INVESTIGATION INTO THE INSIGHTS GENERATED THROUGH THE APPLICATION OF INTERACTIVE PROTOTYPING DURING THE EARLY STAGES OF THE DESIGN PROCESS

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Declaration

This work has not previously been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

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Statement 1

This work is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes and through explicit references. A full list of references is appended.

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Abstract
The early stages of the product design process are defined as those when initial product concepts are conceived in accordance with a design brief. High numbers of ideas will be generated as designers iteratively develop concepts towards more refined design solutions. The early stages of the design process are rich with trial and error providing the optimum time for making major design decisions with minimal risk. Prototypes play a critical role in designers’ ability to explore and evaluate concepts against the user’s requirements and needs during this time. The role of prototypes is emphasised to an even greater degree when adopting user centric design methodologies.

The term computer-embedded device is used to describe a type of product which features embedded processing power. Examples of this type of device include hospital monitoring equipment, satellite navigation devices, microwave ovens, washing machines, car park ticket machines and mobile phones to name just a few examples. Such devices typically feature bespoke hardware with custom user interfaces. These devices are inherently complex to design due to reliance upon a multitude of disciplines including industrial design, software engineers, electronics engineers and human computer interaction experts. The need for such a multi disciplinary team presents a major challenge for industrial designers when attempting to prototype this type of product.

A number of attempts have been made to alleviate the prototyping challenges faced by designers associated with these products. Some of this work has resulted in the development of so called prototyping toolkits which aim to abstract some of the electronics and programming knowledge required to create interactive prototypes. However, previously there has been little research which focused on exploring the interactive prototyping needs of designers during the very early stages of the design process. This thesis explores the needs of designers involved in the development of computer-embedded devices during the early stages of the design process, in relation to interactive prototyping.
The research includes the development of an experimental prototyping toolkit. The toolkit's development was informed through the findings of a critical literature review which identified suggestions relating to early stage interactive prototyping requirements. The toolkit provided a means of directly exploring to what extent the requirements previously suggested met with the actual needs of designers working at this stage of the design process by creating an intervention in existing design processes.

The research trialled the toolkit with six carefully selected industrial collaborators. These collaborations ranged in profile and market from an independent User Centric Design consultant through to a Global Mobile Phone Corporation.

This research has found that it is possible to produce tangible interactive prototypes during the early stages of the design process within a timescale of one to two hours. The research has also concluded that the barriers towards interactive prototyping during the early stages extend beyond being solely attributed to a lack of suitable prototyping tools. The research identified major limitations in the existing prototyping tools available to designers, as well as a lack of integration between the industrial design and the interaction design associated with the design of computer-embedded devices. This lack of integration poses a major barrier towards the successful design of computer-embedded devices.
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I would like to thank my supervisors Dr. Gareth Loudon and Professor Steve Gill for their commitment, guidance and professionalism throughout the time I have spent on undertaking this piece of research. Without their advice and support this research would not have been possible. I would also like to thank the other members of staff at the University of Wales Institute Cardiff (UWIC) for their advice and support along the way.

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I am also grateful to all the people I have had the pleasure of discussing my work with whilst attending conferences and seminars.

Finally, I would like to thank my family and also my girlfriend Nicola for their never ending support and encouragement that they have all offered me whilst undertaking this research, and for putting up with me along the way.
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Glossary of Terms & Acronyms

The Programme for Advanced Interactive Prototyping Research – PAIPR

The University of Wales Institute Cardiff – UWIC

The National Centre for Product Design and Development Research – PDR

Rapid Prototyping – RP

User Centric Design – UCD

Interaction design – IxD

User Experience - UX

Integrated Development Environment - IDE

Printed Circuit Board - PCB

Input / Output - I/O

Universal Serial Bus - USB

1-Wire - I²C

Information Architecture - IA

Radio Frequency Identification - RFiD

Fused Deposition Modelling - FDM

User Interface - UI

Application Specific Integrated Circuit - ASIC

Graphical User Interface - GUI
About the Author

Ian Culverhouse moved from Cornwall to Cardiff in September 2003 and began studying an undergraduate degree at the University of Wales Institute, Cardiff (UWIC). Ian studied Computer Aided Product Design, graduating in 2006 with first class honours, Bachelor of Science Degree. During this time Ian developed a particular interest in the design and prototyping of interactive and digital products. The Information Ergonomics module introduced him to the IE prototyping system, which had been developed at UWIC (Gill, 2003). This began his interest in methods which enable designers to create interactive prototypes that facilitate exploration of user interactions with digital products. It also allowed him to combine his knowledge of computer programming, which he has gained from studying at A Level prior to university, with his knowledge and passion for product design.

Ian went on to study an MSc in Advanced Product Design at UWIC, choosing to focus on the design of computer-embedded devices. Throughout this time, Ian's interest in the design and prototyping of digital products continued, in addition to the adoption of user centric design methods. The masters included a three month industrial placement module. During this time, Ian worked within the commercial design office at The National Centre for Product Design & Development Research (PDR). Ian's role within PDR was to undertake a design brief set by PDR and develop an initial product concept into a more finalised design, informing the design development through the adoption of interactive prototyping methods. The goal was to introduce the subject of interactive prototyping to the rest of the design team at PDR with the intention of integrating the methodology into their design process. One aspect of this project included the trial of an experimental prototyping approach which had been developed by Woolley (2008). The lessons learnt and experiences of using this approach lead to Ian's desire to continue working in the area of early stage interactive prototyping and study the topic as a PhD subject area. Ian was awarded a three year studentship at UWIC to study this topic at doctorate level.
1 Introduction and Overview

The term computer-embedded device can refer to a vast array of products which span many different markets. Examples of computer-embedded devices include microwave ovens, mobile phones, car parking ticket machines, hospital monitoring equipment and in car stereos to name just a few. Whilst we may not think of these products as computers, they all in fact feature embedded computational power (Norman, 1998). These types of devices are inherently complex to design due to the reliance on a multitude of disciplines being involved in their development. These disciplines include industrial designers, electronic engineers, software engineers and human computer interaction designers (Moggridge, 2006, Norman, 1998, Cooper, 2004, Goodwin, 2009).

The need for such a multidisciplinary team to design these products presents a major challenge for industrial designers when attempting to prototype this type of product. Industrial designers simply do not have the electronics or the programming knowledge required to prototype such products, and therefore have limited ability to explore and evaluate design concepts against the product requirements (Gill, 2004, Moggridge, 2006). The subject of prototyping computer-embedded devices has been a popular topic of research for over two decades. Much of this research has looked to alleviate the prototyping challenges faced by designers when dealing with this type of product. Largely this has been approached through the development of prototyping toolkits which aim to reduce the electronics and programming knowledge required.

However, so far there has been very little research which has focused on the interactive prototyping requirements involved with designing computer-embedded devices during the very early stages of the design process. The very early stages are defined as being those when initial ideas and concepts are first conceived by designers. This is a time when designs evolve rapidly and major design decisions can be made with minimal risk (Baxter, 1995, Ulrich and Eppinger, 2008). Some authors have made suggestions relating to what is thought to be required for interactive prototyping during this stage, however these requirements have not been investigated in depth.
This research was undertaken to address this gap within the literature, in particular to explore the interactive prototyping needs of designers involved in the development of computer-embedded devices during this stage of the design process. The approach taken for the research was as follows:

**Critical Literature Review**

A critical literature review was conducted to examine the role of industrial design and prototyping during the early stages of the design process. Existing work relating to the topic of interactive prototyping, within the context of computer-embedded devices, was also reviewed to identify gaps in the current literature.

**Development of Experimental Prototyping Method**

An experimental prototyping tool was developed to facilitate the investigation into the early stage interactive prototyping needs of designers. This tool was developed to act as an intervention in the current design processes of designers, providing an exploratory probe into their needs. The requirements for this tool were informed through the findings and lessons learnt through the critical literature review.

**Investigation into early stage interactive prototyping needs**

A form of experimental case study was used to gain insights into the interactive prototyping needs of designers involved in the early stages of designing computer-embedded devices. Six companies were selected to be involved in the research, with a participant from each company trialling the prototyping tool in a form of user trial. The companies ranged in size and market, from an independent user centric design consultant through to a global mobile phone corporation. The experimental prototyping tool facilitated the exploration of designers needs through its use in the context of a design exercise with a participant from each company.

The research was conducted in order to address the following research aim:

*Explore the interactive prototyping needs of designers during the very early stages of the design process, when developing computer-embedded devices.*
2 Critical Literature Review

2.1 Overview & Background

In the year 2000 the total annual sales of personal computers (PC’s) were reported to be approximately 150 million units’ worldwide. In the same year, approximately eight billion embedded processor units were sold and used in various devices and systems (Want et al., 2002). In 2010 it is estimated that the number of embedded processors present in devices will have doubled to 16 billion units (Fisher et al., 2005). These figures show that in the year 2000 PC sales only accounted for approximately 2% of processor sales and that there were more embedded processors than the population of the world. This clearly demonstrates a tremendous period of growth surrounding the use of embedded processors within products.

Some examples of products and devices where these embedded processors exist are: microwaves ovens, TV set top boxes, MP3 players, games consoles, mobile phones, tablet devices, self serve checkouts, ticket machines and medical devices. Rational for this increased use of embedded processors within products is described by one author as resulting from the fact that it is now often cheaper for manufacturers to use computers than it is to develop mechanical alternatives (Cooper, 2004). Collectively these devices are commonly referred to as Computer-embedded devices. For the purpose of this thesis a computer-embedded device is defined as:

"A product which features embedded computational power, and conveys information to a user through the means of an electronic user interface (e.g. visual, audio, haptic feedback)."

Moggridge (2006), Norman (1998), Cooper (2004) and Kim (1990) state that the design of a computer-embedded device will be dependent upon the skills and expertise of a multi-disciplinary team. This team will often include Industrial Designers, Electronic Engineers, Software Engineers and Human Computer Interaction Experts.
2.1.1 Industrial Design of Computer-embedded devices

Ulrich and Eppinger (2008) state that the role of industrial design is to address the form and user interactions associated with a products design. Heskett (1980) and Dreyfuss (1967) both provide similar definitions; stating that the utility and aesthetics of a product are defined by industrial designers. Dreyfuss became widely known in the 1950's for emphasising the importance of considering the user in detail when designing products. Dreyfuss adopted a scientific approach in order to address the function, look, feel and use of a product. This approach to design differed from others of his time who were typically more focused towards the styling and aesthetics of the products they were designing (Flinchum, 1997).

A number of authors have suggested that successful design of computer-embedded devices will not come from a technology lead approach (Norman, 1998, Sacher, 2002, Moggridge, 2006). Norman (1998) suggests that a model of “technology first, consumer second” can be witnessed across the technological markets. However, he states that adopting such an approach results in products that ignore the real user needs. Using an example of a technology led approach dating back to the late 1800’s, Norman illustrates his point: Thomas Edison was, and remains today, a prime exemplar of an inventor of technologies. However, his products were frequently beaten by competitors who chose to listen to what consumers wanted and valued, as opposed to competing on a purely technical level.

Instead, a User Centred Design (UCD) approach is considered by many to be the key to successful computer-embedded device design. UCD aims to identify, understand and address user needs and goals, and encompass them within a design solution. In addition to addressing functional needs, UCD embraces the much broader factors which make up an overall experience of a product in a user’s life. Sacher and Loudon (2002) described how a UCD approach was key to the successful adoption of 3G technology. Sacher and Loudon emphasised that the success of 3G would not come from a technical understanding of its use, but instead a cultural one. They argue that the development of meaningful applications which use 3G technology was only possible through first developing an understanding of its role within the culture of users. Using a UCD approach, Sacher and Loudon were able to design
interactions, behaviours between a user and a device that would find a value to a new technology.

Norman (1998) suggests that without properly understanding the user of a product, even simple objects such as door handles can lead to confusion and frustration.

According to Ulrich and Eppinger (2008), in general the more interactions a user has with a product, the more the product will depend on industrial design. A door handle, for example, typically has just a single user interface (or interaction). A washing machine on the other hand has multiple interfaces and ways in which a user can interact with it; opening the door, opening the detergent drawer or choosing an appropriate programme / setting.

The washing machine is one example of a computer-embedded device. This type of product will typically present users with a large number of possible interactions varying in complexity and manner. Applying Ulrich and Eppinger's logic, the design of computer-embedded devices will be highly dependent on industrial design. However, interactions with computer-embedded devices exist not only across physical user interfaces but also include digital user interfaces and, in a less tangible manner, also in a mental model that the user develops within their head as to how the device operates. Norman (1998) describes this mental model as the predictions we make in our mind in relation to the effects of our actions.

Defining the use of a product, and how users achieve their goals effectively, easily and enjoyably is increasingly being referred to as Interaction Design (IxD). Goodwin (2009) defines IxD as providing answers to the following questions about a design:

- What activities does the product or service support, and how?
- What flow will allow users to best achieve their goals?
- What information is needed to be displayed to the user at this point in time?
- What does the product or system need from the user at this point in time?
- How can the user move from one function to the next?
- How are the functions of the product organised for ease of use?
Goodwin states that the answers to these questions can all have direct implications on the form and use of a product. It is therefore critical that industrial designers are in a position to explore and answer these questions when designing such products.

Industrial designers are taught to consider the users of products and the implications it may have on a design. Industrial designers have been demonstrating this kind of thinking for many decades through the inclusion of ergonomic principles. For example, if designing a garden fork, a designer may produce a number of different design variations for the handle. The designer can then explore the physicality, ease of use and ergonomics for each design. However, the interactions between a user and a computer-embedded device present industrial designers a much greater challenge.

Mohageg and Wagner (2000) highlight that many user interface design methods have been developed with desktop PC applications in mind. Inevitably this makes their application in relation to the design of user interfaces for computer-embedded devices somewhat limited. For this reason, these devices require bespoke user interfaces which are tuned to the needs of the device and the user, and not that of a desktop PC. Industrial designers are therefore required to design and select appropriate Input / Output (I/O) mechanisms that fulfil the physical and digital user interface requirements appropriately (Mohageg and Wagner, 2000).

Gill (2004) states that industrial designers simply do not have the technical skills needed to prototype electronic circuits, nor do they possess the computer programming knowledge needed to simulate digital user interfaces. Without such skills, industrial designers have limited opportunity to explore the user interactions of a product. Typically designers will only experience the use of a computer-embedded device once a working prototype has been produced much later in the design process (Gill, 2003).

According to Buchenau and Suri (2000) designers are increasingly finding themselves stretching the limits of existing and accessible prototyping methods when designing computer-embedded devices. Consequently they are unable to explore and communicate what a design is like to interact with at a time when
changes can easily be made. Cooper (2004) acknowledges the problem but defends designers by saying they are no less skilled than they were twenty years ago. Therefore he presents an argument that the problem must lie with the nature of the products they are designing and the obsolete prototyping methods available to them.

2.1.2 Prototyping
The term prototyping is used to describe a broad range of methods which are used in a multitude of disciplines. Within the context of product design, prototypes are created throughout the design process for a plethora of reasons and purposes. Furthermore, due to its use across a number of disciplines a number of definitions and connotations associated with the use of the word. The varying definitions, types of, and use of prototypes are examined here.

2.1.2.1 Definitions
In the context of product development, Ulrich and Eppinger (2008) define prototypes as being “an approximation of the product along one or more dimensions of interest”. They go on to state that prototypes have an important role throughout the product development process with four key purposes: Learning, Communication, Integration and Milestones.

Also in relation to product development, Kelley (2001) describes prototyping as a mechanism for problem solving. The key to successful use of prototyping is to ensure each prototype provides something that moves the project forwards, achieving part of your goal.

Houde and Hill (2004) describe prototypes as “a widely recognised core means of exploring and expressing designs”. Within the field of Human Computer Interaction (HCI), a prototype might refer to a test program, or a block of code to try out an algorithm.

According to Lidwell et al., (2003) the goal of a prototype within industrial design is to provide stakeholders, clients and designers with insights into real world requirements. Prototypes allow the visualisation of concepts and allow an
opportunity to learn from design decisions in an environment where changes can be fed back into the specification.

Buxton (2007) believes that sketches are exploratory, whilst prototypes are evaluative. Prototypes, according to Buxton, are tools which set out to answer or define attributes of a products design.

Whilst a number of definitions for prototypes exist, for the purpose of this thesis, the term prototype is defined here as:

“a method or process which results in the development of a tangible object that can be utilised for exploration of specific facets within the design of a product or system at a time when changes can easily be made”

2.1.2.2 Types of Prototypes

Prototypes are used throughout the design process by different people, for different purposes. Ulrich and Eppinger (2008) suggest that prototypes can usually be classified along two dimensions; “physical or analytical” and “comprehensive or focused”. As the name suggests, physical prototypes are tangible artefacts which are built for testing and experimentation. Conversely, analytical prototypes are non-tangible, typically mathematical or virtual models, such as a computer simulation built to determine the structural strength of a component. The second dimension, "comprehensive to focused", refers to the breadth of attributes that a single prototype covers. A comprehensive prototype is one that implements almost all aspects, closely resembling the final intended design in a working manner. The opposite of this is a focused prototype; developed to explore a singular aspect of a design, for example a test bed circuit board.
Lidwell et al., (2003) suggest that there are three types of prototyping: concept, throwaway and evolutionary. The characteristics of these three types of prototypes are summarised in Table 1.

<table>
<thead>
<tr>
<th>Type of Prototype</th>
<th>Characteristics</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td>- Explore preliminary design ideas quickly</td>
<td>Concept Sketch</td>
</tr>
<tr>
<td></td>
<td>- Communicate a design intent to others</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Reveal design requirements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Identify design problems</td>
<td></td>
</tr>
<tr>
<td>Throwaway</td>
<td>- Useful for collecting information about certain aspects of a system</td>
<td>Automotive models for wind tunnel testing, Soft Models</td>
</tr>
<tr>
<td></td>
<td>- Understand and improve upon a design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Learn about a specific aspect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Disposable</td>
<td></td>
</tr>
<tr>
<td>Evolutionary</td>
<td>- Useful when many requirements are unknown</td>
<td>CAD model – FEA</td>
</tr>
<tr>
<td></td>
<td>- Used for evaluation, but built upon in next iteration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- A product of continuous refinement</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Summary of Lidwell et al., (2003) types of prototypes

A common type of prototyping found within the design development process is the use of Rapid Prototyping technologies. Rapid prototyping is defined as a group of technologies that can be used to quickly fabricate a physical representation, or prototype, of a part using three dimensional Computer Aided Design (CAD) data (Wohlers, 2009). Commonly used RP processes include Stereo-lithography (SLA), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS) and Computer Numerically Controlled (CNC) machines, such as milling machines and lathes. The application of such RP techniques is largely suited to the later stages of the design process and is more commonly used for the production of high-fidelity prototypes. This is due to a number of reasons; the cost of such processes is relatively high, and requires detailed CAD data to build the components.

Within a User Centric Design process, one common use of prototypes is for the purpose of usability testing. Usability testing typically compares two or more design variants against each other with target users to determine attributes such as ease of use (Nielsen, 1993). Aside from usability testing, prototypes can provide a tangible property to a design which can be highly valuable when informing opinions
surrounding a design. Concepts which are presented on paper exist in a 2D format only. Kelley (2001) suggests that this can make them easy to reject whereas a tangible prototype encourages excitement surrounding a design.

2.1.2.3 Fidelity of Prototypes

The completeness or level of detail exhibited by a prototype is commonly described as the prototype's level of fidelity. Fidelity is usually described as ranging from low to high. Generally speaking, low fidelity prototypes are most commonly used during the stages of the design process when designs need to be explored quickly and cheaply. High fidelity prototypes are generally more expensive and provide a more comprehensive representation of a design. Consequently, high fidelity prototypes are better suited for use towards the later stages of the design process when major changes are less likely to be required. Rudd et al., (1996) discuss the relative arguments for and against the use of low and high fidelity prototypes during the design of digital systems. A summary of these advantages and disadvantages are shown in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Fidelity Prototype</td>
<td>Lower Development Costs</td>
<td>Limited Error Checking</td>
</tr>
<tr>
<td></td>
<td>Evaluate Multiple Designs</td>
<td>Poor Detail for Specification</td>
</tr>
<tr>
<td></td>
<td>Useful Communication Device</td>
<td>Limited Prototype Automation</td>
</tr>
<tr>
<td></td>
<td>Identify Market Requirements</td>
<td>Limited usefulness for usability testing</td>
</tr>
<tr>
<td></td>
<td>Proof of Concept</td>
<td>Richness of Interaction Limitations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Fidelity Prototype</td>
<td>Complete Functionality</td>
<td>Expensive to Develop</td>
</tr>
<tr>
<td></td>
<td>Fully Interactive</td>
<td>Time consuming to create</td>
</tr>
<tr>
<td></td>
<td>User Driven</td>
<td>Inefficient for proof of concept designs</td>
</tr>
<tr>
<td></td>
<td>Use for Exploration &amp; test</td>
<td>Not effective for requirements gathering</td>
</tr>
<tr>
<td></td>
<td>High level of visual refinement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inform detailed specification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stakeholder leverage tool</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Advantages and Disadvantages of Low and High Fidelity Prototyping as described by Rudd et al., (1996)

McCurdy et al., (2006) argue that in the context of a complex system, the term fidelity is unclear as to which aspect of the system it might be referring to, be it the level of visual refinement, the richness of the dataset being used or the representation of the intended interaction. Instead, they argue that a prototype can be considered to exist across five dimensions:
• Level of Visual Refinement
• Breadth of Functionality
• Depth of Functionality
• Richness of Interactivity
• Richness of Data Model

McCurdy et al., suggest that by each of these five dimensions having its own scale ranging from low to high, allows the purpose of the prototype to be better defined, resulting in a more precise allocation of design resources.

Houde and Hill (2004) agree and also believe it is impossible to prototype all aspects of an interactive system during the early concept stages due to the complexity of prototype required. Instead they suggest prototypes should focus on one of three dimensions, look and feel, implementation and role. They define Role prototypes as being ones that investigate the values a product may possess and how it would impact on a person’s life on an emotional level. Look and feel is described as being used to explore the experience of interacting with a prototype. Finally, Implementation prototypes allow exploration of technical feasibilities and trial possible future interactions using a “works like” approach.

