni™, a slightly lower specification but less expensive model aimed at commercial users such as the 3D modelling market (Figure 96).



Figure 95: PHANTOM® Desktop™
Reproduced by kind permission of
SensAble Technologies Inc.®



Figure 96: PHANTOM® Omni™
Reproduced by kind permission of
SensAble Technologies Inc.®

Multiple point force feedback

Immersion produce a family of products based around their CyberGlove® (see above). The CyberTouch™ option provides a sense of tactile feedback through the addition of vibrotactile stimulators to the palm and fingers of the CyberGlove (Figure 97). While not true tactile feedback, it can give the perception of touching an object. The CyberGrasp™ is a full hand force-feedback exoskeletal device, which is worn over the CyberGlove (Figure 98). Resistive force can be exerted on the fingertips through a series of ‘tendons’ controlled by actuators, allowing the user to experience resistance when interacting with virtual objects. This force is hand-referenced: it can prevent the user from crushing a virtual object in their hand, but it cannot prevent them pushing through a wall, or allow them to feel weight, for example. This can be achieved through the CyberForce®, a fixed-base force-feedback armature designed to be used with the CyberGrasp to provide ground-referenced forces to the hand and arm (Figure 99).

Another variety of haptic device can provide multiple point force feedback via a system of lightweight tensioned cords. Originally developed by researchers at the Tokyo Institute of Technology the SPIDAR-8 (SPace Interface Device for Artificial Reality)

provides force feedback to the fingertips of four fingers on each hand (Figure 100) [Sato, Walairacht et al. 2000]. Other researchers have built on this concept: the prototype Scaleable-SPIDAR provides one ‘fingering’ for each hand to interact in a large-scale environment (Figure 101) [Buogulia, Ishii et al. 2000], while the Stringed Haptic Workbench adapts the idea for interacting directly with stereoscopic 3D images on a workbench-scale display (Figure 108) [Tarrin, Coquillart et al. 2003].



Figure 97: CyberTouch™

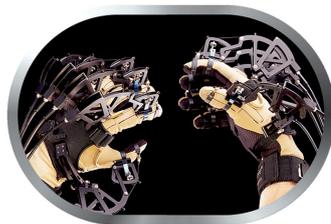
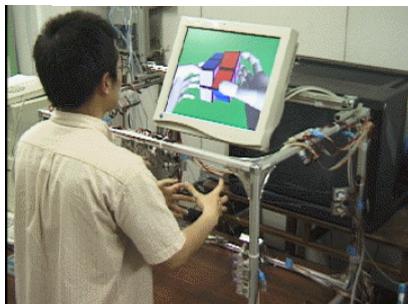
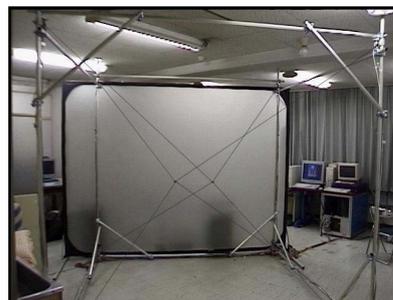


Figure 98: CyberGrasp™



Figure 99: CyberForce®

Figures 97-99 Reproduced by permission of Immersion Corporation, Copyright © 2005 Immersion Corporation. All rights reserved.

Figure 100: SPIDAR-8
P&I Laboratory, Tokyo Institute of
TechnologyFigure 101: Scaleable-SPIDAR
P&I Laboratory, Tokyo Institute of
Technology

Direct manipulation: coupling physical and virtual objects

Another method of achieving direct manipulation of virtual objects is to couple them with physical devices or objects. Although such devices, or ‘props’, do not give haptic feedback to the user, they enable tangible interaction, often with both hands, taking advantage of our existing skills and experience in manipulating objects. A well-designed prop has a physical form which gives cues to the way it works, making it more intuitive and easier to learn than traditional techniques for manipulating virtual objects.

The CubicMouse™, a “physical co-ordinate system prop” initially developed at GMD⁷⁹ and until recently supplied by Fakespace Systems, is a hand-held cube with three rods running through its centre, one along each of the x, y, and z axes (Figure 102) [Kruijff 2000]. The cube is mapped to the position and orientation of the virtual environment, and the rods to the co-ordinate system of an object within that environment. Rotating a rod rotates the object around its corresponding axis, while pulling or pushing a rod through the cube will move the object along that plane within the environment.

Hinckley et al at Microsoft Research, Carnegie Mellon University and the University of Virginia developed an environment for neurosurgical planning in which the user manipulates “passive real-world props” with both hands (Figure 103) [Hinckley, Pausch et al. 1998]. A doll’s head, “rich in tactile orientation cues”, is mapped to a virtual brain model, and a clear plastic plate is mapped to a cutting plane. The viewer can examine different cross-sections of the brain, by rotating and moving the doll’s head to orientate the brain model, and by moving the plate in relation to the doll’s head to move the cutting plane through the model.