Some authors have written about the dangers and problems which can be associated through the introduction of high levels of detail and fidelity into prototypes during the early stages (Buxton, 2007, Arnowitz et al., 2007, Cooper, 2004, Anon, 2010b, Kelley, 2001). These authors state that high fidelity prototypes can often lead the recipient of the prototype into a false belief that the design has already been finalised. This can inadvertently result in users or stakeholders being restraining in their willingness to offer criticism or honest feedback relating to a design, stemming from the belief that it’s too late to change anyway. User trials may result in users commenting on the smaller issues, such as colour or weight, rather than identifying higher level more serious problems with a design. Furthermore, many authors have promoted the use and benefits of low fidelity prototyping. Gill et al., (2008b), Lim et al., (2006), Sefelin et al., (2003) and Hare et al., (2009) have all written about the value low fidelity prototypes can provide in
comparison to higher fidelity prototypes when prototyping computer-embedded devices. However, it is important to note that the majority of this work has been in relation to the use of prototypes for the collection of usability data and not in relation to the exploration of design concepts.

The literature clearly demonstrates the important role that prototypes play throughout the design process. However, the work within this thesis will concentrate on the use of prototyping during the early stages of the design process.

2.1.3 Early Stages of the Design Process

The early stages of the design process are sometimes referred to as the Fuzzy Front End. Kim and Wilemon (2001) describe it as being the time between "when an opportunity is first considered and when an idea is judged ready for development." The fuzzy front end is regarded widely across literature as being a critical stage in the successful development of new products (Cooper, 1998, Dwyer and Mellor, 1991, Baxter, 1995). Pugh (1990) describes the initial stages of the design process as being a cyclical blend of two essential components:

1) The generation of as many ideas that meet the stated needs as possible.

2) The evaluation of these solutions against the stated needs, identifying which ones offer the greatest level of fulfilment.

When presented with a design problem industrial designers will display a “try early, fail often” mindset (Kelley, 2001). This means that during the early stages of a design project designers will try to pursue as many ideas as possible within a relatively short period of time. A key characteristic of the fuzzy front end comes from a high failure rate and reliance on trial and error (Stevens and Burley, 1997). Learning from both the successes and failures of trying multiple ideas during the early stages, industrial designers will make many fundamental design decisions during this time. This process is defined as Iteration.

An example of a traditional design process is shown in Figure 1. The Fuzzy Front End is made up of the "Concept Generation" phase and the "Prototyping / Testing" phase. Iteration is represented during this time by the circular arrows in Figure 1.
Iteration within the design process allows designers to progressively explore, test and refine design concepts. Wright (1998) states that although iteration is present in all levels of the design process, the initial stages feature a much greater level of iteration than the later stages. A study by Stanford University found that in a comparison of design output, error identification and knowledge gained, those students who used an iterative design approach significantly outperformed those who did not (Dow et al., 2009).

Despite the initial stages being rich with ideas and decision making, the actual costs associated with working during the early stages of the design process are lower than the later stages. Baxter (1995) states sufficient investment of time and effort during the Fuzzy Front End is a critical factor for a successful design process. Investment during this period can reduce the risk of needing to make costly changes during the later stages.
Figure 2 illustrates the relationship between the costs and benefits that can incur during the different stages of the design process. Investing time and effort during the early stages not only provides a return of low costs and high benefits, but furthermore Mabert et al., (1992) state that time reductions of up to 30% can be achieved in overall New Product Development (NPD) processes with sufficient investment of time during the initial stages.

Schrage (2000) defines this process of rapid ideation that occurs during the early stages as “Serious Play”. He goes on to state that without Serious Play, true exploration of ideas or innovation cannot take place. McGrath (1984) suggests that the generation of concepts is best achieved on an individual basis, whilst the evaluation and selection is better suited to working in groups. Pugh (1990) also emphasises the importance of ensuring concepts can be understood by not only the conceiver, but more importantly other people from different disciplines.

2.1.3.1 Prototyping during the Fuzzy Front End

Ulrich and Eppinger (2008) state that during the preliminary conceptual design phases industrial designers will build models for the most promising concepts. Low fidelity prototypes created during this time are often referred to as either “soft models” or “sketch models”. Prototypes of this kind are characterised as being quick and cheap to produce, and are typically considered disposable assets.
Industrial designers will use materials such as blue foam\(^1\) and cardboard for creating rough, low fidelity, prototypes of designs. Sketch models allow designers to explore a concept in a three dimensional form after an initial period of sketching on paper. Designers are able to carve their ideas using basic tools such as band saws, sand paper and hand forming tools, skills which are taught on most industrial design courses. Low fidelity prototypes are commonly recognised for their ability to validate designs and predict potentially major design flaws at an extremely low cost.

The use of such materials during the early stages of design is considered an essential phase in the design process used by Dyson. After an initial stage of sketching and brainstorming, Dyson states that the next stage will always be to move onto working with card and paper, allowing the designers to see if the design can be built and how it works. Dyson’s choice to work with card and paper comes from the low cost, accessibility and the accuracy offered by these materials.

Alterations can be made rapidly and easily, making changes in minutes rather than the hours it may take if working in CAD (Anon, 2010b).

Critical design considerations including the interaction between a user and the product, the overall form, its ergonomics and scale can all be explored through the

\(^1\) Blue foam used by designers is in fact sheets of wall insulation, however it has been used for years within the design industry as a means of producing models to explore three dimensions aspects of a product’s design.
use of low-fidelity prototyping methods. For example, the cardboard model of a vacuum cleaner shown in Figure 4 allows the designer to evaluate and explore various handle designs. Quick studies can be conducted, whereby a number of people are asked to hold and imagine using the card prototype. This can provide highly valuable feedback on the design. Modifications can be made rapidly by simply creating a new handle using card and attaching it to the existing prototype. Myerson (2001) states that at IDEO, three dimensional tangible prototypes are produced at the end of each and every stage of the design process as a matter of necessity.

Second only to hand drawn sketches, sketch models are considered to be one of the fastest methods for evaluating concepts (Ulrich and Eppinger, 2008). Sketch models enable industrial designers to evaluate designs in terms of both the form and use; the two primary roles of industrial design, as stated by Heskett (1980) and Dreyfuss (1967). For these reasons, prototyping of this kind is considered an essential and highly valuable activity within the product design process.

Sketch models have been used during the early stages of product design successfully for a number of decades. However, in the context of computer-embedded device design, the use of a product cannot be sufficiently explored or evaluated through the use of traditional sketch modelling materials and methods alone. This is due to the complexity of the user interactions associated with computer-embedded devices. As described in section 2.1.1, Norman (1998) highlights the fact that interactions with computer-embedded devices exist across the physical and digital user interfaces. Exploration of these interactions, and ultimately the use of a product, requires additional electronics and software prototyping knowledge. As highlighted by Gill (2004), Norman (1998), Cooper (2004), Moggridge (2006), these skills are something that industrial designers do not have. Additionally, the adoption of UCD methodologies for the development of computer-embedded devices further emphasises the need for effective prototyping processes throughout the design process. The availability of suitable prototyping methods to facilitate design exploration is of key importance to the successful adoption of UCD methodologies within product design.
This therefore indicates a significant shortcoming in the ability to prototype designs sufficiently during the early conceptual phases of industrial design when developing computer-embedded devices.
2.2 Existing Research in the Field

The challenges associated with the design, and in particular, prototyping of computer-embedded devices have been an active area of research for some time. Research has derived from academia, the design industry and the HCI community. This work has resulted in a variety of prototyping tools and techniques being developed with the aim to assist the design of computer-embedded devices.

This section reviews a number of the early prototyping techniques which have been adopted from software development and discusses their suitability and limitations for use as a prototyping platform in relation to computer-embedded devices. A case study by Pering (2002) is also reviewed which describes the use of an integrated approach to the prototyping of a computer-embedded device. Finally, the work of the Programme for Advanced Interactive Prototyping Research (PAIPR) is reviewed. The work of PAIPR outlines a number of suggested requirements believed to be essential for early stage interactive prototyping of computer-embedded devices.

2.2.1 Historical Overview of Prototyping Methods for Computer-embedded devices

As described by Mohageg and Wagner (2000), techniques that were originally developed for the purpose of prototyping desktop PC software applications have been adopted for the prototyping of computer-embedded devices. The most common of these techniques are; State Transition diagrams, Façade Prototypes, Paper Prototyping, Wizard of Oz Techniques and Storyboarding. These techniques are critically reviewed below.

**State Transition Diagrams**

State transition diagrams are a method that can be used to illustrate the individual states and relationships that exist within an interactive system (see Figure 5). The use of state transition diagrams for this purpose was first introduced by mathematician and computer scientist Taylor Booth in the late 1960’s (Booth, 1967). State transition diagrams allow the designer to explore and communicate the flow and dynamics of an interface. Construction of a state transition diagram
on a large area such as a wall makes it possible for the designer to "walk-through" an interface to assess the pathway towards achieving specific functions (Jenson, 2002).

Figure 5 - Example of Basic State Transition Diagram for Microwave Oven User Interface

State transition diagrams allow for interfaces to be developed and explored very rapidly as they do not require coding or programming knowledge. This allows the designer to explore far more iterations of a design than if they had to write programming code. This makes the approach highly suitable for use during the initial stages of development (Buxton, 2007). However, they do not allow for any exploration of an interface in relation to the physicality of a device. What is more, according to Buxton state transition diagrams often give more attention to the individual states than they do the transitions between them.

**Onscreen Only Prototypes (Façade Prototypes)**

Onscreen only prototypes, or *Façade prototypes*, are another prototyping method commonly used during the early stages of software development. Façade prototypes are typically created using drawing editing software applications such as: *Adobe Flash, Microsoft PowerPoint* and previously *Macromedia Director*. *Façade prototyping* tools allow designers to construct screens that look and behave like a real application, except there is no real application behind them. The prototypes consist of a series of static screens that simply interchange to give the illusion that the user interface is operational. Unlike state transition diagrams, façade prototypes can be enriched with graphical transitions between each screen (Szekely, 1995). From a software development point of view, the greatest area of weakness relating to façade prototypes is a lack of reusable code. More importantly, from a computer-embedded device perspective, the prototype is only
represented in a two dimensional manner on screen. This therefore provides no opportunity for the user to gain an understanding of, or experience the three dimensional properties of the design (Gill, 2005).

**Paper Prototyping**

The term *Paper Prototyping* is used to describe a method of user interface design, testing and refinement. Dating back to 1990, a handful of usability pioneers explored its use, although at this time it remained largely unknown to the design industry. During the 1990’s its use became increasingly popular, companies such as Microsoft and IBM were among those who adopted the technique. One definition of *Paper Prototyping* is:

“... a variation of usability testing where representative users perform realistic tasks by interacting with paper versions of the interface that is manipulated by a person “playing computer”, who doesn’t explain how the interface is intended to work.” - (Snyder, 2003)

Paper prototypes are associated with the early stages of User Interface (UI) design, and typically are developed to a low level of visual refinement, although the technique can also be used for more refined UI concepts. Despite having originated for software and website development, *Paper Prototyping* can be, and has been, used when designing computer-embedded devices. Low fidelity "soft model" prototypes can be combined with paper prototypes of UI concepts with ease (Spreeenberg et al., 1995). This approach allows the ergonomics and physicality of a product to be explored in tandem with the user interface and interactions (see Figure 6).

Paper prototypes can be simple hand drawn sketches of the individual screens and screen elements, or created using software applications such as Adobe Illustrator or Photoshop to create more refined sets of screens. Construction of this kind provides a very low technical threshold and is highly accessible to industrial designers since it involves no programming or electronics knowledge, providing a close fit with their existing skills.
Unlike many other prototyping methods, Paper Prototyping allows changes to be made to a UI rapidly, even whilst a user test is being conducted. Aside from the ease of construction, conducting user tests with paper prototypes can be labour intensive for the facilitator playing computer. In order for the prototype to work effectively the facilitator must have a comprehensive understanding of the interface and be well practiced in the changing of the paper UI elements prior to conducting a user trial. Nevertheless, paper prototypes have been proven to be a useful method for uncovering high level interface design issues with a minimal investment of time (Snyder, 2003).

The last decade has seen an increased interest in research surrounding the use of Paper Prototyping within the field of HCI. A study by Liu and Khooshabeh (2003) concluded that as interfaces progressively migrate from the confines of desktop computers and onto an increasing array of computer-embedded devices, Paper Prototyping is able to offer a much less complete prototyping method, when compared to an interactive prototype. However, they reported a significant difference in the time needed to implement major changes to the design. The results of Liu and Khooshabeh’s study found that iterating the interactive prototype took no less than one day to implement, whilst changes to the paper prototype could be made on the spot.
A similar study by Sefelin et al., (2003) concluded that Paper Prototyping and low fidelity computer based interactive prototyping led to almost identical data in terms of quantity and quality of critical user statements. However, it was also discovered that users preferred interacting with the computer based prototype over the paper one. According to the results this was largely due to a reduced feeling of being watched when using the computer based prototypes. The authors concluded their study by saying Paper Prototyping remains a powerful tool and can be useful in particular when prototyping tools do not support design ideas and when members of the team lack software programming skills.

**Wizard of Oz Prototyping**

*Wizard of Oz Prototyping* is a term used to describe a technique for prototyping a device or system which may feature future, or incomplete technology. To the users of a Wizard of Oz prototype, the device appears to be fully functional. In reality the device is a dummy with its functionality being controlled remotely by a human, known as the “Wizard”. Through the use of trickery and simulated system responses, Wizard of Oz prototypes are not restricted by currently available technology, and therefore provide great flexibility for testing future concepts. Wizard of Oz prototypes are particularly useful during the early stages of the design process for rapidly gaining user feedback on an early design concept. Wizard of Oz prototypes are not limited to the application of product design and frequently used within the film industry. Examples of this are the robots C3-PO and R2D2 from the Star Wars films. Rather than trying to build real robots to play the characters, elaborate costumes where created and worn by actors. Whilst it not directly related to the design of computer-embedded devices, this example does demonstrate the possibilities of Wizard of Oz prototyping.
The use of Wizard of Oz prototyping techniques within the design industry has been a recognised method for almost 30 years. John D. Gould (1983), a lead researcher at IBM, explored the concept of a ‘listening typewriter’ as being a potentially useful tool for recording notes, memos and documents. The state of automated speech recognition in 1983 was not advanced enough to produce a reliable system. Instead the team created a simulated system to study the value of a listening typewriter. The simulation set up can be seen in Figure 7.

Sat in separate rooms, the wizard listened to the user talk and typed what they heard. As the wizard typed, the text appeared on the user’s computer screen, creating the illusion of a computer that was able to interpret speech and convert text. By using Wizard of Oz prototyping in this way, the development team were able to introduce variables such as accuracy of recognition, very easily without the need to do any programming. This is an example of one of the first recorded times Wizard of Oz prototyping was used to test a new product concept. Although this dates back to almost three decades ago, it remains a strong example of the strength Wizard of Oz prototyping has for testing new product ideas which feature incomplete technology.

Maulsby et al., (1993) also reported their use of Wizard of Oz Prototyping, for the testing of an “instructible” [sic] computer agent. In particular it was found that the ability to test a system without the need for actually implementing a working
prototype was of significant benefit. This enabled the involvement of real users in a number of iterations to the system’s design, without requiring long periods of time to alter the prototype system.

Similar to Paper Prototyping, Wizard of Oz techniques are not without their own shortcomings. Both prototyping methods require the heavy involvement of a facilitator taking the role of a computer, or offering some kind of computational power to the prototype. This can not only become tiring over time for that person, but as the system increases in complexity so does the level of concentration required. This does not alter the fact that both Wizard of Oz and Paper Prototyping are methods which offer a high level of flexibility and speed when it comes to prototyping and testing interactive user interfaces.

**Storyboards**

Pictorial storyboards allow a designer to understand and communicate the context of a product’s use within a fictional setting. Storyboards are similar in nature to state transition diagrams consisting of a sequence of frames, with the additional benefit of placing the product in a context of use. Storyboards can be paper or multimedia based. For the purpose of computer-embedded devices a storyboard may tell a story about a potential new feature of a product and how it might be used. Buxton (2007) describes storyboards as being powerful tools for encouraging designers to place their design "in the wild" and for communicating an idea to other stakeholders. Storyboards, like state transition diagrams, offer no opportunity to experience the relationships between the physical and software elements of a design first hand.

2.2.2 An Integrated Approach to Prototyping Computer-embedded devices - Handspring Case Study

Perring (2002) described the use of a physical prototype, referred to as a ‘BUCK Device’ during the development of the user interface for one of Handspring’s communicator devices. Prior to using this method, Handspring used Paper
Prototyping and façade prototypes when developing initial user interface concepts. The ‘BUCK device’ was a high fidelity physical device tethered to a laptop PC via a cable. The laptop ran a simulation of the software user interface, which could be operated by pressing the buttons on the physical device. Compared to the previous prototyping methods used by Handspring, the addition of a physical prototype used to trigger a software UI prototype lead to an increased number of design issues being identified. These issues included:

- Holding the product with two hands whilst interacting with it
- Correlation and relationships between hardware keys and the on-screen graphics
- Physicality of the device introduced the concept of associated mappings with existing similar devices such as TV remote controls.
- Ergonomic issues relating to user with varying hand sizes, and the consequential button placements.

Subtle differences were also found to exist between the use of Paper Prototypes and what this method offered. For example, the reaction time between a user and the device was smoother and reported to feel more "real" when using the ‘BUCK device’. Paper Prototyping suffered from a delay whilst the facilitator swapped the screens following a user’s interaction. Finer details such as the length of time a button is held down for were highlighted as being benefits of a hardware-software integrated approach.

Approaching prototyping in this integrated manner had shown that testing a user interface in tandem with a physical device offered a number of clear benefits to a design process over a software only approach. However, the example described by Pering only afforded Handspring the opportunity to work in an iterative manner in relation to the software user interface development. This was because the physical device design had already been largely defined by this point in the design process. Furthermore, and perhaps more critically, the production of the physical device, the ‘BUCK’, was reported to have required the expertise of five engineers; mechanical, hardware, electronics, software and industrial. This therefore presented a serious
barrier in terms of the approach being suitable for use by industrial designers, despite having proven to offer valuable design insights.
2.2.3 Programme for Advanced Interactive Prototyping Research (PAIPR)

PAIPR has been researching the design of computer-embedded devices for almost a decade. As a research group, PAIPR's aim has been to identify and understand the prototyping needs and barriers faced by designers of these challenging products. Using this knowledge, PAIPR set out to develop prototyping methods which would reintroduce the use of test rig style prototypes back into the hands of the industrial designer when developing computer-embedded devices. PAIPR's proposed design process for computer-embedded devices is shown in Figure 8.

![Figure 8 - PAIPR's proposed design process for computer-embedded devices design](image)

Work began with the development of a low tech piece of hardware called an IE unit (Gill, 2003a).
Similar to the ‘BUCK’ device described by Pering (2002) used by Handspring, the IE unit allowed a physical device to interface with a software user interface (UI) simulation running on a PC. Despite sharing a number of similarities, there were two fundamental differences between the IE System approach and that of the approach taken described by Pering. Firstly, the IE system aimed to provide an iterative prototyping method for the software UI and the physical device design. Secondly, it was important that the actual construction of the physical interactive prototype was achievable and accessible by industrial designers.

The IE unit allowed software user interface events to be triggered via keyboard outputs. Unlike the ‘BUCK’ device produced in the Handspring case study, the tangible prototype required very little technical ability in order to produce. A soft model or facsimile prototype, featuring embedded micro-switches, could be attached to the IE unit via a ribbon cable (see Figure 9). The result was a realistic interactive prototype that allowed iteration in terms of hardware and software (Gill, 2004) which required only basis electronics and programming skills. The method provided a good fit for designers’ skill set and has been used to produce hundreds of prototypes by designers and undergraduate students.

In addition to use by students, the early version of the IE system was trialled with three key industrial collaborators: Sony Ericsson, Samsung Design Europe and Alloy Total Design. The system was also extensively used to support academic research.
surrounding the impact of prototype fidelity on the quality of data gathered during usability testing (Woolley, 2008).

Summary of PAIPR’s Findings

Through a number of studies and collaborations with industry, PAIPR have trialled the IE system resulting in a number of valuable lessons being learnt relating to the prototyping of computer-embedded devices. Empirical studies had proven that the use of tangible interactive prototypes provided a greater level of accuracy when representing the user experience than was possible with on screen only prototyping methods. The importance of physicality was also shown to be a key element that can affect the efficacy of a prototype during user testing (Hare et al., 2009). PAIPR’s research also provided insights into subtler needs of designers involved in the development of computer-embedded devices through qualitative research.

Extensive research by PAIPR has proven the value and benefits of adopting an integrated prototyping approach when developing computer-embedded devices. Despite having made significant progress in reducing the time and resources required to produce interactive prototypes, further work is still required in the area. Gill et al., (2008a) suggest that for interactive prototyping to be successfully integrated with the design process of computer-embedded devices, more work is needed to fulfil the needs of designers during the early stages of concept development. The following criteria are suggested by Gill et al., (2008a) as being essential criteria for interactive prototyping to achieve adoption during the early stages:

- **Providing a close fit with the ways designers work is key to the success of a prototyping method. Therefore low fidelity interactive prototyping should be achievable within one-two hours, and require no electronics or programming knowledge to use and be easy to learn.**

- **A wide range of inputs should be supported, including touch screen, analogue and digital inputs.**
- Ideally a wireless solution would be preferable. However, the technical implications to this may impact the scale of input devices and the wireless distance (range).

- Toolkits should not be limited to use by industrial designers, as it is likely other members of a multidisciplinary team may require to use it.

- Scale of prototyping is perhaps more critical than first believed, therefore a toolkit should be capable of allowing 1:1 scale prototyping.

- Inclusion of a screen in a prototype in some applications, however further research is needed to ascertain exactly when this is required.

The extent to which a prototyping method of this kind would fulfil the needs of designers during the early stages of the design process has yet to be explored. An investigation into the interactive prototyping needs of designers during the early stages represents a gap in the existing knowledge.

2.3 Interactive Prototyping Toolkits

Over the last decade a number of research groups have also attempted to tackle the problems of designing and prototyping computer-embedded devices. Much of this research has resulted in the development of so called "toolkits" aimed to alleviate some of the prototyping barriers. As is the case of PAIPR's IE system each approach has its place and has contributed to making some progress within the field. These toolkits are critically reviewed below, drawing on both their respective authors’ findings as well as the findings already discussed earlier in this chapter in terms of their suitability for prototyping computer-embedded devices.

Phidgets

Phidgets, short for physical widgets, is an electronics prototyping platform developed for use by computer programmers (Greenberg and Fitchett, 2001). It was originally developed to allow software developers to integrate hardware and software systems during the development process. The platform consists of a wide
range of input sensors including buttons, sliders, dials, touch sensors, force sensors and proximity sensors to name a few.

Phidgets also supports the integration of output devices including servos, relays and numerical LCD panels. Each I/O device is mounted on a Printed Circuit Board (PCB) and attaches to a central microcontroller board which in turn connects to a computer via USB. Phidgets’ key strengths come from the wide variety of sensors that are supported by the platform and the abstraction of electronics knowledge needed to connect components. However, since Phidgets has been developed for use by computer programmers, its integration with interface authoring software such as Microsoft PowerPoint or Adobe Flash is not trivial and requires an understanding and working knowledge of computer programming, something many industrial designers are simply lacking. Furthermore, the physical scale of the Phidgets hardware is somewhat large (see Figure 11, Figure 12 and Figure 13), making the embedding of components within small handheld device prototypes a significant challenge for designers. What’s more, embedding the electronics inside
of a prototype naturally has a negative effect on the ease of iteration, something that is known to be essential during the early stages of the design process (Schrage, 2000, Wright, 1998, Pugh, 1990, Baxter, 1995).

**Switcharoos**

Switcharoos is a toolkit that eliminates the need for a prototype to be hollowed out in order to add interactivity (Avrahami and Hudson, 2002). Intended for use during the very early stages of the design process, Switcharoos allows interactivity to be added to a foam sketch model without needing to commit to wiring and soldering. Instead, Switcharoos were based upon a set of modified passive RFID tags which featured a switch spliced into the circuit between the *Integrated Circuit (IC)* and the coil antenna. The modification meant that the tags could be within the read range of a reader, yet would remain undetectable until the switch / button was pressed, completing that particular tag’s circuit. This essentially created a set of wireless, battery-less, uniquely identifiable buttons that could be positioned freely on the surface of a sketch model. Drawing pins on the base of each Switcharoo allowed the buttons to be added, removed and repositioned without committing to a permanent position, unlike the construction of prototypes built using the IE system (Gill, 2003a). The system initially showed great potential at achieving a similar prototyping speed to that of a product that does not feature embedded computational power.

Despite showing great potential at providing designers with an interactive prototyping method suitable for use during the very early stages, Switcharoos was not without some major limitations. Firstly, as was the case with Phidgets (Greenberg and Fitchett, 2001), the individual interactive buttons were large in physical size. Unlike Phidgets, the scale of each I/O device was not dictated by a PCB, but rather the use of passive RFID meant that each button featured a coil antenna approximately 25mm in diameter. Whilst it is possible to get passive RFID tags with antennas around 10mm in diameter, as the size of the antenna is reduced, the read range also gets smaller. Switcharoos was reported to have a very limited read range of approximately two to three centimetres; therefore using
smaller tags would only exacerbate this short read range even further. Whilst the individual buttons were wireless, in order for them to work, the prototype needed to be held very close (nearly touching) a desk-based reader. This therefore created an invisible field in which the prototype needed to be held within, potentially altering the true interaction that the user would have between the device and its use.

**Calder**

The authors of Switcharoos went on to develop another attempt to produce an interactive prototyping toolkit, The Calder Toolkit (Lee et al., 2004) using the lessons learnt from Switcharoos. Similar to Phidgets (Greenberg and Fitchett, 2001), The Calder Toolkit supported a much greater range of inputs than Switcharoos, including dials, sliders and four way directional pads. Wireless components featured an improved read range than had been possible with Switcharoos. This was achieved by abandoning the use of passive RFID technology and opting for battery powered Radio Frequency (RF) communication. Consequently, this impacted the size of the wireless controls, making them even larger than the individual Switcharoos due to the need for internal power supplies for each I/O device as well as the wireless electronics also required. The wired components on the other hand did show some improvement on the size of each component, however, the flexibility and fluidity of Switcharoos had now been lost for two fundamental reasons. Firstly, the need for connecting wires made prototypes fragile during use. Whilst secondly, precise reconfiguration of the input devices was also limited due to the grouping of input components into predefined configurations mounted on PCB’s. For example, the four-way d-pad could only be repositioned as a whole array, and did not allow individual buttons to be repositioned. This therefore meant that the exploration of the hardware UI was largely limited by the formation of the predefined button arrays supplied by the tool.

**BOXES**
BOXES (Hudson and Mankoff, 2006), short for Building Objects for eXploring Executable Sketches, looked to remove the complexity brought about by the Calder toolkit and facilitate a button based approach focusing on size and component positioning. Similar to Switcharoos (Avrahami and Hudson, 2002), BOXES was intended for use at the earliest stage possible in the design process. The toolkit featured a small microcontroller unit, capable of supporting eight capacitive touch sensors that could be made out of everyday materials such as drawing pins and tin foil.

Instead of opting for integration with existing software authoring packages such as Adobe Flash, BOXES featured its own software application. Instead of providing a tool similar to Adobe Flash, Microsoft PowerPoint, or DENIM (Lin et al., 2002), in which designers can construct their own software user interfaces, the authors opted for an altogether novel approach. The application allowed the hardware to be programmed to operate controls within existing software applications. For example, if a designer was developing an MP3 player, rather than having to construct a simulation interface capable of playing, stopping, pausing, choosing a music track etc, BOXES provided a method to use an existing music playing application such as Windows Media Player. The designer would simply highlight the element of the existing interface they wanted to relate to one of the hardware touch sensors and a relationship would be established. Once again, some progress was made in overcoming some of the previous challenges faced by Calder and Switcharoos. The scale of the touch sensors was an improvement upon the passive RFID enabled buttons of Switcharoos and also allowed for individual component level customisation, unlike the Calder toolkit. The software application did provide a simplistic method of integrating the hardware and software elements. However, BOXES failed to address a number of fundamental requirements. Firstly, the software application was extremely limited in functionality and restricted the flexibility of the system. Early trials revealed those who tested the system would have preferred integration with Adobe Flash. Furthermore, the hardware prototypes constructed using BOXES were only two-dimensional cardboard outlines, far from supportive of the 3D nature of sketch modelling discussed in
Section 2.1. Moreover, by using capacitive touch sensors, BOXES inadvertently removed the tactile feedback typically found when pressing a button. Whilst an attempt to replace the physical feedback of a button with an audio beep was made by the authors, this proved to be unpopular during testing with potential users of the system. Although Gill et al., (2008b) found significant merit in low fidelity prototyping during the early stages, they also found that the removal of physical attributes, in particular, tactile feedback could have significant adverse affects on user performance. Furthermore, rather surprisingly, the Calder toolkit (Lee et al., 2004) previously identified robustness issues associated with wires running on the surface of a prototype connecting components. Despite this previous knowledge, BOXES too was found to suffer from robustness problems owing to the very same problem. Finally, BOXES was only capable of supporting up to 8 separate inputs, far fewer than suggested as being needed by the findings of (Gill et al., 2008a).

**d.tools**

Around the same time as the work of BOXES was published, another approach that had been developed by Stanford University was also published. d.tools (Hartmann et al., 2006) is perhaps one of the most comprehensive toolkits and efforts made towards developing an approach for computer-embedded device prototyping. The system aims to cover iterative interactive prototyping, testing and analysis of the data gathered by using the resultant prototypes. d.tools comprises a wide range of input/output devices including both analogue and digital inputs. The kit also includes a small LCD screen which can be embedded within a prototype (see Figure 14).
Besides the hardware prototyping capabilities of d.tools, the toolkit included a software application that featured a custom software UI authoring platform allowing users to create interactive UI simulations via a state transition diagram metaphor approach, similar to DENIM (Lin et al., 2002). The software application also provided a means of analysis, capturing the inputs made by the user from the hardware prototype and the related UI journey taken. As did Gill et al., (2008b), the authors of d.tools recognised the importance of prototyping accurately to the desired scale. As such the I/O devices featured by the toolkit are indeed relatively compact. d.tools clearly outperforms many other prototyping toolkits and methods as it offers a highly integrated design and analysis approach.

However, its suitability for use during the initial stages of the design process is fairly limited and would require some modification to make it more suitable. Studies conducted by the authors of d.tools revealed that, like BOXES (Hudson and Mankoff, 2006), the custom software interface authoring platform proved unpopular with designers, and an integration with Adobe Flash would have been preferable. The construction of the hardware prototype using d.tools presents the same problem as the IE system (Gill, 2003a), Phidgets (Greenberg and Fitchett, 2001) and Calder (Lee et al., 2004), that is that the prototype needs to be hollowed in order to embed components and wires. Furthermore, while d.tools supports the integration of a small screen into a prototype, a large amount of supporting hardware is required to drive the screen. Some of this hardware can be seen in the right hand side of Figure 14 at the top edge of the image. This supporting hardware
either needs to be embedded in the prototype, or creates a bulky tether between the prototype and the desk.

Nam (2005) explored a possible solution to overcome the need of embedding bulky hardware when dealing with screens through the use of Projected Augmented Reality. Preliminary studies, however, resulted in poor legibility of interfaces on smaller prototypes due to the limited resolution of the projector, as well as the shadow of the user obstructing the video projection. Additionally the user is forced to hold the prototype inside an 'invisible box' to ensure it is within range of the projector. This invisible tether of a prototype is similar to the limitation of using passive RFiD's identified by Switcharoos (Avrahami and Hudson, 2002). Furthermore, examples of prototypes which have been built using d.tools show components mounted within plastic housings in fixed positions. This rigid nature does not offer the speed and flexibility needed by designers to explore concepts during the early stages where rapid iteration is essential. This suggests that prototypes built using d.tools would provide a good fit at a similar stage in the design process as the IE system (Gill, 2003a). While it could be argued that the d.tools I/O devices could be mounted to the surface of a blue foam model, the connecting wires could cause issues with prototype robustness and inhibit use as was found with BOXES (Hudson and Mankoff, 2006).

Arduino

Like d.tools, Arduino (Anon, 2007) is another prototyping platform that is perhaps better suited to the later stages of the design process as opposed to use during the initial stages. Arduino is an open source electronics prototyping platform that can build computers for sensing the world around us. In the past three years the Arduino platform has become an extremely popular prototyping tool ‘for artists, designers, hobbyists and anyone interested in building interactive objects or environments’ (Anon, 2007).
The platform orientates around two main elements: a custom Integrated Development Environment (IDE) and a microcontroller based on the Atmel AVR chipsets (Anon, 2010a). Resulting from the fact the Arduino platform is open source, a number of designs have been conceived for the microcontroller. Variations provide a range of processing power, physical size and the number of I/O devices that can be supported. Possibly the most common version is the Diecimila (see Figure 15) which supports 14 digital I/O devices and 6 analogue I/O devices. Owing to the fact that Arduino is, in essence, a microcontroller that is packaged to make its features more accessible, its application of use spans a vast array of possibilities. The platform has seen many extension libraries being developed to further its functionality. The development of these libraries has also been driven by the open-source community. One of these libraries allows Arduino hardware to communicate with Adobe Flash, including more recently, a library making it possible to programme the Arduino using Actionscript 3.0, instead of the Arduino IDE. The combination of Arduino driven hardware and Adobe Flash is of particular interest to those prototyping computer-embedded devices as Adobe Flash has been found to be widely used by industry for the purpose of developing interactive UI
simulations (Gill, 2004, Hartmann et al., 2006, Hudson and Mankoff, 2006). However, this compatibility does not come without the introduction of new problems. Arduino hardware communicates to other devices and PC’s via serial data transmission. Unfortunately, Adobe Flash is not able to directly translate Serial data; therefore a Proxy needed to be established to act as an intermediate between the Arduino hardware and Adobe Flash. While this does provide an answer to the problem, Adobe Flash is not designed to handle large amounts of data being received in this manner, resulting in errors occurring in communication and of data packets. This can mean prototypes which rely on sending constant streams of data, for example an accelerometer measuring the orientation of a product, may perform poorly, making it unstable for tasks such as usability trials where accuracy of interaction is critical.

Arduino presents a very flexible platform, its use by industrial designers, particularly during the early stages of the design process is however somewhat limited. A high degree of programming knowledge and also electronics knowledge is required for its implementation. Moreover, prototypes built using Arduino are typically constructed on breadboards using jumper wires (see Figure 17).

![Figure 17 - Arduino and breadboard prototype](image1.png)  
![Figure 18 - Arduino Interactive Prototype](image2.png)

The construction is such, that integration into a physical prototype is often a challenge in itself, in addition to the electronics and programming knowledge.
barriers. Integration into a prototype will typically involve the fabrication of a PCB (see Figure 18). The labour involved in making a robust Arduino based prototype makes the platform more suitable for use by persons skilled in electronics and programming for the production of higher fidelity interactive prototypes at the later stages of the design process.

**Fritzing**

Knörig et al (2009) identified that many of those who use Arduino, may not be fluent or able to use PCB design software packages. To address this need, Knörig et al., developed a software application called Fritzing. It allows users to replicate their physical Arduino breadboard circuit using on-screen components from a drag and drop library (see Figure 19).

Fritzing uses this information to create circuitry information files suitable for PCB fabrication. Despite not addressing the initial need for electronics or programming knowledge required to construct Arduino circuits, Fritzing does provide an interesting methodology of use. The ‘drag and drop’ visual metaphors used to replicate the physical circuitry in a digital environment show a potentially good fit with how designers work. Abstracting some of the intricacies often associated with learning PCB design software packages can only be described as a positive step in the drive towards meeting Branham (2000) and Cooper’s (2004) needs for providing designers with improved tools.
Figure 19 - Fritzing Software User Interface

LittleBits

LittleBits (Bdeir, 2008a) is a library of discrete electronic components that has gone some way to abstracting the knowledge needed to construct basic electronic circuits. It is described as providing designers with the same level of flexibility and ease of use when dealing with electronic components as they would have with choosing a type of screw from a stock room. Instead of requiring soldering or a breadboard, connections between components are made using tiny magnets. The magnets allow for both a physical connection between parts, as well as providing an electrical connection for building a circuit (see Figure 20).

The kit certainly offers an extremely fast prototyping method for building basic electronic circuits, presented in a novel way, removing much of the electronics knowledge needed for using Arduino (Anon, 2007). In a number of short videos presented by the developer of Littlebits it is possible to see that it allows for rapid iteration with minimal investment of time (Bdeir, 2008b) (Bdeir, 2008c). It can also be seen that the size of the individual elements of LittleBits allow for even early
stage prototypes to be constructed within an accurate scale of the design intent. However, it is not possible to link the LittleBits components to a PC to integrate with a Graphical User Interface (GUI).

![Figure 20 - Littlebits](image)

This presents a considerable drawback for the prototyping of a large proportion of computer-embedded devices which do feature the inclusion of GUI’s in their design. Additionally, the wires used to connect each of the components could present a similar robustness issue that was found to be a problem with the Calder Toolkit (Lee et al., 2004), BOXES (Hudson and Mankoff, 2006) and also breadboard based Arduino (Anon, 2007) prototypes. What’s more, the inclusion and necessity of the two rows of magnets on either side of the PCB’s also impacts the footprint of each I/O device, potentially posing an issue when trying to prototype a 1:1 scale.

**VooDooIO**

Although not having intentionally been developed to be used by industrial designers, VooDooIO (Villar, 2007), provides some potential for use as a rapid prototyping approach for use during the early stages of computer-embedded device design. Building on from the principle of PushPin technology developed at
MIT (Lifton et al., 2002), VooDooIO provides a soft-wired flexible user interface. Its intention was to give users the same level of customisation found within a software interface, at a hardware level. For example within a software environment users can rearrange icons and tools to suit their style of working, VooDooIO aimed to provide a similar approach with hardware.

VooDooIO consists of two main elements; a substrate (featuring two layers of silver coated nylon insulated by layers of silicone foam) and a series of input controllers including joysticks, buttons, dials and sliders. Each VooDooIO input controller has a number of co-axial pins protruding from the underside of the PCB’s. These co-axial pins provide two-fold functionality, firstly; a means of attachment to the substrate, and secondly; a method for communication and power transfer for the individual I/O's. When an I/O device is pushed into the substrate the co-axial pin makes contact with the two layers of silver coated nylon within the substrate material (see Figure 21).

![Figure 21 - VooDooIO Co-axial Pin and Substrate connection](image)

The substrate is connected to a PC via a cable. Built upon the \( \text{i}^2\text{C} \) (1-wire) communication protocol, each I/O device essentially acts as a network node, and the substrate becomes the \( \text{i}^2\text{C} \) bus (Villar and Gellersen, 2007). VooDooIO offers a very similar level of speed in terms of adding and removing I/O's as was found with Switcharoos (Avrahami and Hudson, 2002). The use of a wired connection to a PC eliminates the connectivity issues of Switcharoos, however it does create a tether between the conductive substrate material and the PC.
Exploration of Rapid Sketch Based Prototyping

In 2006 Woolley, a member of PAIPR, saw potential in the combination of DENIM and VooDooIO as a possible route towards extremely rapid sketch based prototyping for designing computer-embedded devices. The concept was not published formally, however a video demonstration was uploaded to YouTube (Woolley, 2006). Shortly after the video demonstrating the combination was created, the experimental prototyping methodology was trialled during an MSc Major Design Project undertaken by the author of this thesis (Culverhouse, 2007).

The experiment tested combining the physical prototyping of VooDooIO (Villar, 2007) and the software interface prototyping of DENIM (Lin et al., 2002) as a means of rapidly developing prototypes for computer-embedded devices. PAIPR had previous identified that DENIM could possibly be a useful tool for prototyping software UI’s. In order to explore DENIM’s potential, they commissioned the modification of an open source version of DENIM to allow transitions between states to be triggered via keyboard presses, thus making it suitable for use with the IE system (Gill, 2003a). Villar, developer of VooDooIO, also provided a modified version of the VooDooIO software, allowing the hardware I/O controls to be assigned an ASCII character.

The combination of the two was trialled during a design project undertaken by the author during an industrial placement within the commercial design team at The National Centre for Product Design and Development Research (PDR). The brief was to develop a conceptual digital camera into a final design, informing the design partially through interactive prototyping methodologies.
Figure 22 - VooDooIO Digital Camera Prototype

Figure 22 shows an example of the physical prototypes that were created using the VooDooIO toolkit, and Figure 23 illustrates the combined prototyping methods.

Figure 23 - Illustration of Combined DENIM and VooDooIO Prototypes

The sketch based development that the experimental system offered, both on a physical prototyping level and at software level showed strong potential. However, as the DENIM interface expanded, it became increasingly unstable. The decision was made to progress using traditional post it note based state transition diagrams as opposed to DENIM. At a later stage within the design process VooDooIO was combined with Adobe Flash, which although lost the state transition metaphor
offered by DENIM, was able to provide a more stable, and extendable, platform for the interface development.

A number of valuable insights were gained through the exploratory combination of VooDooIO / DENIM, and VooDooIO / Flash. It was clear that a toolkit with the very fast and fluid sketched state transition elements of DENIM, coupled with a system that allows for a similar approach for the physical prototyping, as offered by VooDooIO, had great potential. The speed and ease of prototype construction, also the subsequent iterations, showed strong potential at matching traditional early stage prototyping methods for non-interactive products. DENIM’s sketch based method of interaction eliminated the need for programming in order to switch between states of an interface. VooDooIO allowed the interactive input elements to be quickly added, removed and replaced. The need for electronics knowledge was eliminated through the plug and play metaphor, as was found with Switcharoos (Avrahami and Hudson, 2002). For all their plus points however, there are also features of both DENIM and VooDooIO that would require significant alteration to make them ideal for computer-embedded device design.

Although it showed great promise, DENIM quickly became unstable as the interface grew beyond the first few states. Additionally, Hartmann et al., (2006) noted the importance of the ability to support the extension of a low fidelity interface towards a higher level of fidelity as the design develops. DENIM does not support this ability, whereas Flash does. Flash also has the twin advantages of being a design industry standard for designers and popular with designers (Hartmann et al., 2006, Greenberg and Fitchett, 2001, Gill, 2004, Hudson and Mankoff, 2006) and also is a very stable platform. Nevertheless it does require some programming knowledge for the application described here.

Although VooDooIO allowed very fast and flexible physical prototyping, it too had limitations in this particular type of application. The first of these was scale. The importance of physicality has been emphasised by Gill et al (2008b), (Hudson and Mankoff, 2006) and Hartmann et al., (2006) as being a critical factor relating to the tangible prototyping of digital devices. The scale of a handheld product critically
influences the user’s interaction experience, although this has been found to be often overlooked by researchers. VoodoolIO was not designed for this type of application and so its controls are oversized (see Figure 24 and Figure 25).

As a result the prototype was around twice the intended size of the concept. As well as ergonomic analysis limitations, this also increased the chance of errors based on user test data because the size of the product influences the way it is held and operated. Another major limitation of VoodoolIO in this type of application is that it is essentially a two dimensional product. Fortunately the designs being explored in this case only featured input controls on one face of the product but many devices feature controls on multiple surfaces and in some cases do not feature flat surfaces. Attempting to “wrap” the VoodoolIO substrate around a small organic form would be problematic.
2.3.1 Summary of Prototyping Toolkits

The adoption of an integrated prototyping approach, combining a physical device and software UI, has been proven by many to provide significant benefits and merit over a separated approach (Pering, 2002, Gill, 2003, Nam, 2005, Selefin et al., 2003). Prototyping processes which have evolved from HCI and software development disciplines have also been proven to only provide a partial solution when used in the context of prototyping computer-embedded devices (Liu and Khooshabeh, 2003).

Although there have been a number of proposed prototyping methods and toolkits that have come as a result of research in this area, none appear to address the needs suggested by Gill et al., (2008a) in terms of providing a fit with working during the early stages.

The importance of being able to prototype in a rapid and fluid nature has been identified as a key requirement in the work by PAIPR (Gill et al., 2008a). It has been stated that for an interactive prototyping approach to provide a fit within the design process, then it needs to allow for low fidelity prototypes to be produced in less than two hours. It is fair to say that approaches such as Switcharoos (Avrahami and Hudson, 2002), BOXES (Hudson and Mankoff, 2006) and littleBits (Bdeir, 2008a) do come close to this speed. Unfortunately, none of these methods fully achieve this whilst also supporting other critical factors.

Similarly, Arduino (2007) offers a very flexible platform, capable of supporting a wide range of hardware. However, the requirement of electronics and programming knowledge places it outside the skill set of most industrial designers. D.tools (Hartmann et al., 2006) is arguably one of the most comprehensive attempts to tackle the issues of prototyping computer-embedded devices. Despite offering many benefits to designers, d.tools remains perhaps less well suited for use during the very early stages of the design process and is instead better suited for later phase formal usability testing.

The importance of scale, robustness and flexibility are key areas that are often insufficiently fulfilled by existing prototyping methods. Since a large proportion of
the research in this area has derived from the HCI community, many of the shortcomings in prototyping approaches relate to subtle issues about the nature in which industrial designers work. The VooDooIO and DENIM and VooDooIO and Adobe Flash hybrids explored by Culverhouse et al., (2009) demonstrated strong potential for fulfilling the required speed and ease of prototyping suggested by Gill et al., (2008a) however, it too suffered from issues such as scale and suitability for integration into a 3D prototype.