Figure 102: CubicMouse™. Image courtesy of Fakespace Systems Inc.



Figure 103: Environment for neurosurgical planning with “passive real-world props”. [Goble, Hinckley et al. 1995] Reproduced by kind permission of IEEE, © 1995 IEEE

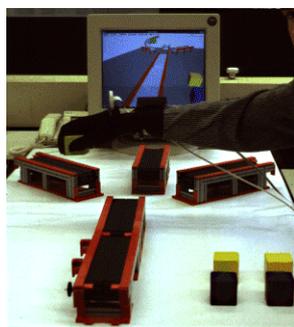


Figure 104: Graspable Real Reality User Interface. Reproduced by kind permission of arteLab, Universitat Bremen



Figure 105: Hybrid Environment [Lok, Naik et al. 2004]. Reproduced by kind permission of IEEE, © 2004 IEEE

⁷⁹ GMD - The German National Research Centre for Information and Communications Technology – now Fraunhofer IMK

The Graspable Real Reality User Interface concept at the University of Bremen took an alternative approach to coupling physical and virtual models (Figure 104) [Bruns & Brauer]. In this system, the user's hand was sensed, rather than the physical object. A data glove measured the shape and position of the hand, allowing the system to recognise 'grasp patterns'. A virtual model was built of each type of physical object to be used in the modelling. The system was trained to recognise a grasp pattern for each type of physical object, which was then used to map the physical object to the virtual object. Virtual models could then be built by manipulating the physical objects. The advantage of this system is that any physical object could be incorporated into the modelling system, and the same interface used to work with physical and virtual models.

In a more recent project using real objects to interact with virtual environments, Lok et al. are developing a 'hybrid environment' (HE) which uses input from multiple cameras to create dynamic 'avatars' of real objects in a fully immersive virtual environment [Lok, Naik et al. 2004]. This allows the user to see, for example, their hands and objects they are holding within the virtual environment; software allows the user to interact with virtual objects using these real objects (Figure 105).

Integrating advanced technologies for visualisation and interaction (co-incident interaction)

Integrating advanced technologies for visualisation and interaction combines the benefits of more natural ways of working with moving the three-dimensional virtual model into the user's physical workspace, allowing co-incident interaction between the eye and hands or tools.

MIT's Spatial Imaging Group have combined computer-generated holographic video and a PHANTOM haptic device to explore naturalistic, real time interaction with a 'tangible hologram' (Figure 106) [Plesniak & Pappu 1998; Plesniak & Pappu 1998; Plesniak, Pappu et al. 2003]. To achieve near real-time interaction, series of pre-computed holographic images are displayed in response to the user's interaction with the three-dimensional image. The 'Lathe' experiment allowed the PHANTOM stylus to modify a cylinder in a lathe scenario: the user had the sensation of feeling the cylinder spinning beneath their touch, and when they applied sufficient force, the cylinder surface deformed in response. This principle was extended in the 'Poke' experiment, which still combined pre-computed elements of images for real-time display, but provided a more flexible

model: a “sheet of pliable material, which could be felt, poked, and deformed” using the PHANTOM.

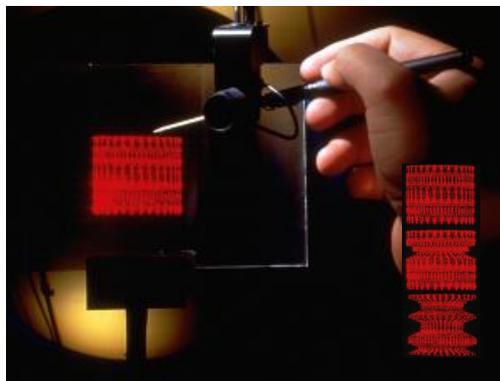


Figure 106: “Lathe”
Reproduced by kind permission of Webb Chappell



Figure 107: Two-handed direct manipulation on the Responsive Workbench. [Cutler, Fröhlich et al. 1997] © 1997 ACM, Inc. Used by permission.

A number of research groups have been investigating the potential benefits of interfaces which allow two-handed manipulation of three-dimensional virtual objects on ‘workbench’-type stereoscopic 3D displays. Cutler et al at Stanford University developed a framework for two-handed interaction based around Guiard’s observations of how humans distribute work between their hands [Cutler, Fröhlich et al. 1997]. Using this framework, they explored a variety of two-handed 3D tools and interface techniques to provide users with natural ways of manipulating 3D models on a Responsive Workbench (a semi-immersive stereoscopic table-type display) (Figure 107).