Table 3 summarises the relative strengths and weaknesses associated with each of the prototyping toolkits reviewed in Section 2.3. The strengths and weaknesses indicate the toolkits suitability for use during the early stages of the design process, based on its level of fit against the characteristics of the fuzzy front end described in section 2.1.4.

<table>
<thead>
<tr>
<th>Prototyping Method</th>
<th>Strengths</th>
<th>Weaknesses</th>
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</table>
| Paper Prototyping (Snyder, 2003) | - No coding required  
- Highly supportive of rapid iteration  
- Cheap to implement | - Heavily dependent on facilitator  
- Study shown less effective at detecting UI errors than interactive prototype  
- lack of physicality with interaction  
- no real time interactivity |
| Wizard of Oz (Maulsby et al., 1993) | - Highly flexible method when technology availability is constrained  
- Reduces reliance on other disciplines | - Heavily dependent on facilitator  
- Complex systems can be complex to perform consistently |
| Phidgets (Greenberg and Fitchett, 2001) | - Wide choice of i/o Devices  
- Plug & Play - removes need for soldering or electronics knowledge | - Requires coding knowledge  
- Scale of physical components limits use for ergonomic evaluation  
- Embedding circuitry limits fluidity of prototype construction |
| Switcharoos (Avrahami and Hudson, 2002) | - Facilitates rapid prototype construction  
- Facilitates rapid iteration  
- Removes need for soldering or electronics knowledge | - Very limited read range for passive RFID tags  
- Scale of physical components limits use for ergonomic evaluation |
| Calder (Lee et al., 2004) | - Wide choice of I/O devices  
- Plug & Play - removes need for soldering or electronics knowledge | - Scale of physical components limits use for ergonomic evaluation  
- Embedding circuitry limits fluidity of prototype construction |
| BOXES | - Facilitates rapid prototype | - Prototype only represented |
As it can be seen from Table 3 a single prototyping approach which meets the suggested requirements by Gill et al., (2008a) does not currently exist. This presents somewhat of a challenge in determining whether the requirements described by Gill et al., (2008a) may or may not meet the interactive prototyping needs of designers.
2.4 Conclusions

Over the past decade the number of products which we use on a daily basis that feature embedded computational power has increased dramatically (Want et al., 2002, Fisher et al., 2005). This group of products are often referred to as Computer-embedded devices. Many authors have written about the inherent complexities involved in designing such products (Norman, 1998, Buxton, 2007, Moggridge, 2006, Cooper, 2004). A multidisciplinary team often consisting of industrial designers, electronic engineers, software engineers and human computer interaction experts can be involved in the development of computer-embedded devices. The need for such a multidisciplinary team means that industrial designers simply do not have the necessary electronics or programming skills required to prototype their designs. As a result, prototypes are often only available towards the later stages of the design process, or worse, not available at all (Gill, 2004). This presents a serious problem for designers as they do not have the opportunity to sufficiently explore a design at a time when changes can still be made (Cooper, 2004).

The role of an industrial designer is to appropriately define both the aesthetics and the user interactions of a product which satisfy the product and user requirements (Ulrich and Eppinger, 2008, Dreyfuss, 1967, Heskett, 1980). Ulrich and Eppinger (2008) state that the need for industrial design is directly proportionate to the complexity of the user interactions involved with a product. It is stated that products featuring a high level of user interaction will be more heavily dependent upon industrial design.

Baxter (1995), Kim and Wilemon (2001) state that the fuzzy front end is the optimum time within the design process to make fundamental design decisions. The fuzzy front end provides designers with a crucial time when changes can be made to a design with ease, without the risk and financial implications found with the later stages of the design process. During this time, industrial designers will typically create a high number of sketch model prototypes using materials such as cardboard and blue foam (Anon, 2010. Myer son, 2001). These prototypes are a highly valuable means of exploring, refining and communicating design ideas during
the early stages (Ulrich and Eppinger, 2008). Sketch models of this kind are typically quick and cheap to produce and considered disposable assets. A high failure rate and reliance on trial and error are key characteristics of the fuzzy front end. The ability to try ideas and learn from successes and mistakes is an invaluable part of a designer's decision making process (Stevens and Burley, 1997).

Computer-embedded devices feature complex user interactions which exist not only in terms of the physical design, but also through digital user interfaces and non tangible mental models of how a device should work (Norman, 1998). In addition to this, industrial designers are required to design and select Input / Output (I/O) mechanisms that fulfil the physical and digital user interface requirements appropriately (Mohageg and Wagner, 2000). The implication of these complex interactions is that the skills required to prototype a computer-embedded device extend beyond that of an industrial designer. Industrial designers do not have the necessary electronic or programming knowledge required for prototyping a computer-embedded device (Gill, 2004).

In turn, industrial designers are unable to explore a design concept against its users needs sufficiently during this critical time. The adoption of User Centred Design methodologies further emphasises the importance of access to prototypes from the earliest stage possible in the design process (Norman, 1998. Moggridge, 2006. Sacher and Loudon, 2002). The limited access to appropriate prototypes presents a barrier in the adoption of UCD methodologies.

A review of the existing literature has shown that whilst a variety of work exists which has looked to address the prototyping challenges faced by industrial designers, only a few have focused on prototyping during the very early stages (Bdeir, 2008, Avrahami and Hudson, 2002, Hudson and Mankoff, 2006). Many authors have written about the significant merit that can be gained through the adoption of an integrated prototyping approach when developing computer-embedded devices and the benefits which can be gained from such an approach (Tek-Jin and Woohun, 2003, Sefelin et al., 2003, Liu and Khooshabeh, 2003, Pering, 2002, Gill et al., 2008b). Additionally, many authors have written about the
development of prototyping tools that aim to alleviate the knowledge barriers associated with creating interactive prototypes. However, the majority of these prototyping methods have not been developed with a focus on providing approaches suitable for the very early stages of the design process (Hartmann et al., 2005, Lee et al., 2004, Gill 2003, Pering 2002, Greenberg and Fitchett 2001). A review of literature within the field has shown that there is limited research which has focused on the needs of designers relating to interactive prototyping during the very early stages of the development process.

Research conducted by the PAIPR research group has resulted in a set of requirements thought to be important for the adoption of interactive prototyping during the early stages (Gill et al., 2008a). This work suggests that designers should be able to create interactive prototypes within a time scale of one-two hours. Furthermore, this should be achievable without the need for detailed knowledge of electronics or computer programming. Prototyping speed is considered to be a highly important attribute for early stage interactive prototyping. Gill et al., suggest that a time scale of one to two hours is considered necessary in order to provide a close fit to the level of fluidity and ease of prototype construction that is typically associated with sketch modelling techniques used by industrial designers during the very early stages. The scale of a prototype is also thought to be critical, enabling the designer to evaluate the physicality and ergonomics of its design. Despite these criteria being suggested, there has been no research conducted to explore this space further, to investigate to what extent a prototyping method of this nature would fulfil the needs of designers.

This research proposes to explore the interactive prototyping needs of designers involved in the early stages of computer-embedded device design, building upon the existing work of the PAIPR research group as well as that of the wider literature reviewed.

The toolkits reviewed in section 2.3 clearly show that a great deal of progress has been made in addressing some of the prototyping barriers faced by designers. It is fair to say that some of the methods reviewed have come close to the suggested
prototyping speed state by Gill et al., (2008a), namely Switcharoos (Avrahami and Hudson, 2002), BOXES (Hudson and Mankoff, 2006), and littleBits (Bdeir, 2008). Unfortunately, these methods have not achieved this prototyping speed whilst also providing a close fit to the ways in which designers typically work. For example, the importance of scale and the three dimensionality of prototypes produced. Other toolkits such as Arduino (2007) offer a vastly flexible platform. However, it too suffers from some significant shortcomings, in particular the high dependency on both programming and electronics knowledge required for its use. d.tools (Hartmann et al., 2006) offered perhaps the most comprehensive approach to prototyping computer-embedded devices out of those reviewed. However, due to the limited flexibility of the resultant prototypes and the need for embedding bulky hardware inside prototypes, d.tools does not provide a close fit with the process of early stage prototyping.

Table 3 summarised the relative strengths and weaknesses for each of the prototyping toolkits reviewed and its suitability for use during the early stages. Although some toolkits show potential, none are considered suitable for use on their own as a means of further investigating the research question. Instead the information in Table 3 will be used to inform the development of a new experimental prototyping toolkit intended for use during the early stages of computer-embedded devices design. This new toolkit will be developed in order to create an intervention to facilitate an exploratory investigation into the space surrounding designers’ needs for prototyping computer-embedded devices during the fuzzy front end.
3 Methodology

3.1 Methodology Overview

The literature review has clearly indicated that the very early stages of the design process are regarded as being rich with trial and error, and provides the opportune time for making major design decisions (Baxter, 1995, Kim and Wilemon, 2001). Prototypes play an essential role during this time, providing designers the ability to explore and develop concepts in a manner where risk and investment is substantially lower than the later stages of the design process. However, the multidisciplinary skills required to prototype computer-embedded devices means that industrial designers are unable to prototype concepts in a fast, fluid and iterative manner during this time. This causes disruption and creates barriers towards following the traditional ways in which products are designed and developed.

Whilst a number of attempts have been made to alleviate the prototyping challenges associated with computer-embedded devices, these have typically been aimed at the later stages of the product design process. A review of these prototyping toolkits has shown that none fully address the ways in which designers work during the very early stages.

Gill et al., (2008a) outlined a number of requirements, thought to be necessary in order for interactive prototyping to be adopted during the very early stages of the design process exist. However, the literature review undertaken has shown that there has been no research conducted to explore the extent to which these requirements meet the needs of designers.

Therefore, it is the aim of this research to:

*Explore the interactive prototyping needs of designers during the very early stages of the design process, when developing computer-embedded devices.*

In order to achieve this aim, the research was divided into two sections:
Section 1

The requirements outlined by Gill et al., (2008a) were used as a type of design brief to guide the development of an experimental interactive prototyping tool. This tool was developed in order to provide an exploratory probe that could be used to gain rich insights into the early stage interactive prototyping needs of those involved in computer-embedded device design. The tool was used to create an intervention in the existing design and prototyping processes used when developing computer-embedded devices.

Section 2

A comparative case study method was used to examine the use of the experimental prototyping method within a variety of design companies in order to address the research aim.

3.2 Section 1 - Development of an Experimental Prototyping Approach

The toolkits reviewed in section 2.3 demonstrate a great deal of progress which has been made in the effort towards improving prototyping methods available to industrial designers. As previously stated, it is fair to say that some existing methods come close to providing the speed that is thought to be required for early stage prototyping (Hudson and Mankoff, 2006, Avrahami and Hudson, 2002, Snyder, 2003, Villar and Gellersen, 2007). However, factors such as physicality, scale, ease of use and fit within the skill set of industrial designers have frequently been overlooked.

The individual shortcomings associated with each prototyping method reviewed in section 2.3 were considered to be significant enough to prevent any one single method from being used to investigate the research aim. However, it was evident that a number of lessons could be learnt from these approaches and inspiration drawn from the technologies used in some. In strengths and weaknesses of each approach (summarised in Table 3, section 2.3.1) were used to inform the development of a new prototyping tool.
3.2.1 Requirements for Experimental Prototyping approach – Design Criteria

Using the findings from Gill et al., (2008a) alongside the described characteristics of the fuzzy front end described by authors including Baxter (1995), Kim and Wilemon, (2001) and Myerson (2001) a design brief for the experimental prototyping approach was developed. The key criteria for this prototyping tool were identified as:

- Designers should be able to construct interactive prototypes within a time frame close to that of prototyping a non-digital product. Hudson and Mankoff (2006) state that changes should be possible in seconds and minutes as opposed to hours and days. Gill et al., (2008a) suggested an overall time period of one to two hours is required for a prototyping method to fit in with current design practices.
- It should be possible to produce an interactive prototype without the need for a detailed understanding of electronics or programming knowledge, and not entail a steep learning curve prior to being useful.
- It is important that prototypes are able to accurately represent the intended scale and physicality of the design concept across all aspects of the prototype.
- Integration between the hardware interactive prototype and commonly used software interface authoring software, such as Adobe Flash and Microsoft PowerPoint should be supported and provided in an accessible manner.

The literature review presented in chapter 2 illustrated the mixed opinions within the research community and industry relating to the importance of the integration of screens into early stage prototypes. It was decided that for this investigation the prototyping tool would adopt a method whereby the software UI would be displayed on a computer monitor, similar in nature to methods such as Switcharoos (Avrahami and Hudson, 2002), the IE system (Gill, 2003a) and BOXES (Hudson and Mankoff, 2006).
It was also considered that the ability to allow integration with a wide range of inputs posed more of an engineering challenge than a more philosophical question relating to the fine details of the needs of designers. Consequently, the scope of the prototyping tool was set to primarily address the issues faced when prototyping button based interactions. The decision to focus on this form of interaction was made for the following reasons:

1) Prototyping methods reviewed in critical literature identified that a number of shortcomings still existed relating to the ability to prototype button based interactions in a rapid and iterative way.

2) The primitive nature of a button can in fact provide an opportunity to prototype more complex interactions. For example, the interaction of a slider can be simulated with a series of buttons positioned in a linear array.

3) Buttons and switches remain one of the most common forms of interaction in relation to computer-embedded devices. Since the purpose of this research is to investigate a principle, it seemed logical to address a common form of interaction rather than narrowing the scope of the research by focusing on a more specific type of interaction.

3.2.2 Summary of Prototyping Tool

A prototyping tool was developed to facilitate an intervention in the current prototyping practices of computer-embedded devices during the early stages of the design process. The tool was given the name StickIT. StickIT was developed to facilitate an investigation into the needs for early stage interactive prototyping of computer-embedded devices. StickIT was designed to address a number of the key points Gill et al., (2008a) suggested were required if an interactive prototyping tool was to achieve adoption during the very early stages of the design process. It was also developed to provide a close fit with the skills and prototyping characteristics commonly associated with industrial design during the fuzzy front end. StickIT's approach towards prototyping focused on speed of prototype construction, facilitation of rapid iteration and ease of use by designers.
Figure 26 - Proposed Design Process provided using StickIT

Figure 26 shows the proposed design process that could be implemented through the use of StickIT. The key difference between the process shown in Figure 26 and the process shown in Figure 8 (p44) is the proposed availability of interactive prototyping capabilities at a much earlier point within the design process.

It is important to note that StickIT was developed to a level where it would be suitable for facilitating an investigation into the research aim. StickIT was not developed to provide a commercially feasible or ready prototyping solution. Accordingly, it is important to acknowledge that StickIT had a number of known limitations.
3.3 Section 2: Comparative Case Study Exploration of Early Stage Interactive Prototyping Needs

The literature review presented in Chapter 2 identified that the prototyping of computer-embedded devices during the very early stages of the design process is an area that requires further research. Whilst some progress has been made in alleviating a number of the challenges associated with prototyping these products, little research has focused on the prototyping of these products during the early stages. Gill et al., (2008a) has suggested a number of requirements which a prototyping method must provide in order for it to be adopted during the early stages of the design process. Whilst these criteria exist, there has been no research to explore the extent to which a method of this kind would fulfil the needs of designers during this time. There has been little research to investigate the factors which are important for an interactive prototyping method to support during the early stages.

It was therefore the aim of this research to explore the interactive prototyping needs of designers of computer-embedded devices during the early stages of the design process.

Using the suggested requirements outlined by Gill et al., (2008a) as a form of design brief, an experimental prototyping tool was developed, named StickIT. This prototyping tool was developed to act as an intervention in the current design processes of computer-embedded devices, enabling interactive prototyping to be adopted at a much earlier stage. In order to address the research aim, three research questions were developed in line with the gaps identified in the existing literature surrounding early stage interactive prototyping. These questions are described below, providing links back to the key areas of literature which helped develop each question.

The speed with which a prototyping tool can enable a designer to produce an interactive prototype has been clearly identified through the literature reviewed as an important attribute for early stage prototyping (Gill et al., 2008a, Hudson and Mankoff, 2006, Bdeir, 2008, Avrahami and Hudson, 2002). The development of
StickIT was largely informed through the suggestion by Gill et al., (2008a) that an early stage interactive prototyping tool should enable a designer to produce an interactive prototyping in less than two hours. This timescale is suggested to be necessary in order to achieve successful adoption by providing a similar speed to prototyping as traditional sketch modelling processes. This naturally poses the following question:

- Is it possible to produce an interactive prototype during the early stages within a timescale of one to two hours, and if so is this appropriate?

The literature review also indentified a plethora of existing prototyping methods which can be used to produce interactive prototypes. It was therefore important to identify which prototyping methods are currently used during the early stages. Additionally it was important to examine the relative strengths and weaknesses of StickIT in comparison to these existing practices. This lead to the development of the second question:

- How does a prototyping method of this nature and capability compare with existing methods used within industry?

Finally, it was important to examine the extent to which a prototyping tool such as StickIT meet the requirements and needs of designers involved in the development of computer-embedded devices.

- How does StickIT meet the interactive prototyping needs of designers involved in prototyping computer-embedded devices during the early stages of the design process?

The following sections of this chapter provide a detailed description of the study developed to investigate the research aim and answer the questions presented above.
3.3.1 Considered Study Designs

When designing a suitable study to investigate StickIT's use as a prototyping method, a number of methods and routes were considered. The methodologies that were considered are discussed below.

3.3.1.1 Incorporation into Undergraduate & Postgraduate Design Courses

Both undergraduate and postgraduate product design courses are taught at the University of Wales Institute, Cardiff (UWIC). Included in the programmes of study for both routes are modules which include teaching techniques for designing computer-embedded devices. The aims of these modules are to expose students to the challenges of designing these complex products and to provide an opportunity for them to learn about possible prototyping methods available. These modules were identified as potential platforms for testing StickIT. They could have provided access to approximately 60 undergraduate students and 10 postgraduate students at the time of the research. Unfortunately, this was ruled as unsuitable for a number of reasons:

Firstly, some previous pieces of published literature had trialled experimental prototyping techniques through use with undergraduate and postgraduate students (Hudson and Mankoff, 2006, Dow et al., 2009, Lee et al., 2004, Avrahami and Hudson, 2002, Gill, 2003a, Gill et al., 2008b). It is fair to say that this method was appropriate in some cases, for example using students as users for comparative usability testing. However, for the evaluation and measuring of an approach’s suitability for use within industry, it was obvious that the results were limited by the students’ lack of real world commercial experience or exposure to industry constraints. Therefore the use of such a method could result in data that would not accurately reflect StickIT's potential performance within a commercial design environment.

A further limiting factor was that only one full StickIT toolkit had been constructed. From a practical perspective this would make it impossible to provide 60+ students equal access to the prototyping tool throughout their projects.
Finally, the nature of undergraduate courses requires students to be taught a broad range of subject areas relating to industrial design. Naturally this can result in varying levels of competency and interest across different modules by different students. Whilst this diversity is essential for the student’s learning and completion of their degrees, it is normally the case that some students do not engage with some modules as well as they do others. This could therefore affect the results, reflecting the level of interest and engagement of each student in the overall topic of interactive prototyping rather than an actual evaluation of StickIT’s performance in addressing the issues associated with early stage interactive prototyping. Taking these facts into consideration it was recognised that in order to gain a valid and informed evaluation of StickIT’s effectiveness it was essential this knowledge was obtained through deployment with practicing industrial designers.

3.3.1.2 PDR Commercial Design Team

The National Centre for Product Design & Development Research (PDR) consists of three main strands; an academic research department, an international award winning design consultancy and workshop department. This integrated relationship would, at first glance, appear to afford a hugely valuable opportunity for providing access to commercial design projects and practicing designers. It was hoped that StickIT could be adopted by the design team at PDR for use on consultancy projects. However, at the time this too proved to be unfeasible. Undertaking projects requiring interface and interaction design was a relatively new area that the commercial design department within PDR had moved into. Consequently the number of projects relating to computer-embedded devices that PDR undertook was sporadic, with no guarantee of a suitable project being available at the time of the research. Furthermore, although many past projects had featured some kind of interface, these elements had generally been specified by the client before PDR’s involvement. Therefore it was not considered a reliable method of trialling StickIT as there was no guarantee of a suitable project being available at the time of the research taking place.
3.3.1.3 Action Research Methodology

Action research is described as being a method of research that takes a critically reflective view upon one’s own learning and actions (McNiff and Whitehead, 2002). An action research methodology was also considered as a possible method for evaluating the performance of StickIT.

The use of such an approach could have seen the author adopt the role of an industrial designer and undertake a number of simulated design briefs in which StickIT would have been trialled, exploring its strengths and weaknesses against other existing methods. Whilst the author has a strong background in product design as well as experience of designing and prototyping computer-embedded devices, it was felt that this approach would be unsuitable for a number of fundamental reasons:

Firstly, the author’s experience of computer-embedded device design primarily related to working within a consultancy environment. Research by Gill (2004) had previously shown that there were differences between the needs and uses of prototyping methods between ‘in house’ design departments and those of design consultancies. Secondly, the author’s opinions could be viewed as being biased due to their involvement in developing the novel prototyping approach. Thirdly, this method would only explore StickIT’s potential fit within one design process (that of the author) and would fail to appreciate the differences of how companies operate.

3.3.1.4 Sandpits

A sandpit is an intensive, interactive and innovative workshop event, where a group of free thinking individuals from diverse backgrounds are invited to attend an event, typically lasting between two to four days. The objective of a sandpit is to immerse the attendees in a creative environment and encourage collaborative thinking. The idea of running a sandpit to evaluate the effectiveness of StickIT was considered. Unfortunately, it too faced a number of limitations. While a sandpit could provide access to a number of practitioners in the field of computer-embedded device design, the fact remained there was only one full version of StickIT that could be used. Therefore it would not be possible to allow more than
one person or group to use it at a time, presenting a significant potential barrier in the running of such an event.

3.3.2 Study Design Requirements

The possible approaches that were reviewed previously all have their own strengths and weaknesses in terms of being suitable methodologies for using StickIT to investigate the research aim. The strengths and weaknesses of the approaches considered were used to develop criteria for a suitable study design. These criteria are outlined below:

The aim of the research was to "explore the interactive prototyping needs of designers of computer-embedded devices during the early stages of the design process". As a result in order to gain truly valuable feedback on the real world appropriateness and effectiveness of StickIT, it was critical that those providing feedback were professionals involved in the design of computer-embedded devices. This would ensure the opinions were based upon commercial experience and grounded with real world design process constraints.

It was therefore decided that participants must have active experience of interactive prototyping within their current job role. Furthermore, it was also considered crucial that those trialling StickIT should be involved in the early stages of design projects in order to be able to comment on the fit it may provide with their existing practices. The title of "designer" can be applied to a number of roles within the design industry. It was therefore important to target those closely involved with the interaction and prototyping aspects of design to ensure a sound understanding of the issues they face and therefore be in a position to provide well informed statements.

To assist in measuring the perceived effectiveness of StickIT it was considered necessary for the study to allow the participants to draw a comparison between StickIT’s approach and the current methods of prototyping being used. An objective of the study was to identify current practices used, relating to early stage interactive prototyping, and wherever possible actively encourage participants to compare their typical methods of working with StickIT.
Finally, it was important that the data gathered provided an accurate account of well informed opinions which truly reflected StickIT’s fit as an early stage prototyping tool. This therefore indicated the need for a method which would allow designers to gain firsthand experience of using StickIT within the context of their design processes.

These criteria were used to develop a suitable methodology and inform the design of a study that was able to provide an in-depth and detailed insight into the effectiveness of StickIT.

According to Best and Kahn (1989) there are three possible strategies for undertaking research: quantitative, qualitative and a mixed approach which uses both. Bryman (2008) provides the following descriptions for the characteristics of each strategy:

- Broadly speaking, quantitative research entails the collection of numerical data as a method to view the relationship between theory and research. Quantitative research is described as being deductive and objectivistic towards social realities. Quantitative research often results in statistical findings and the development of generalised conclusions.

- Qualitative research tends to be concerned with the analysis of words as opposed to numbers. Additionally, Gubrium and Holstein (1997) state that qualitative research is Naturalistic in nature, seeking to "understand social reality in its own terms...providing rich descriptions of people and interaction in natural settings".

- A mixed method approach is one that uses both quantitative and qualitative methods.

The aim of this research was not simply to determine whether StickIT was a successful or unsuccessful prototyping method. StickIT was developed to facilitate interactive prototyping at a very early stage within the design process. StickIT was developed to act as an exploratory probe, which it was hoped would allow the interactive prototyping needs of designers to be explored and understood in great depth and detail. An aim of this kind strongly suggests that the Naturalistic
approach to research as described by Gubrium and Holstein (1997) is the most suitable research method for investigating the aim. Grey (2004) argues that case study research is best suited to "how" or "why" questions. Yin (2009) states that in a situation where the researcher has little or no control over events, and when the focus of research involves "real life context", then case study design is a "preferred strategy".

Bryman (2008) states "the basic case study entails the detailed and intensive analysis of a single case". Case study research is not generally used for the formulation of statistical data, unlike surveys or questionnaires; however, it does offer a much greater level of depth and understanding to the data that is gathered. According to Yin, single case studies are vulnerable to the risk of placing "all your eggs in one basket". Comparative Case Study research is a method that entails the studying of two or more cases using very similar research approaches (Yin, 2009). In comparative case analysis the cases can be examined for areas of similarities and differences. The use of a comparative case study method allowed StickIT to be trialled by a number of companies with the introduction of variables such as company size, structure, markets, skill sets and current practices used. Such variables were considered to be highly important in order to gain a greater level of understanding for the effectiveness StickIT offered to the design of a broad spectrum of computer-embedded devices.

When designing any piece of research the question of sample size needs to be carefully considered. Yin (2009) describes the process of determining an appropriate sample size as not being the result of any formula, but rather a matter of discretion and judgement by the researcher. This decision can be informed by the number of anticipated literal replications between cases and time constraints of research projects to name a few variables.

Voss et al., (2002) explains that whilst comparative, or multiple, case study research increases the ability to augment external validity, there are some drawbacks to its use also. They explain that as the number of cases increases, the depth per case is reduced, and the resources required increases (see
Table 4).

<table>
<thead>
<tr>
<th>Choice</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Single Case</td>
<td>Greater Depth</td>
<td>Limits on the “generalisability” of conclusions drawn. Biases such as misjudging the “representativeness” of a single event and exaggerating easily available data.</td>
</tr>
<tr>
<td>Multiple cases</td>
<td>Augment external validity, help guard against observer bias</td>
<td>More resources needed, less depth per case</td>
</tr>
</tbody>
</table>

Table 4 - Choice of number and type of cases - (Voss et al., 2002)

A comparative case study design was deemed the most appropriate research method for addressing the research aims and questions. The exploratory nature of the research lends itself well to the naturalistic nature of case studies, leading to an in-depth understanding of a particular issue within its broader context.

3.3.3 Participant Recruitment

Recruitment for the study was approached using two methods: firstly existing relationships between industry and PAIPR were explored. This method quickly became exhausted as a number of the existing contacts that PAIPR had within industry had since moved to different companies, many no longer being involved in designing computer-embedded devices. Once these sources and contacts had become exhausted a secondary method was used; *Snowball Sampling*. The term is used to refer to a technique that is often used when desired characteristics of participants are rare or specialised (Howitt and Cramer, 2005 ). *Snowball Sampling* works by starting with an initial point of contact, in this case revisiting the existing relationships between PAIPR and industry, and from this point gaining new contacts through referrals and recommendations. This method of recruitment was found to be particularly effective at attracting participants within the required criteria for the study. However, it is important to highlight that the persons required for this research were practicing design professionals working in a specialised field. The study not only required them to give up a lot of their time, but also that their participant was required on a voluntary basis.
During the recruitment phase it was noted that while happy to partake in the research, some of the companies wished to remain anonymous in any subsequent reports or literature produced that disclosed any information from the study. In order to adhere to this request, the identities of all companies featured in the research have been protected and the companies given code names. A summary of the companies that were selected is provided below, along with justification for their value and inclusion in the study.

3.3.3.1 Design Consultancy A

Design Consultancy A is a UK based Product Design consultancy that has been running for over 15 years, employing between 40 - 45 people from a wide range of disciplines. Having won over 13 major international design awards in the past 5 years, Design Consultancy A has experience of working in a wide number of market sectors and has worked on over 200 projects. Design Consultancy A offer the following services to clients: Product Design, Graphic Design, Packaging Design, interaction design, Prototyping and Manufacture, Design Research and Knowledge Transfer. In particular Design Consultancy A have a strong reputation in the development of medical devices, many of which requiring interface and interaction design. Much of the work undertaken by Design Consultancy A has been offering design consultancy services to SME’s. Design Consultancy A do not have dedicated electronics engineers or software development capabilities ‘in-house’ and rely on relationships with external companies for the fulfilment of such work.

3.3.3.2 Design Consultancy B

Design Consultancy B is also a UK based Product Design consultancy that has been in business for over 50 years, and is now one of Europe's largest and leading product design consultancies. Design Consultancy B employs between 80 - 100 members of staff, ranging in disciplines including electronic hardware and software engineering capabilities available in house. Services offered by Design Consultancy B include: industrial design, Design Research, Strategic support, Usability and Human Factors, interaction design, Engineering, Prototyping and Electronics & Software development. Design Consultancy B work in numerous market sectors
including, but not exclusively, consumer goods, medical devices, transport, office equipment, defence and security.

### 3.3.3.3 UCD Consultant

Having worked within industry for over 10 years specialising in User Experience and Interaction, UCD Consultant has experience of working in areas that include, Design Research, Interface and interaction design, Prototyping, Usability Testing, User Research and Ethnographic studies. Projects undertaken by UCD Consultant include a number of international clients in America, Canada, France, India and the UK. Being specialised in UCD methods and strategies, UCD Consultant is not personally an expert in electronics or software programming. Consequently they would typically hire in or outsource such skills as and when required on a project basis.

### 3.3.3.4 Film Industry Equipment Ltd.

Film Industry Equipment Ltd. is a privately owned international firm specialising in the design, development and supply of high quality post production digital film editing equipment for the film industry. Film Industry Equipment Ltd. also develops bespoke software solutions to accompany their product range. Although Film Industry Equipment Ltd. has offices in 5 different countries, the research and development department is situated in their London head office. Film Industry Equipment Ltd. has a small ‘in-house’ design team which consists of industrial designers, software engineers and electrical engineers. The company operates in a very specific market sector, producing high value products in low volume. The products produced include large desk based control panels measuring over two meters in width costing in excess of £28,000 per unit.

### 3.3.3.5 Multi-Platform Communications Corporation

Multi-Platform Communications Corp. is the youngest of the companies featured in this research, founded in 2003. Despite being relatively young, is now considered to be one of the world leaders at developing and providing Peer to Peer communication applications and employ between 1000 - 1250 people. During the early years Multi-Platform Communications Corp. would not have necessarily considered itself as being associated with the design of computer-embedded
devices and were more strictly involved in software development. However, over the past 3 years an increasing number of hardware manufacturers have worked alongside Multi-Platform Communications Corp. to design device specific and compatible versions of their products for use on a number of third party devices.

Consequently this has forced Multi-Platform Communications Corp. to work with an increasing number of different devices. Each device brings its own set of physical constraints and hardware features which influence the development of the applications. According to the research findings of PAIPR, (Gill et al., 2008a, Gill, 2005, Gill, 2009), Goodwin (2009) and Buxton (2007) the need for interactive prototyping tools and methods is not exclusively for industrial designers, but can extend to other disciplines and should therefore offer a multidisciplinary level of accessibility. In addition to this published research, the authors own experience prior to the commencement of this research found this to be true and that it was not strictly the hardware developers who required access to tangible interactive prototypes. Multi-Platform Communications Corp. feature a wide range of disciplines amongst its staff including, interaction design, usability experts, software engineers, anthropologists, graphic design, user experience design to name a few.

3.3.3.6 Global Mobile Phone Corporation

Global Mobile Phone Corp. is one of the world’s leaders in the mobile phone design and manufacturing market. With over 100,000 employees, Global Mobile Phone Corp. is by far the largest of the companies featured in this research and like Film Industry Equipment Ltd. and Multi-Platform Communications Corp. have offices around the world. As a result of being divided across multiple geographical locations it was important that StickIT was trialled with the most appropriate department to ensure the greatest level of validity in the data gathered. Using the Snowball Sampling recruitment method described in Section 3.3.3, it was discovered that a specialist interactive prototyping team existed within Global Mobile Phone Corp. based at their London offices. The purpose of this team was to provide interactive prototyping support for the user interface and interaction design team for both their hardware and software prototyping needs. This therefore made them the perfect department within Global Mobile Phone Corp. to
trial StickIT as they dealt with prototyping computer-embedded devices on a daily basis.

### 3.3.3.7 Recruitment Summary

The criteria for the required research strategy outlined in Section 3.3.2 suggested a comparative case study method as being most suitable approach for addressing the research aim. Primarily by using *Snowball Sampling* (Howitt and Cramer, 2005) six companies were selected for participation in the research. The profiles for each of the companies varied from independent consultants to multinational corporations. Similarly the markets which each of the companies worked within also varied. A diverse selection of companies was chosen in order to explore the prototyping requirements across a selection of very different companies and products. Table 5 provides a summary of the companies recruited.

<table>
<thead>
<tr>
<th>Company</th>
<th>Type of Business</th>
<th>Primary Market Sector</th>
<th>'In-house' electronics / software engineers</th>
<th>Employees (Approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Consultancy A</td>
<td>UK Based Design Consultancy</td>
<td>Medical Devices</td>
<td>No</td>
<td>40-50</td>
</tr>
<tr>
<td>Design Consultancy B</td>
<td>UK Based Design Consultancy</td>
<td>General</td>
<td>Yes</td>
<td>100</td>
</tr>
<tr>
<td>UCD Consultant</td>
<td>Independent Consultant</td>
<td>Interaction &amp; User Experience</td>
<td>No</td>
<td>1</td>
</tr>
<tr>
<td>Film Industry Equipment Ltd.</td>
<td>Design &amp; Production</td>
<td>Post Film Editing</td>
<td>Yes</td>
<td>&lt;75</td>
</tr>
<tr>
<td>Multi-Platform Communications Corp.</td>
<td>Application Development</td>
<td>Communications</td>
<td>Yes (S/W only)</td>
<td>750 - 1000</td>
</tr>
<tr>
<td>Global Mobile Phone Corp.</td>
<td>Mobile Phone Corporation</td>
<td>Global Mobile Phone Markets</td>
<td>Yes</td>
<td>100,000 +</td>
</tr>
</tbody>
</table>

**Table 5 - Summary of Companies Recruited**

### 3.3.4 Need for Design Exercise

Despite the six companies which were selected all being enthusiastic about being involved in the research it became clear that the likelihood of StickIT being trialled in "live" design projects would prove to be extremely challenging for a number of reasons. Firstly, as discussed in Chapter 2, design is an expensive activity which often is conducted within tight timescales. Therefore, the adoption of experimental processes, outside of what a company would typically undertake, could not only
affect project deadlines, but may also be difficult to justify with customers as to how their money was being well spent on reaching a design solution. Secondly, many design projects take a number of years to complete before reaching the public domain. Consequently concerns over the disclosure of intellectual property rights and confidentiality may have caused reservations about the deployment of StickIT in live projects. Finally but not least of all, StickIT is intended for use during the early stages of the design process. It was therefore not feasible, in terms of the overall research programme, to wait until each company had such an opportunity in which StickIT could be used. Despite these concerns it was still strongly felt that the trialling of StickIT needed to be informed through its use and not just a superficial evaluation. To address this need it was decided that a fictional design brief was required that would allow StickIT to be tested by each company within the context of a design project.

A fictional design brief was created outlining the need for the design of a new product that would fall into the category of being a computer-embedded device. It was important that the design brief represented a realistic problem whilst being based around a subject area that the different companies could understand without having to undertake extensive background research.

The importance of scale with regards to prototype construction and the relative freedom of movement between the prototype and a desk had been key objectives when developing StickIT. As a result, it was felt that the design brief needed to focus on handheld devices, therefore providing opportunity to explore these issues. At the time of the research study being conceived, there had been a noted increase in the number of awareness campaigns relating to a rise in drink driving offences being committed in the UK. One particular detail of these offences suggested there was a rise in the number of suspects needing to be taken to a police station to provide a blood sample after an inconclusive breath sample had been given at the side of the road. This process was reported to be costing the police force a considerable amount of time and money. However, if police officers were able to test a blood sample at the side of a road then it could lead to a smoother process and better use of police resources. The design brief was conceived to design and
prototype a new concept for a roadside breathalyser which was capable of testing both breath and blood samples (Refer to Appendix 10.2 for a full copy of the provided design brief).

The expected deliverables of the design brief were deliberately described in a broad fashion, and simply stated:

“Produce a low fidelity interactive physical prototype and accompanying software UI of your design concept using StickIT as a prototyping method”.

Since the purpose of StickIT was to explore extremely rapid prototyping of very early stage conceptual designs, participants were provided with approximately 4 hours to undertake the design brief. It was suggested that 50% of the time be spent for initial concept development and the remaining 50% of the time used for prototyping within the design brief. However, it was emphasised to participants that this was purely a suggestion and that they were free to manage their time as they saw fit and could work for longer than 4 hours is they wished.

The participants would be provided access to the following pieces of equipment and materials during the study:

- StickIT prototyping toolkit
- Foam Board
- Pens and Pencils
- Laptop with Adobe Flash
- Craft Knives
- Sticky tape
- Marker pens
- Blue Foam
- Cardboard
- A3 Sketch paper
- Internet connection
- Sanding Paper
- Masking Tape
- Post it Notes

The materials and equipment that the designers were given access to were deliberately chosen as they were considered items that designers commonly have access too.

3.3.5 Data Gathering Methods

It was essential that a consistent method of data gathering was used across each case. This would assist the cross case analysis at a later stage in the research. The initial design that each case would follow was divided into 4 sections:
3.3.5.1 Stage 1: Introduction & Setting of Design Brief

Stage 1 of each study was used to provide each participant with a short introduction to the background research that had led to the development of StickIT. Although the participants were carefully chosen to be people who were experienced in designing computer-embedded devices it was important to introduce StickIT and its rationale to them.

3.3.5.2 Stage 2: Design Exercise

Stage 2 aimed to provide each participant an opportunity to experience the use of StickIT through the fulfilment of the design brief. The initial study design used a number of data gathering methods in order to capture the use of StickIT by the participant. The investigator used ethnographic observational techniques (Mariampolski, 2006), taking field notes and photographs throughout the exercise. A video camcorder was used to record the trials. Field notes were used to record the length of time the participant spent on specific activities during the design exercise and when certain stages began and ended.

3.3.5.3 Stage 3: Semi structured interview

Bryman (2008) describes the aim of an interview as being an opportunity for the interviewer to elicit specific information from an interviewee such as attitudes towards a subject, beliefs, values, norms and behaviours. There are many types of interview used for social research. According to Bryman the term ‘semi structured interview’ is typically used to refer to a situation where the interviewer has a list of
questions relating to fairly specific topics. However, unlike a structured interview, the order in which these questions or topics are covered is only loosely defined, as is the general framing of the questions. Semi Structured interviews provide the interviewer with some latitude to ask further questions in response to any seemingly important topics. A document called an Interview Guide is generally used during semi structured interviews to ensure that each interview covers the same topics of subject area (Patton, 1990).

Topics featured in the interview guide were heavily geared towards identifying the current practices used for early stage interactive prototyping by each company. Interviewees were encouraged to draw comparisons between StickIT and their current practices wherever possible. A copy of the interview guide that was used can be seen in Appendix 10.3.

To ensure that the interviewer was able to engage with the interviewee fully during the interview a digital voice recorder was used to capture an audio recording of the interviews. This freed the interviewer from the task of note taking and allowed greater attention to what was being said.

3.3.5.4 Stage 4: Rating / Weighting Scale

In addition to the data gathered throughout the design exercise and also the semi structured interview, a further method for specifically comparing StickIT against existing practices was used. In an investigation into the comparison of "Traditional Workshop Fabrication Techniques verses the Integration of Rapid Prototyping Technologies within the Product Design Industry", Evans (2002) used a method called a Rating / Weighting scale. The technique is based on a scoring system around a set of predefined criteria in a similar way to a Likert scale. Each criterion is given a weighting factor dependant on its perceived level of importance by the participants. Two rating factors are then given to each criterion, the first indicating a level of perceived fulfilment that criterion is felt to achieve using one method (in Evans’ case Traditional Workshop Fabrication), followed by a second rating factor for the perceived level of fulfilment through an alternative method (Rapid Prototyping in the case of Evans). Evans used a scale of one to five when
implementing the *Rating / Weighting* method. However, in this case a scale of one to six was used for the possible rating and weighting values, therefore encouraging participants to favour either a positive or negative stance for each criteria. A *rating* value of one indicating very little importance, while a 6 indicating a criterion being considered an essential attribute. Meanwhile, a *weighting* of one indicated little or poor fulfilment of a criterion, with a 6 indicating complete fulfilment of needs. An example of the *Rating / Weighting Scale* that was developed and used within this study can be found in Appendix 10.4.

The literature reviewed in chapter 2 was used to extract specific topics of interest relating to the practice of interactive prototyping. These topics were carefully selected and provided a set of 15 attributes which formed the criteria for the Rating Weighting scale. The criteria selected were:

1. Representation of Intended Interaction
2. Richness of Interaction
3. Ease of Prototype Iteration
4. Immediate Exploration of Error Solving
5. Effective Communication of Design Intent
6. Effective Representation of Intended Physicality of Concept
7. Level of Technical Understanding
8. Level of Visual Refinement
9. Fit within Designers Skill Set
10. Interaction between Designer & Prototype
11. Robustness of Prototype
12. Suitability of Prototype for Conducting User Testing
13. Level of Prototype Automation
14. Level of Ergonomic Evaluation
15. Client / Managerial Persuasion tool

In addition to these 15 criterions, participants were informed they could add their own to the list if they felt an area of importance was missing. Descriptions for each of the criterions are given below along with the key references from which each criterion was identified through. Participants were provided with these definitions to ensure that in each case a consistent interpretation for each topic was established.
1. **Representation of Intended Interaction** - how closely does the prototype represent the intended interaction between the user and the device? Prototyping tools such as Paper Prototyping (Snyder, 2003), Wizard of Oz (Maulsby et al., 1993) and the I.E system (Gill, 2003a) all feature very different levels of representation for the intended interactions.

2. **Richness of Interaction** – How rich or deep is the interaction between the user and the device? Richness of interaction is described by McCurdy et al (2006) as being one of five dimensions that need to be considered when prototyping an interactive system.

3. **Ease of Prototype Iteration** – with what degree of ease is it possible to make subtle iterations to the design and the prototype? It is important to consider both hardware and software changes in relation to this criterion. Rapid iteration is described by Stevens and Burley (1997) as being a critical factor for facilitating the high levels of trial and error which typically take place during the early stages of design. Gill et al., (2008a) also states that rapid iteration is an essential attribute for any easy stage prototyping process to provide.

4. **Immediate Exploration of Error Solving** - How easily does the process allow the immediate exploration of potential solutions to uncover errors during use? Rudd et al., (1996) suggest that whilst low fidelity prototypes facilitate a designer to explore a number of ideas rapidly, with low development costs, prototypes used during the early stages offer little opportunity for error identification with designs. This does however, differ from the work of authors such as Gill et al., (2008), Sefelin et al., (2007) who argue that low fidelity prototypes can be high effective at the identification of design flaws.

5. **Effective Communication of Design Intent** - How well does the prototype communicate the design intent? If the prototype was to be presented to an external person who was unfamiliar with the project how well would they understand the concept? Amongst many other authors, Kelley (2001) and Schrage (2000) both emphasise the use of prototypes as being particularly valuable as a method for communicating a design to others.
6. **Effective Representation of the Intended Physicality of the Concept** - How well does the prototype represent the intended physicality of the concept? Many of the limitations acknowledged in section 2.3 relating to existing prototyping methods relates to the physicality of the resultant prototypes which can be produced. The works of Pering (2002) and Gill et al., (2008b) discuss the inherent importance of the physicality of an interactive prototype.

7. **Level of Visual Refinement** - How well refined is the prototype from an aesthetical perspective? The topic of fidelity, or level of refinement, was clearly identified as a common topic within the literature when discussing prototyping processes.

8. **Level of Technical Understanding** - How well can the technical aspects of the product be represented by the prototyping method? Houde and Hill (2004) suggest that prototypes can be defined as falling into one of three categories: look and feel, role and implementation. Prototypes focused on implementation are developed to enhance a technical understanding relating to a design.

9. **Fit within Designers Skill Set** - How well does the prototyping method fit within the skill set of the designer. Is there a heavy reliance on the learning of new skills, or venturing in methods that are generally unknown to the designer? Fit within the skill set of a designer is one of the key recommendations outlined by Gill et al., (2008a). Furthermore, many of the key challenges associated with prototyping computer-embedded devices stem from the requirement of skills which fall outside of the skill set industrial designers typically have (Norman, 1998, Buxton, 2007, Moggridge, 2006, Cooper, 2004, Goodwin, 2009).