Researchers at INRIA and Tokyo Institute of Technology have combined a workbench with both vertical and horizontal screens (TAN Holobench) and a SPIDAR force-feedback device to produce the Stringed Haptic Workbench (Figure 108) [Tarrin, Coquillart et al. 2003]. This configuration allows the user to interact directly with the stereoscopic 3D image, and receive ground-referenced force-feedback (currently to the tip of one finger) within the large volume of the workbench display.

Commercially-available systems based on integrated visualisation and interaction are now reaching the desktop: the Reachin Display combines a stereoscopic display, a haptic device, and a positioning device, allowing eye and both hands to work co-incidentally with the three-dimensional virtual model (Figure 109) [Reachin Technologies AB]. Different configurations are available to suit a variety of applications. In their Haptic Workstation™ (Figure 110), Immersion have combined left-handed and right-handed CyberForce systems with a head-tracked fully-immersive 3D display; it can also be configured for semi-immersive displays.

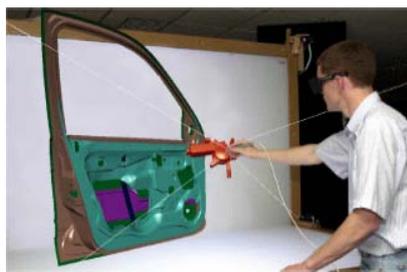


Figure 108: Stringed Haptic Workbench [Tarrin, Coquillart et al. 2003] © Eurographics Association 2003. Reproduced by kind permission of the European Association for Computer Graphics



Figure 109: Reachin Display © Copyright 2006Reachin Technologies AB



Figure 110: Haptic Workstation™ Reproduced by permission of Immersion Corporation, Copyright © 2005 Immersion Corporation. All rights reserved.

Software modelling to support interaction and visualisation

Haptic devices and 3D displays are of little value without software to model the ‘physical’ properties of the virtual material and its response to interaction, both haptically and visually: when you press a springy material, for example, you expect to feel it ‘give’, and see it deform.

A group of researchers at GMD⁸⁰, Stanford University and Carnegie Mellon University integrated the simulation of physical behaviours into a system to support complex assembly tasks, based around a Responsive Workbench (Figure 111) [Fröhlich, Tramberend et al. 2000]. In this system, multiple-user and multi-handed interaction with objects is enabled, a common requirement in assembly tasks. Although users receive no haptic feedback, the physical simulation means that objects move naturally during interaction, and good visual feedback is achieved.

James at Carnegie Mellon University is researching techniques in Linear Elastic Modelling which allow people to interact in real time with simulations of elastic or

⁸⁰ GMD - The German National Research Centre for Information and Communications Technology – now Fraunhofer IMK

‘springy’ materials. The virtual material responds haptically and visually to the user’s touch, providing an engaging experience (Figure 112) [James & Pai 1999; James & Pai 2001].



Figure 111: Physically-based manipulation on the Responsive Workbench. [Fröhlich, Tramberend et al. 2000]. Reproduced by kind permission of IEEE, © 2000 IEEE



Figure 112: Linear Elastic Modelling
Reproduced by kind permission of Doug L. James, Carnegie Mellon University

A major challenge in building applications which combine haptics and advanced visualisation is to integrate the various hardware components with haptics and graphics software so that they work together seamlessly. A growing number of toolkits are being developed for this purpose: one example is Reachin Technologies’ Reachin API which manages the technology integration, allowing developers to focus on the application.

Rapid prototyping

Rapid Prototyping is a term used to describe a number of technologies and techniques for creating physical objects directly from digital data. Unlike ‘subtractive’ technologies used for this purpose, such as CNC (Computer Numerically Controlled) milling machines, Rapid Prototyping is an ‘additive’ process of building objects up in multiple thin layers; it can therefore produce geometrically more complex objects.

A variety of different techniques exist, all using the same underlying ‘layered’ principle: these include Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (Figure 113), Three Dimensional Printing (Figure 114), Laminated Object Manufacturing, and photopolymer jetting (Figure 115). Each has advantages and drawbacks (speed, size, expense, etc), and so they are suited to different purposes; they also use different materials, and some techniques can incorporate different colours within the object. Depending on the technique used more or less ‘finishing’ of the model may

be required. In industry they are most often used to produce prototypes, however they can be used for finished objects where appropriate.



Figure 113: CALM project - final object produced by fused deposition modelling (Katie Bunnell). Reproduced by kind permission of the Learning Development Unit



Figure 114: Colour 3D printing
Reproduced by kind permission of [Z Corporation]



Figure 115: Photopolymer jetting
Reproduced by kind permission of [Objet Geometries Ltd.]

For further information on these and other techniques the reader is referred to guides such as The Learning Factory's *Rapid Prototyping Primer* [Palm 1998] and Castle Island's *Worldwide Guide to Rapid Prototyping* [Worldwide Guide to Rapid Prototyping]. The *Rapid Prototyping Homepage* contains links to a wide range of resources on rapid prototyping [Rapid Prototyping Homepage].