10. **Interaction between Designer and Prototype** – What level of interaction between the designer and the prototype exists? Does the prototype support the ability to interact with both physical and digital aspects of the prototype? A separation between the physical and digital interactions of a prototype has been identified as key limitations with techniques such as Paper Prototyping (Snyder, 2003). Additionally, Pering (2002) suggest an
integrated approach to prototyping provides an increased number of lessons which can be learnt.

11. **Robustness of Prototype** – How robust is the prototype – will it withstand being used for prolonged periods? Prototyping tools reviewed which include the Calder toolkit (Lee et al., 2004) BOXES (Hudson and Mankoff, 2006) and littleBits (Bdeir, 2008) all reported concerns and limitations relating to the robustness of the prototypes produced.

12. **Suitability of Prototype for Conducting User Testing** – Would the prototype be suitable for use as a tool during early user testing phases? Could the use of the prototype in a user test provide valuable user feedback on the design?

13. **Level of Prototype Automation** - How automated is the prototype? Is there a heavy reliance on human “computational power” in order to simulate functionality? Methods such as Paper Prototyping (Snyder, 2003) feature very low levels of prototype automation, whilst prototypes produced using tools such as Arduino (Anon, 2007) can be developed to function in an almost fully autonomous manner.

14. **Level of Ergonomic Evaluation** - How well does the prototype enable efficient evaluation of ergonomic aspects of the design? The importance of evaluating the ergonomic characteristics of a products design through the use of prototypes was discussed by many authors, including (Ulrich and Eppinger, 2008, Moggridge, 2006, Norman, 1998).

15. **Client or Management persuasion tool** - Suitability of using a prototype as a tool when discussing or presenting a concept with a client or stakeholder during the early stages. Kelley (2001) highlighted the value which a prototype can provide when discussing concepts with stakeholders. The tangibility of a prototype often reinforces a designer’s argument when discussing particular design features.

### 3.3.5.5 Participant Consent, Confidentiality & Ethical Approval

An information sheet was produced providing participants with detailed background information on the nature and rationale of the study (See Appendix
Participants were informed prior to and at the beginning of the study that their participation was voluntary and that they were free to withdraw at any point during the study. In addition to the information sheets, participants were also required to sign two copies of a consent form. One copy was for the participant to keep while the other was for the researcher’s records (see Appendix 10.6 for an example of the consent form).

Due to the study involving human participation, it was necessary to gain Ethical Approval from the University of Wales Institute, Cardiff (UWIC) prior to the research being conducted. An application was written detailing the study (see Appendix 10.7) for the application submitted), which was submitted to the Ethics Committee for The National Centre for Product Design and Development Research (PDR). Approval for the study was granted on the 27th October 2009, with the recommendation that as an element of the study would include a prototype modelling stage, that a short healthy and safety introduction be given to the participants prior to use of any tools or equipment required for the study (refer to Appendix 10.8 for a copy of the confirmation of approval letter). The inclusion of such safety guidelines was included during Stage 1 of the study.
3.3.6 Initial Study Design Overview

It had already been anticipated that obtaining time with practicing leading design professionals involved in the development of computer-embedded devices might prove difficult. Furthermore, having developed an initial study design, it was estimated that each study would take approximately 7.5 hours to complete, or the equivalent of one full working day. Bryman (2008) suggests that wherever possible it is good practice to conduct at least one pilot study prior to undertaking a piece of research. According to Silverman (2010) piloting provides an opportunity to learn from your mistakes and to refine a research study design. One might consider a pilot study to be a kind of prototype for the design of a piece of research. Silverman explains that pilots are useful for developing an interview strategy, allowing the interviewer to become practiced in the process and to gauge an understanding of whether a study will result in substantial levels of data from the participants. Using the initial study design described in Section 3.3.5 an initial pilot study was conducted.

3.3.7 Pilot Study #1

The use of undergraduate and postgraduate students had been considered as unsuitable for providing the depth of knowledge required for evaluating StickIT. However, the use of expert practitioners from the design industry for the purpose of piloting the study was not a realistic proposition. As a result, it was felt that the careful selection of a postgraduate student from the MSc Advanced Product Design course at UWIC could provide a suitable participant for a pilot study. The chosen student had shown a particularly keen interest during his undergraduate studies in the Information Ergonomics module that introduces students to computer-embedded device design. In addition to his MSc studies, he had been working as the lead industrial designer alongside a team of medical doctors and engineers on the development of a gesture based input device for disabled people. The keen interest in computer-embedded device design displayed by this particular student, in addition to his exposure to working in a commercial capacity made him an ideal candidate for the pilot study. The student was approached and happily agreed to take part in the pilot study.
3.3.7.1 Pilot Study #1 Findings

As was to be expected, the pilot study uncovered a number of areas relating to the study's design that were in need of refinement or modification. The findings of the pilot are discussed below, in addition to details of the subsequent changes that were required to the study design. The data gathered through the pilot study was not analysed for the purpose of extracting information to address the aims of the research, but rather to assist in the identification of those areas in need of refinement with the study design.

Only one major change was required to be made to Stage 1 of the study. It became clear from the pilot that when introducing StickIT to the participant, simply talking about its purpose and features failed to communicate its use or operation sufficiently. Instead, what was needed was a short demonstration of the system to communicate its use in a clearer manner. The need for some subtle changes to the exact wording used to outline the design brief was also highlighted to ensure clarity over the expectations of the participant.

Stage 2 uncovered a much larger and potentially problematic issue with the initial study design. As described in Section 3.3.5.2, a mixture of video recording, photography, note taking and ethnography were used as methods of data capture. During the study, the author remained present in the same room as the participant for the duration, allowing them to observe the use of StickIT closely. Additionally, the video camcorder was positioned on a tripod at an appropriate angle where it could film over the shoulder of the participant. On reflection, the combination of the author being present throughout the design exercise and the camcorder resulted in the participant feeling. At one point, the participant commented saying, "this silence feels like an exam". Upon reviewing the data from the camcorder it was found to be consistently failing to accurately capture useful footage of the participant as they moved from working at a desk to on a computer to in a workshop. The participant did not comment on the presence of the author, however, he did comment on the video camcorder and stated "the camera feels like I'm on Big Brother". Due to the inconsistency in data capture and also placing the
participant in a situation of un-ease it was decided to remove the video camcorder entirely from the methods of data capture.

The presence, or otherwise, of the author created somewhat of a dilemma in terms of data gathering. The participant was not actually adverse to the author being present during the design exercise. However, the author’s presence may have inadvertently been causing "the observer effect". Patton (1990) notes that the observer themselves may in fact influence the validity and reliability of the data being gathered simply through their presence. Put simply, Patton suggests that when a person is aware that they are being watched they may become self conscious and behave differently than if they are unaware of an observer being present.

Some changes were made to the study design in an attempt to minimise the influence an observer may have had on the behaviour of the participant. A method was needed that would allow for sufficient data to be gathered and that would not fail to record any potentially valuable insights whilst at the same time making every effort to place the participant at ease and not to influence their behaviour. Diaries are often used in field research, providing an individual with an opportunity to document thoughts, events and feelings which are considered to be important (Burgees, 1984). Diaries offer the advantage that the participant is able to record events without the need for the presence of the ethnographer. Participants were asked to keep a record of how long they spent on particular activities, such as initial sketch work, prototype construction, interface prototyping by using the diaries. They were also asked to note any thoughts they had relating to StickIT while using it.

The pilot also uncovered that during Stage 2, the participant struggled to correctly insert the button elements of StickIT into the conductive substrate when constructing their prototype. Correct insertion of the pins into the substrate is a critical requirement in order to create a connection between the RFID ASIC’s in each button and the common antenna. The problems experienced by the participant during the pilot study led to frustration and confusion as to why the interactive
prototype was failing to trigger events on the Flash software interface prototype. This indicated that a small learning curve was inevitable when first using StickIT. It was therefore decided that the study should include an opportunity for participants to trial StickIT prior to the design exercise and familiarise themselves with tasks such as correctly inserting the buttons into the substrate. The aim was to provide the participants with an opportunity to ask questions relating to the correct operation of StickIT outside the design exercise. This opportunity for the participants to "play" with StickIT would therefore be included during Stage 1 of the study design. To facilitate this period of play, a simple game was developed using Adobe Flash.

![Flash game](image.png)

**Figure 28 - Flash game developed for "playing" with StickIT prior to design exercise**

The aim was to make a cartoon picture of a monkey smile by providing a specific keystroke using StickIT. This provided participants with an opportunity to practice the following tasks related to using StickIT:

- Correctly inserting the buttons and common antenna into the conductive substrate.
- Assigning the individual buttons an appropriate ASCII character using the StickIT software application.
- Successfully triggering a Flash movie using StickIT.

The pilot also provided the author with an opportunity to rehearse the semi structured interview procedure in Stage 3 of the study design. The author found
the need for a greater level of familiarisation with the order of the interview guide, but in general Stage 3 required little refinement.

Finally, Stage 4, the use of the rating / weighting scale did not uncover any unforeseen problems and required no changes to be made to its inclusion in the study.

3.3.7.2 Summary of Changes to Study Design following Pilot Study #1

In summary the pilot study successfully identified the need for the following changes to the initial study design:

- The inclusion of a demonstration of StickIT being used during Stage 1 rather than simply describing its use.
- The inclusion of an opportunity for the participants to "play" with StickIT to allow them to familiarise themselves with its use prior to undertaking Stage 2, the design exercise.
- Subtle changes to design brief wording to clarify what the design exercise output expectations were.
- Changes to the data gathering methods used during the design exercise. Video recording and full duration observation were replaced with a diary method and interval observational periods.
- Rehearsal of the interview guide.

3.3.8 Pilot Study #2

Due to a number of significant changes being made to the study design following the first pilot study, it was considered necessary to conduct a further study to trial the refined study design before deploying it with the recruited leading practitioners. The participant for the second pilot study was a graduate from the MSc Advanced Product Design course (at UWIC). The graduate had chosen the Computer-embedded device route during their major project for the MSc, which provided them with foundation knowledge for the design and development of computer-embedded devices. As was the case before, this particular student was also chosen due to their enthusiastic attitude towards the design and prototyping of computer-embedded devices.
3.3.8.1 Pilot Study #2 Findings

Fewer significant changes to the design of the study were required following the second pilot study. The inclusion of a demonstration and an opportunity to "play" with StickIT during Stage 1 of the study proved to be successful. This allowed the participant to become comfortable with using StickIT prior to implementing it during the design exercise in Stage 2. This therefore allowed the participant to concentrate on using StickIT as a prototyping tool. Unfortunately, while they have successfully increasing the participants’ level of comfort in using StickIT, the inclusion of these two activities had also increased the length of time required to complete Stage 1 of the study. It was therefore decided that for the subsequent studies the information sheet and design brief would be sent to the participants prior to their study date. This allowed each participant to read the documents at their own leisure and in their own time, reducing the time required for Stage 1 on the actual day of the study.

The inclusion of the diary and shorter periods of ethnographic observations also proved to place the participant at a greater level of ease during the design exercise. The diary entries were simply short notes at the side of sketch work that recorded any related points that the participant felt was significant.

During the second pilot, the participant stated that he would like to be able to visualise how StickIT may look if it were to be developed into a commercially available prototyping tool. At this stage, there had been little consideration given to how StickIT might look. However, it was considered that by providing participants with a product visualisation might be beneficial in allowing them to engage further with the concept of the experimental approach. A short period of time was therefore spent creating a conceptual design and producing CAD renderings to illustrate it.

3.3.8.2 Summary of Changes to Study Design following Pilot Study #2

The revisions to the study design resulting from the second pilot study were mainly attempts to streamline the process. No major changes to the study design were needed, and only the following minor changes were made:
• Sending the participant information sheet and design brief to the participants prior to the study day in an effort to reduce the length of Stage 1.

• The Inclusion of a product visualisation to further encourage engagement between the participant and StickIT.

3.3.9 Data Analysis Approach
The data analysis approach which was taken was split into two stages. Firstly, each case was analysed on an individual basis, independent of the other cases. Following the analysis of each case in this way, the cases were cross examined using a cross case analysis approach. The cross case analysis was used to look for similarities and differences between the cases.

Transcripts from the interviews were produced using the NVivo software package. This particular piece of software was chosen as it provided a comprehensive environment capable of managing data in a number of different mediums; including audio recordings, photographs and linking to word documents containing field notes. Creswell (2003) described the process of coding as the organisation of material and data. Coding assists the researcher in bringing meaning to the data which has been gathered. Creswell states that coding will often result in the generation of labels for segments of paragraphs, pictures or audio clips using the actual language of the participant. NVivo was initially used for coding the transcriptions of the interviews, however, the author found the number of codes developing became confusing and clouded the analysis process. Instead the transcriptions were printed and coded manually using highlighter pens and post it notes to identify themes and points of interest within the data.

Notes which had been taken during the observations of the design exercises, along with photographs of the exercise were also managed using NVivo. These were also included in the coding process as a source of data and tagged accordingly.

The study timings which were also recorded were entered into a spreadsheet and were broken down into the individual activities which made up the process taken during each of the design exercises.
Finally, the data gathered from the Rating / Weighting scales was entered into a spreadsheet and normalised using the same process described by Evans (2002) in his use of the Rating Weighting method. Normalisation of the data was required to allow the data to be compared across cases during the cross case analysis stage. The normalisation process is described in the following section.

### 3.3.9.1 Normalising the Rating / Weighting Data

Table 6 provides an example of the raw data that would be collected from a Rating / Weighting scale. The method and equations used to normalise the data are described below:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor 1-6 (W)</th>
<th>Rating Factor 1-6 (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation of intended interaction</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>5</td>
<td>4</td>
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<td>4</td>
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</tr>
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<td>Suitability of prototype for conducting user testing</td>
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<td>4</td>
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<td>Level of prototype automation</td>
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<td>4</td>
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<tr>
<td>Level of Ergonomic Evaluation</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Client or Managerial Persuasion Tool</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 6 – Example of Rating / Weighting raw data – (Data for Illustrative purpose only)

The calculations below use the illustrative data above to demonstrate the process for normalising the data within the table.

Firstly to calculate the **Normalisation Factor (Nf)** the following equation was used:

\[
\frac{100}{\sum W} = Nf \quad e.g. \quad \frac{100}{48} = 2.08
\]

---

2 The data shown in this table is for illustrative purposes only and is not related to any particular case featured within this research.
The equation normalisation factor is reached by adding together all of the weighting factors. Dividing 100 by this sum provides a normalisation factor.

Secondly, each weighting factor was multiplied by $N_f$ to provide a **Normalised weighting** ($N_w$) value. The equations below are based upon the data within Table 7 for the "Representation of the intended Interaction":

$$ W \times N_f = N_w \quad e.g. \quad 4 \times 2.08 = 8.33 $$

Thirdly, to produce **Normalised Rating** ($N_r$) the following equation was used:

$$ \frac{R}{6} = N_r \quad e.g. \quad \frac{2}{6} = 0.3 $$

The next calculation produces an **Overall Score** ($O_s$) for each criterion:

$$ N_w \times N_r = O_s $$

Finally, the sum of the individual $O_s$ values would provide a percentage for the level of perceived level of fulfilment for that particular method:

$$ \sum O_s = \% \ of \ fulfillment $$
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<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
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Table 7 - Example of Normalised Rating / Weighting data - Illustrative purpose only

The illustrative normalised data shown in Table 7 indicates a perceived improvement in fulfilment of 18% offered by Process B compared to Process A.

Once each case had been analysed on an individual basis, a cross case analysis was conducted comparing and contrasting each case to identify any trends and interesting results relating to the potential offered by StickIT.
4 Development of Prototyping Tool

Chapter 3 described the approach taken in order to investigate designers' needs in relation to interactive prototyping during the early stages of the design process. From the review of the existing prototyping toolkits presented in Chapter 2, it was clear that an approach in line with the suggested requirements of Gill et al., (2008a) did not exist. However, some of the toolkits featured in the review did show potential and could provide a number of valuable lessons. These lessons could be used to inform the development of a new prototyping tool which could be used to facilitate the investigation into the research aim.

This chapter provides a detailed account of the design process the research conducted which lead to the development of the prototyping tool used as an exploratory probe within the research.

4.1.1 Identification and Exploration of Potential Technologies

From the review of existing literature it was clear that some existing prototyping methods provided strong potential in their ability to fulfil some of the objectives set out for rapid low fidelity prototyping. In particular the methods that were the closest fit with achieving this aim and showed the most potential for further development were Switcharoos (Avrahami and Hudson, 2002), VooDooIO (Villar, 2007) and the IE system (Gill, 2003a).

The fast and fluid placement of I/O devices demonstrated by Switcharoos (Avrahami and Hudson, 2002) and VooDooIO (Villar, 2007) showed great potential for achieving the desired prototyping time. However, as highlighted in the literature review, both approaches were limited by a number of factors including their size and reliability. The use of keyboard strokes to trigger UI changes, as seen with the IE system, proved to provide an accessible method for industrial designers to interface hardware prototypes with software UI prototypes. Despite each approach having a number of limiting factors, each provided a good starting point for the development of a novel prototyping tool.

It could be argued that the use of passive RFiD tags in the Switcharoo (Avrahami and Hudson, 2002) system was ultimately the leading cause of the systems...
limitations. However, passive RFID technology was considered by the author to offer a number of advantages and benefits that were not seen in other prototyping toolkits that were based on other technologies. Passive RFID tags communicate via a technique called modulated backscattering (Rao, 1999). They do not require an internal power source such as a battery, instead each tag is powered via a phenomenon called inductive coupling allowing the tag to gain power from the device attempting to read it (see Figure 29).

![Figure 29 - Diagram showing RFID Coupling](image)

Although available in a variety of forms, all passive tags (sometimes referred to as transponders) consist of two basic elements; an Application-Specific Integrated Circuit (ASIC) and an antenna see Figure 30. The ASIC features two conductive contacts to which each end of the antenna coil is attached. The purpose of the antenna is to absorb the Radio Frequency (RF) field that is emitted by the reading device. This allows power and data to be sent and received between the tag and the reader. The ASIC also features a small amount of Electrically Erasable Programmable Read-Only Memory (EEPROM) which is programmed by the manufacturer with a unique string of data, forming the tag’s ID.
The antenna is made from a coiled enamelled wire, or is sometimes printed on a circuit board. Avrahami and Hudson (2002) modified the RFiD tags by splicing a switch into the circuit between one end of the antenna and one contact on the ASIC. This resulted in a passive RFiD tag that would natively be invisible to a reader, even when inside the reader’s field of detection, due to the circuit being effectively open. This meant that only when the switch was closed would the tag’s circuit once again become complete, enabling it to be identified by the reader (see Figure 31 and Figure 32).

Figure 30 - Diagram of Passive RFiD tag

Figure 31 - Diagram of Switcharoos Modified RFiD Tag Open Circuit
Essentially the modified tags provided uniquely identifiable buttons that could be freely positioned on the surface of a blue foam sketch model without the need for any additional electronic circuitry or wiring. A further benefit provided by the use of passive RFID technology could be considered to be the low cost of each individual tag. Despite a number of positive attributes, the solution was far from perfect for the application of interactive prototyping. As described in Chapter 2, the major drawbacks of Switcharoos (Avrahami and Hudson, 2002) came from the extremely limited read range of the passive RFID tags and the increased physical scale of the input devices. The read range of a passive RFID tag is determined by the size and shape of the antenna, with longer read ranges being possible at the cost of a larger form factor (Rao, 1999). The way in which Avrahami and Hudson had constructed the Switcharoos hardware resulted in the button / switch for each tag being positioned directly on top of the tag itself. This resulted in relatively large input devices making the prototyping of smaller handheld devices on a 1:1 scale unrealistic and unachievable.

An initial attempt to overcome this problem of scale was made by simply increasing the distance between the RFID tags and the button / switch (see Figure 33).
This approach used off the shelf micro-switches, as used with the IE system (Gill, 2003a), on a length of wire, allowing the switch to be positioned as desired, and the RFiD tag could be positioned on the underside of the sketch model (see Figure 34).

This developmental step certainly appeared to address the issue of the scale for each of the I/O devices. This would therefore support the prototyping of concepts to a scale of 1:1. However, the solution was far from perfect:

Firstly, this approach made no progress in resolving the limited read range associated with Switcharoos as the prototype still needed to be held in very close proximity to the desk based reader in order to detect the tags. Secondly, similar to the case of Hudson and Mankoff (2006), the connecting wires between the micro-switches and the individual RFID tags were very fragile with the solder joints on the ASIC frequently found to fail. Thirdly, the wires themselves presented an issue; the question of length quickly became apparent when considering fly-leads. If the
system was intended to be used without the need for electronics knowledge, then the need to solder wires would present a far from ideal solution. Additionally, the need for wiring and soldering had removed the speed and ease of prototype construction that Switcharoos and VooDooIO had previously demonstrated. If the benefits offered by using RFiD were going to be exploited and it was going to be used as a technology for the basis of the experimental prototyping method, then a solution to the scale issue and also the read range was still required.

4.1.2 Boosting Limited Read Range of RFiD Tags

As described in the previous section it is possible to increase the read range of passive RFiD tags by using larger antennas or a more powerful RFiD reading module. Another type of RFiD tag is available, called Active RFiD. A common application of Active RFiD tags is for vehicle identification on tolled sections of road, allowing each car to be identified and payment automatically taken as a vehicle passes a certain point. Like passive technology, each tag has a microchip and an antenna, however, unlike Passive RFiD tags; active tags feature onboard electronics providing a level of computational power which in turn requires an internal power supply (battery). The addition of an internal power source allows active tags to achieve a much greater read range, however, this has a dramatic impact on both the size and cost of the individual tags.

The challenges of working with wireless technologies for constructing prototyping techniques has previously been recognised by Lee et al., (2004) during the development of the wireless I/O components featured in the Calder Toolkit. Typically it had been observed that making an I/O device wireless had a direct negative implication on the scale of the individual components. For these reasons, the use of active RFiD tags to overcome the limited read range of passive RFiD technologies would not provide a viable solution. Instead it would simply introduce further limitations for the system's suitability at addressing the needs and be no closer to providing a suitable method of prototyping than the Calder Toolkit.

Instead, inspiration was drawn from Medynskiy et al., (2007) who had previously used a Serial to Bluetooth device to create a wireless wearable RFiD reader.
Medinskiy et al., (2007) developed a wearable RFID reader for the purpose of a wearable electronic game. In their example, an antenna was sewn into a pouch positioned in the palm of the user’s hand, allowing a tag to be detected when a user placed their hand over it. The RFID reader detected the passive RFID tags at short range, the Bluetooth module then transmitted the detected tags ID to a nearby computer, giving the user (and RFID reader) an increased degree of freedom.

In the application described by Medynskiy et al., (2007) the wearable RFID reader was used to allow users to interact with a number of RFID tags placed on a wall. Depending upon which section of the wall the user placed their hand over, an appropriate event would be triggered. Although this particular application was not for the purpose of interactive prototyping, the wearable Bluetooth RFID reader looked promising as a means to successfully break the invisible tether imposed by the desk based RFID reader. Moreover, the wearable reader would provide a key benefit by eliminating the need to embed cumbersome and expensive electronics within a prototype. This promised to reduce the individual costs of each prototype as the majority of the technology could be worn by the user and need not be built into the prototype itself. This had yet a further advantage regarding the prototype.
construction as it had the potential to mitigate the need to hollow out each prototype in order to embed components within. The hollowing of prototypes had been recognised as being a limiting factor regarding both the speed of prototyping and also flexibility of the previous prototyping methods reviewed in Chapter 2. The hardware used by Medynskiy et al., (2007) was sourced and the wearable reader was constructed, in this case for the purpose of producing an interactive prototyping tool for the rapid development of computer-embedded devices. Once built it was clear that whilst the prototype was no longer bound by an invisible box created by the desk based RFiD reader, the wearable wireless solution presented problems of its own. The antenna in the palm of the glove was only able to detect tags which were placed in very close proximity and in parallel to the palm of the user. When coupled with the extended switch RFiD tags (shown in Figure 33 and Figure 34) it meant that only the tabs positioned close to the palm could be detected. It was, however possible to use the 'extended fly lead' modified RFiD tags and group all of the antennas into a single position on the rear face of the prototype. Whilst this provided a method of using the wearable reader that was capable of detecting all of the tags, the wires connecting the micro-switches and the tags ASIC's still presented concerns over prototype robustness. Prototype iteration was found to place further stress upon the solder joints, adding to the problem. Although use of a Bluetooth link from the RFiD reader showed great potential for eliminating the invisible tether between the prototype and a desk based reader, the robustness and neatness of the prototype itself still required further development.

4.1.3 Development of a Common Antenna System

It had become obvious at this stage that despite the positive attributes of using passive RFiD tags for creating a prototyping tool, the antenna, whilst essential to the tags' functionality, was posing a significant challenge in the technology's suitability for this application. Therefore, in order to benefit from the strengths of passive RFID technology as a foundation of a prototyping tool, a solution to the issues brought about by the antenna needed to be found.
VooDooIO (Villar, 2007) had also previously offered strong potential for the development of a rapid low fidelity prototyping tool. However, compared to the low cost and simplicity of the passive RFID tags involved in Switcharoos (Avrahami and Hudson, 2002), VooDooIO utilised much more complex and expensive components and therefore offered a less 'disposable' asset for prototyping. It also shares many of the same flexibility issues that the comparably complex d.tools (Hartmann et al., 2006) does, namely lack of choice among types of control. Inspiration from VooDooIO however provided a solution to the challenges presented by the antennas needed for using passive RFID tags. As previously described, RFID tags consist of two essential elements; an ASIC and an antenna. However, a breakthrough came when it was realised that the antenna is only required when, in the case of the modified switched tags, the switch is closed (or the button is pressed). Therefore, it was not in fact necessary for each of the tags to have its own antenna. Instead a single antenna could be provided that could be used by all the tags. In order for such a method to work there needed to be a way for each of the ASIC's to connect to the single 'common antenna'. The solution to this was found through the use of the VooDooIO substrate and the coaxial pins from the VooDooIO I/O devices.

The first exploration of the proposed solution was achieved by removing the ASIC from a passive RFID tag and attaching crocodile clips to the two ends of the antenna (see Figure 36). This allowed the antenna to be quickly connected to the two conductive layers in the VooDooIO substrate. The next step was to modify one of the ASIC from an existing RFID tag to allow it to connect to the substrate.

Figure 38 shows a cross sectional view of the VooDooIO substrate material illustrating the connection that exists between the coaxial pin of the common antenna and the coaxial pins of the switched RFID ASIC via the conductive layers.
If this early test proved successful the end intention was to use the same pins as the VooDooIO hardware, but for an early test the ASIC was attached to a piece of VeroBoard (copper Stripboard\(^3\)) containing a micro-switch and two jumper wires (with varying lengths of the plastic coating having been stripped back) to connect to the VooDooIO substrate (see Figure 37). The jumper wires attached to the ASIC were pushed into the substrate and the crocodile clips attached to the common antenna were also attached to the substrate. The wearable Bluetooth RFID reader

\(^3\) Stripboard or VeroBoard is a widely used prototyping tool for electronic circuits. The board consists of parallel strips of copper with holes in, allowing the insertion of electronic components.
that had previously been built was used to test the common antenna test rig. The common antenna was aligned with the antenna of the wearable reader and using Hyper Terminal on a PC, a connection to the Bluetooth reader was established. Upon pressing the micro-switch on the VeroBoard the ID string of the ASIC was displayed on the Hyper Terminal window on the PC. This result meant that a successful connection between the ASIC on the VeroBoard and the common antenna had been made using the substrate. A second switched ASIC was fabricated, the purpose of which was to test the system with multiple ASIC's connected to the substrate.

Further tests concluded that the system worked and that through using the common antenna it was possible to remove the need for individual antennas on each of the RFID tags. This success provided possible hope for addressing both the scale issue and the connectivity problems that had restricted previous attempts at using RFID for creating a prototyping tool. Despite the fact the system had been shown to work, it did however remain in a very crude and workbench form. For the system to be of use for prototyping it would need to be developed further, including development of a method to trigger an interface simulation by an RFID value without the need for complex programming by the designer.

4.1.4 Bespoke Hardware Development

Custom PCB’s were designed and produced in an effort to produce a more robust version of the initial system. Two styles of PCB’s were produced, one for the components that made up the individual RFID buttons to be mounted on, and another for the common antenna to attach to. Schematics and PCB layouts were created using Eagle 5.3.0 PCB Design Software. The layout of the Button PCB designs was critical to ensure that the positioning of components did not affect the overall footprint. This was achieved by stacking the components. The micro-switches used provided enough space for the RFID ASIC’s to be positioned between it and the top surface of the PCB. The Coaxial Pin was mounted on the underside of the PCB, allowing it to be pushed into the substrate. The resulting buttons can be seen in Figure 39, Figure 41 and Figure 42.
The design of the second PCB simply needed to allow the fixture of a coaxial pin and the two wires from the antenna loop to be attached, (see Figure 40).

Whilst the wearable RFiD reader based on the SonMicro SM3005 kit, that Medynskiy et al., (2007) had developed, provided a starting point for the development of the prototyping tool, it was fairly large and cumbersome for the task in hand. The large antenna which had to be sewn into the palm of the glove meant that movement of the hand was limited and that grasping objects was less than easy. The battery life of the system was an additional restricting factor and only lasted for a short period of time. Therefore a search for alternative hardware that could be used to develop a wearable RFiD reader was looked for.

A system was developed based around the following two main components:
• ID-12 Series RFiD reading module
• Sparkfun Bluetooth Modem – BlueSMiRF Gold Module

The ID-12 RFiD module is a self contained 125 kHz reader which features a built in antenna with a read range of up to 12cm (as per data sheet). The Core ID-12 had two main advantages over the SonMicro SM3005 reader, the first being a significantly smaller form factor. The SonMicro SM3005 measures 80mm x 54mm x 17mm (L x W x H), whereas the Core ID-12 measures just 26mm x 25mm x 7mm. Furthermore the internal antenna of the ID-12 provided the same stated read range as the coil provided with the SonMicro SM3005, at almost a quarter of the surface area. The Sparkfun BlueSMiRF Bluetooth modem also provided a smaller package for the Bluetooth components compared to that of the Socket Serial to Bluetooth adapter used in the wearable reader by Medynskiy et al., (2007) at 51mm x 15.8mm x 5.6mm, instead of 62mmx 32mm x 15.5mm. Similar to the SonMicro SM3005, the components were powered by a 9V battery, reduced to 5V with a voltage regulator. The battery was housed in an off the shelf 9V battery holder, whilst the other components were mounted on a PCB that was produced “‘in-house’” and measured approximately 60mm x 60mm See Figure 43.

![Figure 43 - Bespoke hardware design V2.0](image-url)
Further to the RFID module and the Bluetooth Modem, an LED was incorporated into the circuit to provide a visual indication of when a tag has been successfully detected. The LED also provided assistance with software debugging during the later stages of development. Finally a sliding switch was also added to allow the power to the unit to be switched on and off. The PCB was later to be mounted to the back of a lightweight fingerless glove, and the battery attached to a separate elastic wrist strap.

4.1.5 Initial Software Interface Development

As well as developing bespoke hardware for the novel prototyping approach, the first stage of development of allowing the RFID based inputs to communicate to a software user interface prototype also began. Until this stage the hardware had simply been tested by establishing a connection between the Bluetooth Modem in the wearable reader and a PC using Hyper Terminal. This process was used to simply test the technical feasibility and operation of the hardware. However, to allow the system to integrate with a software interface simulation, such as one built in Adobe Flash, a software application needed to be developed that could intercept an incoming RFID string of data and transform it into an event that could be used to trigger an interface. The IE system (Gill, 2003a) used a simplistic method of interfacing between hardware and software prototypes by using keystrokes to trigger events within an interface simulation. This approach had been proved to be both accessible and popular when tested with industrial designers. It was therefore
decided that the experimental prototyping tool should adopt the same method. The high level functionality of the required application is shown in Figure 45.

Although the hardware developed by Medynskiy et al., (2007) was no longer being used, the work provided a further useful starting point for the development of a software application that would allow the hardware to interface with a PC.
Medynskiy et al., (2007) had published a short length of Python script that initiated a serial connection between a PC and a Bluetooth device (see Appendix 1 for programme code.) The source code published by Medynskiy et al., only fulfilled the first two functions of the required software structure as shown in Figure 45. As a result the programme needed to be modified to include the additional functionality. The Python script was modified allowing the output of ASCII characters upon detection of an RFID tag. This was achieved through the inclusion of a Python extension library called 'SendKeys' that was able to provide the functionality to send global keystroke events to other active windows running on a PC. Once the 'SendKey' function had been added, the next stage equipped the application with the ability to output different ASCII characters depending on which tag had been detected. To initially test the Python application, a simple ‘Else-If’ loop was implemented for producing different ASCII outputs dependant on tag's ID. It was realised that if the application was to support more than a small number of possible tags then it would require a more robust function such as a ‘look-up table’, but there was no need to implement such a feature at this stage. The resultant software application and bespoke hardware were labelled Version 2.0 of the novel prototyping approach.

4.1.6 Version 2.0 Testing

A preliminary test to determine the suitability for use of Version 2.0 as an experimental prototyping tool was undertaken. To test both the functionality and suitability of the system it was used to retrospectively prototype both a hardware and software prototype of a Sky television remote control and supporting user interface. The prototypes for each can be seen in Figure 46.

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4 Python is an open source programming language and popular with programme developers for the generation of small very fast applications. Python has the added benefit of being compatible across ALL major platforms including Windows, Mac OSX, Linux.
Through this informal test of the system it was quickly established that both the hardware and software elements still suffered from instabilities that hindered its use as a prototyping platform.

The test revealed that the custom made PCB's and newly constructed buttons provided a greater level of robustness with regards to the individual input devices. In addition, use of the VooDooIO pins provided a stronger and therefore more reliable connection between the individual RFiD buttons and the common antenna than had been experienced with the cruder constructed hardware in version 1.0 of the system. However, despite the Core ID-12 RFiD reader offering a significantly smaller footprint to that of the SonMicro SM3005, when mounted on the rear face of a glove, the internal antenna of the ID-12 was unable to reliably communicate with the common antenna within the physical prototype all of the time. Additionally, the use of a 9V battery to power the components of the wearable RFiD reader was still providing a limited length of use, and the battery frequently required changing.

The Python application proved to provide a successful method of allowing the hardware prototype to integrate with the Sky set top box interface simulation that had been built using Adobe Flash. By integrating the hardware and software user interface prototypes through the use of keystrokes, only basic Actionscript coding was required during development. Although the test had shown that the Python
application had worked successfully, it featured a somewhat limited level of functionality. The application had been 'hard-coded' to produce specific ASCII characters for the RFID ASIC's which had been used to create the buttons. This use of a 'hard-coding' application offered no flexibility within Flash when defining keystrokes to trigger the interface events. This quickly became confusing as the ASCII characters that corresponded to each button had no logical relationship to their function within Flash. For example the down arrow on the remote control prototype produced a "2" character, increasing the ambiguity of the Flash Actionscript functions to the user. Whilst this did not pose an issue in terms of basic functionality of the prototyping system, it did present a usability issue that may affect the ease of use. A more user friendly approach would allow users to define the ASCII characters that each I/O output.

4.1.7 Version 3.0 Development

Further development to the hardware of the system addressed the problems experienced with the ID-12's internal antenna, as well as the battery life that had restricted the system's use over a prolonged period.

The Core ID-12 RFID module that was used in version 2.0 was replaced with a sister module, the ID-2. Slightly smaller in size, the ID-2's main difference was that it did not have an internal antenna, instead it allowed an external antenna to be connected. A 125 kHz antenna was sourced that had a diameter of approximately 30mm. The two ends of the antenna were connected to one end of a fly-lead approximately 20cm in length, while at the other end was a 2.5mm coaxial connector. A female 2.5mm coaxial connector was incorporated into the circuit of the wearable reader allowing the antenna to be connected to the ID-2 module. The addition of an external antenna on a short fly lead slightly altered the way in which the system would be used. The intention of the revised design was to allow the antenna of the wearable reader to be placed on top of the common antenna which was attached to the substrate and embedded in the prototype (see Figure 47). Although this created a tether between the prototype and the user's hand, it is critical to note that this is not the same as creating a tether between a prototype and a PC, or worse still a wireless (and therefore invisible) tether between a
prototype and a short range reader placed on a desk as was the case with Switcharoos (Avrahami and Hudson, 2002). At the time it was acknowledged that placing the antenna on a fly lead was perhaps not the optimum technical solution. However, from a practicality perspective it allowed for the system to work in a reliable way that would in turn enable it to be used to facilitate an investigation into the research aim.

![Figure 47 - Wearable RFID reader & fly-lead antenna schematic](image)

To overcome the limited battery life that the previous version of the system experienced, a rechargeable battery circuit was designed and integrated into the system. The rechargeable battery used was a 3.7V 800mAh Lithium Polymer battery, coupled with a 5V step up circuit to provide the required voltage for operating the ID-2 and the BlueSMiRF modules. A charging circuit was also added (based on the MAX1555 charging chip) allowing the hardware to be charged via USB connection. The components were mounted on a PCB that was produced “in-house” *(measuring approximately 70mm * 48mm * 20mm see Figure 48).*
An enclosure for the electronic components was designed and produced using 3D printing Rapid Prototyping techniques. The housing design enabled the assembled unit to be securely attached to the back of a lightweight glove. The completed design of the hardware can be seen in Figure 49.

Extending the functionality of the software application that supported the hardware prototyping was the next stage of development. Much of the high level design of the application developed in Version 2.0 remained valid, however its functionality and degree of user friendliness needed to be improved. Three main changes were desired from the new software application:

- The development of a Graphical User Interface (GUI)
- The ability to assign ASCII outputs to individual RFID buttons, rather than being 'hard-coded'
- The ability to save programmed profiles of assigned outputs

Figure 50 shows a flow diagram for the software application developed for version 3.0 of the novel approach.
It was considered more practical to build the V3.0 of the software application from 'scratch' using the Java programming language as opposed to modifying the existing Python application. This decision was made for a number of reasons including the availability of local programming expertise. This came in the form of a member of the PAIPR research group, (Zampelis), who had a strong background in Java programming. The newly developed software interface featured a much greater
level of detail with regards to usability and visual communication between the application and the user. For example, it allowed the user to import an image of the device being prototyped and position virtual buttons on the screen in the same configuration as they appeared on the physical prototype. This added a level of visual mapping that assisted in the identification of each of the I/O devices on the prototype. Screenshots of the software application can be seen in Figure 51, Figure 52 and Figure 53.
4.1.8 Version 3.0 Testing

As was the case with version 2.0 of the novel prototyping system an informal test was conducted to establish its suitability for further use. The revised hardware and
software application was once again used in conjunction with the Sky set top box remote control and user interface. The replacement of the ID-12 RFID module for the ID-2 combined with an external antenna was successful in providing a reliable connection between the wearable reader and the common antenna embedded within the prototype.

A peer reviewed paper detailing Version 3.0 of the system was published alongside a demonstration session at the 3rd International Conference on Tangible Embedded Interactions (TEi) held in Cambridge (UK) in early 2009 (Culverhouse and Gill, 2009). Presenting StickIT at TEI gave the author the opportunity to discuss the experimental prototyping tool with a number of influential people within the field of interaction design. Key conversations included speaking with creator of littleBits (2008) Ahay Bdeir, Co founder of Arduino (2007) Tom Igoe and Associate Director of MIT’s Media Lab Hiroshi Ishii. The concept was well received; however a number of interesting observations were made when the system was used by others attending the conference. It was evident that the ID-2 RFID module suffered a delayed response time when the same button was pressed in quick succession. This led to some use confusion as to whether the system was working or if there was a fault. Furthermore, both the ID-12 and the ID-2 RFID modules are unable to continuously stream a tag’s ID, something that should happen in the event of a button being held down. Instead the ID would be sent a single time followed by no data being sent. This subtle difference in interaction was an important feature for the system to support. Many computer-embedded devices use a button hold as a method of triggering an event, for example holding the play button on an iPod turns the device off or a button may be held for the setting of an alarm clock. In order to achieve a faster read rate and the ability to differentiate between a single press of a button and it being held down it was necessary to redesign the system to accommodate these requirements. At this stage it was essential that any redesign or replacement of hardware components not only fulfilled these newly identified needs, but did not compromise the developments of the previous versions.
4.1.9 Version 4.0 Development

The solution to these needs was found through the implementation of the SkyeTek M1 Mini RFID module. Not only was this module capable of faster read rates than the ID-12 and ID-2, it was also able to continuously stream a tag's ID while that tag remained within its field of detection. These benefits of the M1 came at a cost of an increased level of complexity of implementation. The previous modules used in version 2.0 and 3.0 had been self contained units that did not require a microcontroller to process commands in order for them to function. However, the M1 did require the addition of a microcontroller in order for it to operate. The Arduino (Anon, 2007) platform was chosen to provide the computational power required. The reason for this choice was partly due to the author having some previous experience of using Arduino, but largely came from the extensive community of support online that Arduino exhibits. An example of interfacing the SkyeTek M1 with an Arduino had been published and this provided a valuable starting point for its use (Igoe, 2007). Initial development and debugging of the hardware design was completed using an Arduino Diecimila as it allowed the individual components to be configured using a breadboard without needing to make permanent connections. Although suitable for development and debugging of the system, the physical size of the Diecimila PCB meant that it was not suitable for embedding into a wearable reader. Instead, once the ‘breadboard’ development was complete, the finished circuit and Arduino programme were replicated using an Arduino Mini, which affords a much smaller form factor and was suitable for embedding into a wearable device. During development of the hardware it was found that both the SkyeTek M1 and the BlueSMiRF modules communicated via serial transmission. Unfortunately, both the Arduino Mini and the Diecimila only support a single hardware serial connection. To overcome this, an additional library was used within the Arduino program that converted two unused input pins on the Arduino into a secondary serial connection. Figure 54 shows a system diagram of how the components were integrated.
It was necessary to use the 5V 16 MHz version of the Arduino Mini to ensure enough processing power was provided for the SkyeTek M1 to operate effectively. Tests with the 8 MHz 3.3v version resulted in communication errors between the Arduino Mini and the SkyeTek module with packets of data being lost.

The SkyeTek M1 module featured a very small form factor and is described by its manufacturers as being the smallest RFiD module in the world at 25.4mm in diameter and 2.8mm in height. The module also provided the option of using either a built in internal antenna, or adding an external antenna. Due to the small size of the module, it afforded the opportunity to place the module itself on the end of a fly lead which could then be positioned within proximity of the common antenna placed within the prototype. This in turn meant there was less hardware needing to be worn by the user, thus offering a less obtrusive approach whilst still being able to provide a reliable connection with the common antenna. A neoprene wrist pouch was constructed to house the hardware elements of V4.0 of the
prototyping system. It was anticipated that by placing the hardware on the wrist as opposed to the back of the hand would also help to provide a less obtrusive solution than the previous attempt (see Figure 55 and Figure 56).

As well as developing V4.0 of the wearable reader, it was also necessary to create new input buttons for the prototyping system. This was due to the ID-2 and ID-12 working on a frequency of 125 kHz, however, the newly implemented SkyeTek M1 worked on a higher frequency of 13.56MHz. The need for the buttons to be redesigned also afforded an opportunity to make two small design iterations.

The first of these was in relation to the actual button featured on each of the PCB’s. The micro switch previously used was replaced with a low profile dome switch that further reduced the size of the input devices and also allowed cardboard labels to be stuck on top if the user wished to ‘cap’ each of the buttons to change its aesthetic. The second minor change was to buy the ASIC’s individually as opposed to removing them from already manufactured RFiD tags. The revised design for the input components can be seen in Figure 57.

Figure 55 - Wearable Reader V4.0

Figure 56 - Wearable Reader V4.0 in pouch
A final part of the V4.0 development was aimed at simplifying the software interface prototyping side of the toolkit. Previous versions had still required small amounts of Actionscript to be written when developing an interface using Adobe Flash. Whilst the level of coding knowledge required for this was not considered to be out of the reach for industrial designers, it was considered that the process had room for improvement. This was achieved by creating a pre-programmed keyboard library within Flash. The keyboard library was made up of individual movie clips, each containing a piece of Actionscript. The intention of these components was to remove the need for writing Actionscript in order to trigger an interface event through a keystroke. Instead, the library would allow the designer to drag and drop components onto the stage. Each component contained the necessary Actionscript code to enable it to act as a ‘keystroke listener’ (see Figure 59, Figure 60, Figure 61 and Figure 62 for sequence of use). A visual metaphor of a keyboard was used for the arrangement of the Keyboard library components (See Figure 58) providing a visual clue as to the purpose of each component in a similar manner as used by Fritzing (Knörig et al., 2009).
When the designer wishes to insert the necessary code to allow the UI to switch between states via a key-press open the Keyboard Library file in Flash.

Choose the desired Key that they wish to use from the keyboard library and copy it to the clipboard (Edit>Copy or Ctrl +C).
Return to the UI prototype Flash document and paste the content of the clipboard into the file (Edit>Paste or Ctrl + V). Drag the pasted component outside of the workspace to hide it from view.

With the appropriate keyboard library component selected press F9 to view the Actions pane within Flash. Edit the number within the brackets to set the desired target frame.
5 Individual Case Analysis

5.1 Introduction

Chapter 3 described the methodology used to investigate the research aim. A comparative case study method was chosen as the most appropriate method for gaining in-depth insights into the application of interactive prototyping during the early stages of the design process. Six companies were selected to be involved in the research, each company forming an individual case study. This chapter presents the analysis of the data for each case on an individual basis. Each

The data gathered from each of the six studies formed a significant body of data, therefore it was critical to organise and analyse it systematically. The purpose of this Chapter is to present the analysis of the data in accordance with the three questions outlined below:

- Is it possible to produce an interactive prototype during the early stages within a timescale of one to two hours, and if so is this appropriate?
- How does a prototyping method of this nature and capability compare with existing methods used within industry?
- How does StickIT meet the interactive prototyping needs of designers involved in prototyping computer-embedded devices during the early stages of the design process?
5.2  Design Consultancy A Analysis

5.2.1  Introduction

Table 8 provides a summary of the details describing Design Consultancy A.

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
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<td>40 - 45</td>
<td>Design Consultancy</td>
<td>Consultancy Services to SME medical device companies</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 8 - Design Consultancy A Profile Summary

Design Consultancy A gave access to a member of their design team for participation in the study. They had been working at the company for two years at the time of the study. Prior to joining Design Consultancy A, the participant had been involved in setting up a private limited company alongside a team of medical experts. The venture aimed to commercialise a new medical device that had conceived during the participant’s undergraduate and postgraduate degrees. The participant is situated within the product design team at Design Consultancy A as well as having an involvement in business development. Traditionally Design Consultancy A has not had ‘in-house’ capabilities or experience of designing computer-embedded devices, however, this knowledge was introduced to Design Consultancy A when the participant joined. The participant described how in the past Design Consultancy A had typically focused on adding value to a product’s design through its industrial design requirements. Any electronics or software development would be outsourced. Using the qualitative data gathered, it was possible to extract information relating to the design process used by the participant from Design Consultancy A when developing interactive devices. This design process was described by the participant as a combination of prototyping methods they have previously used, placed into the context of a design project undertaken by Design Consultancy A. This design process is shown in Figure 63. This information shows that the participant will typically use Paper Prototyping as a method of designing, testing and refining early iterations of software UI’s. The development of the physical device may be prototyped using foam or cardboard to
create models. The focus of these physical models is on the ergonomics, form and aesthetics of the design. The process described by the participant indicated a separation between the development of the hardware and software aspects of a computer-embedded device.

Once a clearer idea of the design has been achieved, and the basic information architecture of the software UI has been created, the process progresses to using interactive prototyping methods. The participant described that in the past they have predominantly used Phidgets (Greenberg and Fitchett, 2001) as an electronics prototyping platform. Phidgets hardware would typically be used to trigger events and functionality within medium fidelity software UI prototypes built using Flash. It was noted by the participant that the Phidgets I/O’s would generally not be integrated into a physical prototype due to their scale. Instead, the Phidgets circuit would be separate to a sketch model. The resulting prototypes would be used to convey the concept for the interactions and the design intent. At this stage the electronics and systems development would be subcontracted and Design Consultancy A would continue with the industrial design development. The participant was asked how they felt about not embedding the Phidgets circuit in a prototype and if it affected the prototype in anyway. The participant felt that the value of a prototyping method comes from the designer’s ability to use it effectively to communicate the design intent to a third party. He added that although the Phidgets circuits are not generally embedded within prototypes, in their opinion this did not have a negative effect on how it could be used.
The prototyping outputs of the design exercise produced by the participant from Design Consultancy A are shown in Figure 64 and Figure 65. The details of the
prototyping outputs are discussed in a greater level of depth in the subsequent sections.

5.2.2 Speed of Prototyping

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
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</thead>
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<tr>
<td>45 Minutes</td>
<td>45 Minutes</td>
<td>1hr 10 Minutes</td>
<td>20 Minutes</td>
<td>1hr 55 Minutes</td>
<td>3hrs</td>
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</table>

Table 9 - Summary of Design Exercise Timings for Design Consultancy A

Table 9 provides a summary of the times taken by the participant from Design Consultancy A to complete specific stages of the breathalyser design exercise using StickIT. In this case StickIT successful enabled the participant to produce a low fidelity interactive prototype in less than two hours. The software UI prototype took the participant approximately 25 minutes longer than the time required to prototype the physical device. Qualitative data indicated that the participant believed the software UI took longer to create for two primary reasons. Firstly, it was felt that StickIT offered a faster approach to prototyping the physical device than it did for the software UI. Secondly, the participant believed that Flash was overly complex for the development of early stage software UI prototypes. This was still considered to be the case even with the inclusion of the StickIT Keyboard Library. Due to its perceived complexity, the participant felt Flash to be better suited for later stages of development when more time could be given to constructing a UI prototype. Additionally, although having stated prior to the study that they were comfortable with the basics of using Flash, at times it was observed that the participant struggled with some of the fundamental steps in its use as a prototyping platform. This difficulty in using Flash undoubtedly increased the time required to prototype the software UI prototype.

The first 45 minutes of the design exercise were spent sketching initial concepts, after which the participant progressed to developing the physical prototype using the materials provided. During the interview they explained that they felt the swift progression from sketching to physical prototyping was a good thing. They felt that it enabled them to get a feel for the design. Allowing considerations such as which
hand the device would be held in to be addressed, and the consequent interaction requirements.

The participant stated that whilst the breathalyser UI was fairly straightforward, this will not always be the case, explaining that medical devices often feature more complex user interfaces. Drawing on past experiences the participant explained that as an interface grows in size it can become difficult to keep track of its flow and structure, particularly when using a frame based prototyping tool such as Flash. They added that it is not always possible to prototype software UI’s through a series of static frames. They explained that often it is necessary to include animation and multiple feedback loops which, invariably having an impact on the speed of prototyping. The participant felt that StickIT could be improved if it allowed software UI prototypes to be created in a package such as DENIM (Lin et al., 2002), (providing it could offer a stable prototyping platform).
5.2.3 Comparison with Existing Practice

As previously stated, *Paper Prototyping* in conjunction with foam or card modelling was indicated as being the most common prototyping method used during the early stages of developing a computer-embedded device. The *Rating / Weighting scale* was completed by the participant using this approach as Current Practice.

Table 10 shows the raw data gathered using the *Rating / Weighting scale* and the normalised values.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Ox)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C S C</td>
<td>C S C</td>
<td>C S</td>
<td>C S</td>
<td></td>
</tr>
<tr>
<td>Representation of intended interaction</td>
<td>5 7.58 3 3</td>
<td>0.5</td>
<td>0.5</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>5 7.58 3 3</td>
<td>0.5</td>
<td>0.7</td>
<td>3.8</td>
<td>5.1</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>6 9.09 2 4</td>
<td>0.3</td>
<td>0.7</td>
<td>3.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>5 7.58 3 4</td>
<td>0.5</td>
<td>0.7</td>
<td>3.8</td>
<td>5.1</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>4 6.06 5 5</td>
<td>0.8</td>
<td>0.8</td>
<td>5.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>5 7.58 3 5</td>
<td>0.5</td>
<td>0.8</td>
<td>3.8</td>
<td>6.3</td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>3 4.55 3 4</td>
<td>0.5</td>
<td>0.7</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>2 3.03 2 2</td>
<td>0.3</td>
<td>0.3</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>3 4.55 2 3</td>
<td>0.3</td>
<td>0.5</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>4 6.06 3 4</td>
<td>0.5</td>
<td>0.7</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>6 9.09 4 2</td>
<td>0.7</td>
<td>0.3</td>
<td>6.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>6 9.09 4 5</td>
<td>0.7</td>
<td>0.8</td>
<td>6.1</td>
<td>7.6</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>3 4.55 4 4</td>
<td>0.7</td>
<td>0.7</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>4 6.06 1 4</td>
<td>0.2</td>
<td>0.7</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>5 7.58 4 4</td>
<td>0.7</td>
<td>0.7</td>
<td>5.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Totals</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalisation Factor (Nf)</td>
<td>1.52</td>
<td></td>
<td></td>
<td></td>
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</tr>
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</table>

*Table 10 - Rating / Weighting scale data for Design Consultancy A (Current Practice = Paper Prototype and Foam Model)*
Figure 66 - Graph displaying a comparison between existing prototyping method and StickIT - Design Consultancy A
Figure 66 shows the data presented in Table 10 in the form of a scatter graph. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

The normalised data from the Rating / Weighting scale indicates that the participant felt that StickIT provided an overall improvement upon the current practice of Paper Prototyping combined with foam or card models by 12%.

A number of unexpected results were noticed when the data from the Rating Weighting scale was analysed. For example, the participant perceived StickIT to offer the same level of prototype automation as their current practice of Paper Prototyping. This immediately appeared to be an odd result since Paper Prototyping is a non-automated prototyping method, relying 100% on a facilitator to make changes. However, the participant had rated both Paper Prototyping and StickIT a score of 4 out of 6 in terms of the level of fulfilment of the automation criterion.

The ratings given for ‘Ease of Prototype Iteration’ were also a surprising result according to the Rating / Weighting data. According to the data, the participant considered Paper Prototyping to be more difficult to iterate than a prototype built using StickIT. This was surprising as one of the greatest strengths of Paper Prototyping is widely considered to be its ease of iteration. Whilst qualitative data supports the fact that the hardware prototype constructed using StickIT was regarded by the participant as offering a good approach for rapid iteration, it is very surprising that the software UI prototyping which involved the use of Flash could be considered to be easier than Paper Prototyping. A further reason for this result being surprising is the participant’s difficulties in using Flash that were observed during the study. The level of discomfort demonstrated by the participant whilst using Flash also highlights a surprising result in the data for the ‘Fit within designers skill set’ criterion. This criterion was also perceived to be better fulfilled by StickIT than the current practice, despite Paper prototyping not being dependant on any software knowledge.
Some of the results from the *Rating / Weighting data* appeared to be more in line with expectations. For example, the *Level of Ergonomic Evaluation* that StickIT provided was considered to be 4 times greater than using *Paper Prototyping*, which the participant perceived as offering no support for at all. Other criterion including ‘*Representation of Intended Physicality*’ was also considered to be better supported by StickIT than the current practice, which would appear to be a logical conclusion. However, due to the irregularities with some of the data gathered from the *Rating / Weighting scale* the qualitative data was analysed in order to identify comparisons against the participant's existing practice rather than using the *Rating / Weighting data* to triangulate topics of interest.

### 5.2.3.1 What were the strengths of StickIT?

During the interview the participant stated that they considered StickIT to potentially offer a type of rapid iteration that they did not consider possible using any other form of interactive prototyping that they were aware of. Although aware of the rapid iteration possible through using StickIT, the observations of the design exercise saw little use of this attribute. The participant stated during the interview that they did not consider iteration of the physical device to be necessary as they had already reached a design they were content with prior to prototyping.

<Design Consultancy A’s Participant>

"I resolved it on paper. Good enough to be honest."

So whilst it was perceived clearly to be an area of strength by the participant, they did not explore the full potential it offered. Interestingly, during the interview they revealed that the pressures of working within a consultancy environment can often lead to prototyping being substituted for a designer’s experience of previous similar projects.

Another perceived strength of StickIT related to the fact the prototype was not tethered to a desk, allowing the physical device to integrate with the software UI wirelessly. This was seen as being potentially beneficial compared to other methods of prototyping. It was explained that the true value of a wireless prototyping
approach would come from using prototypes within an intended context. The participant suggested that this may therefore require a screen of some kind to be embedded within the prototype in order to view the GUI in relation to the physical prototype.

On a separate note, it was expressed by the participant that they considered the software application used to programme the StickIT I/O's with a desired ASCII value to be a very valuable asset. Comparing to previous experience of the steps required to integrate Phidgets (Greenberg and Fitchett, 2001) with a Flash UI, the participant felt that the method offered by StickIT was a vast improvement. In this case the participant was able to use the StickIT keyboard library to prototype all of the interactions and transitions featured in their software UI prototype. The ability to add interactivity to Flash without having to write code was something the participant believed to be an attractive asset.

The participant was able to construct the physical interactive prototype of their design with a high level of ease. The prototype was constructed modularly, gluing sections of blue foam together and essentially building the prototype around the piece of substrate. The process and methods used appeared to provide a high level of synergy with the participants existing soft modelling skills.

Finally, the participant felt that a key strength of StickIT was the ability to very rapidly place an interactive idea into the hands of someone else. It was thought that this could lead to an improvement in concept communication.

5.2.3.2 What were the weaknesses of StickIT?

Examining the interview transcript it was identified that the participant felt the conductive substrate material used by StickIT presented a constraint in terms of prototyping ability. The participant explained they found it necessary to think ahead and decide on rough positions for the I/O’s prior to cutting the substrate material. This was necessary to determine the size of substrate required, and also to visualise how the prototype might be built around it. The participant felt this somewhat restricted StickIT’s iteration ability. However, they considered it to only
be an issue with the current version of StickIT and not to be an issue with the fundamental principle behind the system.

It was also opined by the participant that they considered the optimum approach to computer-embedded device design would ultimately come from a multi-disciplinary team. They felt that industrial designers are better suited to focusing on the form, aesthetics and mechanics of a product and that individuals trained in disciplines such as interaction design are better positioned to handle the user interface and interaction details of a product. It is interesting that the participant specifically stated that one of the key areas an industrial designer can add value to is the ergonomics of a product. This appears to contradict their previous statement in which they did not consider the use of oversized Phidget controllers to have a negative implication on the exploration of a design concept.

During the design exercise it was noted that the participant experienced some technical difficulties whilst using StickIT. This issue was caused by only partially inserting the I/O's into the substrate material when constructing the prototype. The issue was resolved by the researcher during the design exercise by provided additional instructions on how to successfully achieve a connection. Although the participant did not consider the issue to be a problem with the fundamental concept of StickIT, they did feel that experiencing any problems with prototyping tools in general can lead to a reduction in confidence in their use. The participant considered reliability of a prototype to be essential, particularly if the prototype is intended to be used for the purpose of user testing.
5.3  Design Consultancy B Analysis

5.3.1  Introduction

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 - 100</td>
<td>Design Consultancy</td>
<td>General</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 11 - Design Consultancy B Profile Summary

Design Consultancy B provided a member of their design research team for participation in the study. The participant had been working for Design Consultancy B for approximately 6 months at the time of the study. Despite being fairly new to the company the participant was extremely well qualified and had a PhD in the subject of computer-embedded device design. The participant's role involves the prototyping and testing of new product concepts to further inform the requirements of a design brief.

A typical design process used by Design Consultancy B when designing computer-embedded devices was outlined using the data gathered. This design process is shown in Figure 67. The participant recounted that Design Consultancy B had, within the last 12 months, begun to use Paper Prototyping (Snyder, 2003) more often as a method of early stage prototyping and testing of software user interfaces (UI). It was explained that the Paper Prototypes are often used in combination with a physical non-interactive prototype, generally produced using Rapid Prototyping (RP) methods such as Fused Deposition Modelling (FDM). As described in Chapter 2, the use of rapid prototyping techniques such as FDM requires 3D CAD data. This indicates that at the time of Paper Prototyping being used for interface development in Design Consultancy B, a significant amount of time is likely to have already been spent on the industrial design of the product. The participant did however state that a limited number changes can still be made in relation to the industrial design at this stage:

<Design Consultancy B’s Participant>
"We are at a stage where we can change, we haven't got free reign over the hardware, but if we want more inputs we can have more inputs"

According to the participant the two prototyping methods would be combined, using "Blue-tack" to attach the paper screens to the surface of the RP model. Details such as raised buttons would generally be excluded from the RP model. Instead, features such as button mappings would be communicated using the Paper Prototype. It was explained that the inclusion of raised details such as button mappings limits the number of iterations that are possible with a single prototype. Nevertheless, the use of “flat UI’s” during prototyping has been found to significantly influence the user experience and usability of a prototype (Gill et al., 2008b).

![Diagram]

Figure 67 -- Initial Stages of Design Consultancy B's Design Process

The participant also stated that interactive prototypes that are much higher in fidelity are sometimes used during the later stages of a design project. Prototypes of this nature can be built ‘in-house’ by electronics and software engineers. The
scope of the ‘in-house’ expertise within Design Consultancy B makes it possible to create complete working prototypes of a final design if required.

Figure 68 and Figure 69 show the prototyping outputs produced by the participant from Design Consultancy B, the details of which are discussed below.

5.3.2 Speed of Prototyping

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1hr 15 Minutes</td>
<td>1hr</td>
<td>1hr 40 Minutes</td>
<td>10 Minutes</td>
<td>2hr 40 Minutes</td>
<td>4hrs 5 Minutes</td>
</tr>
</tbody>
</table>

Table 12 - Summary of Design Exercise Timings for Design Consultancy B

Table 12 shows that the participant took a total of two hours 40 minutes in order to prototype their design. In this instance StickIT was not able to provide a method of prototyping in less than two hours. The prototyping of the software user interface (UI) took the participant over 50% longer than the time needed for the hardware prototype.

Examining the outputs of the design exercise and also the qualitative data provided indications as to why the participant required longer than two hours to complete
the prototype. Firstly, Figure 69 shows that the Flash software UI prototype displays the Graphical User Interface (GUI) in context with its position on the physical device. This naturally led to an increased length of time needed to construct the software UI prototype, accounting for approximately 10-15 minutes of the software UI prototyping time taken. Secondly, the participant from Design Consultancy B wanted to include a random "pass or fail" function into their breathalyser, to make it more ‘intelligent’. Switching between frames within the software UI prototype was achieved using the keyboard library components of StickIT. However, the keyboard library was not able to facilitate the desired random "pass or fail" functionality. This meant the participant needed to write custom Actionscript code within Flash to achieve the desired functionality. Although the participant was clearly very competent in the use of Flash for prototyping, writing custom Actionscript lead to an increase in prototyping time for the software UI. Thirdly, the participant chose to include a relatively high level attention to the visual aesthetics for the software UI. This increased the prototyping time too. However, the participant revealed they did not consider it to be strictly necessary to generate such a clean and tidy UI prototype during the early stages.

<Design Consultancy B’s Participant>

"I'd like some way of getting that kind of hand sketchiness into [Adobe] Flash"

The placing of the GUI in context with an illustrated version of the hardware in the software UI prototype proved to not only add time during UI prototype construction, but also caused a bottleneck in terms of iteration fluidity during the testing phase. It was observed that the participant was able to edit the mapping of the physical prototype very quickly (in a matter of seconds). Editing the mapping of the visual representation of the device within the software UI prototype on the other hand proved to be a more complex and time consuming task. The position of the controls needed to be changed in multiple sections of the software UI prototype in order to ensure continuity throughout the UI design. Interestingly, the physical device and the software UI interfaces were iterated. However, the position
of the I/O’s within StickIT’s ASCII assignment application remained unchanged after
the initial ASCII codes had been assigned. This could be due to the fact that once
the appropriate ASCII values had been assigned, this application simply remained in
the background and required no further user intervention.

One particularly interesting statement was made by the participant during the
interview. They stated that the speed of prototyping offered by StickIT was
impressive, however, in their eyes, its greatest strength came from the flexibility
and the speed of iteration that was possible using StickIT. The participant felt that
generally it would be acceptable if the initial construction of a prototype took
slightly longer, providing the prototype was able to offer a high degree of flexibility
for subsequent design iterations. This suggestion that gaining the maximum from
one prototype by offering flexibility towards iteration is supported by the fact the
RP prototypes described by the participant. The designers at Design Consultancy B
had previously deliberately chosen not to include details such as raised buttons
when building prototypes as it enabled them to achieve a greater number of
iterations from a single prototype.
5.3.3 Comparison with Existing Practice

The design process described by the participant from Design Consultancy B states that Paper Prototyping is typically used for early stage software (UI) prototyping, supported by a medium fidelity block model to represent the physical product produced using RP techniques such as FDM. The combination of these two methods was used for the benchmark current practice by the participant for the completion of the Rating / Weighting scale. The raw data gathered and the normalised values are shown in Table 13.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighing (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Os)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation of intended interaction</td>
<td>6</td>
<td>11.32</td>
<td>3</td>
<td>5</td>
<td>0.5 0.8</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>3</td>
<td>5.66</td>
<td>1</td>
<td>3</td>
<td>0.2 0.5</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>6</td>
<td>11.32</td>
<td>6</td>
<td>5</td>
<td>1 0.8</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>4</td>
<td>7.55</td>
<td>2</td>
<td>4</td>
<td>0.3 0.7</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>4</td>
<td>7.55</td>
<td>4</td>
<td>5</td>
<td>0.7 0.8</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>2</td>
<td>3.77</td>
<td>2</td>
<td>4</td>
<td>0.3 0.7</td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>1</td>
<td>1.89</td>
<td>3</td>
<td>2</td>
<td>0.5 0.3</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>2</td>
<td>3.77</td>
<td>1</td>
<td>3</td>
<td>0.2 0.5</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>4</td>
<td>7.55</td>
<td>6</td>
<td>5</td>
<td>1 0.8</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>3</td>
<td>5.66</td>
<td>4</td>
<td>5</td>
<td>0.7 0.8</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>2</td>
<td>3.77</td>
<td>5</td>
<td>3</td>
<td>0.8 0.5</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>3</td>
<td>5.66</td>
<td>5</td>
<td>3</td>
<td>0.8 0.5</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>5</td>
<td>9.43</td>
<td>1</td>
<td>5</td>
<td>0.2 0.8</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>5</td>
<td>9.43</td>
<td>3</td>
<td>5</td>
<td>0.5 0.8</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>3</td>
<td>5.66</td>
<td>2</td>
<td>2</td>
<td>0.3 0.3</td>
</tr>
</tbody>
</table>

| Totals                                          | 53                   | 56%                      | 71%        |

| Normalisation Factor (Nf)                       | 1.89                 |                          |            |

Table 13 - Rating / Weighting Scale data for Design Consultancy B – (Current Practice = Paper Prototype and RP physical Model)
Figure 73 - Graph displaying a comparison between existing prototyping method and StickIT - Design Consultancy B
The data from Table 13 was plotted in the form of a scatter graph, shown in Figure 73. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

The normalised data from the Rating / Weighting scale indicates that the participant from Design Consultancy B perceived StickIT to provide an improvement upon their existing prototyping method (Paper prototyped UI concepts combined with an RP produced model) of 15%.

5.3.3.1 What were the strengths of StickIT?
The participant perceived StickIT's greatest area of improvement compared to their current practice to be the ‘Level of Prototype Automation’ that it supported. Owing to the fact that Paper Prototyping is a 100% non-automated method this was seen as a valid perception of StickIT by the participant. The participant considered the ‘Level of Prototype Automation’ facilitated through StickIT still had room for improvement which was highlighted during the design exercise. The participant wanted their device concept to automatically distinguish between being set-up for use to take a blood sample or a breath sample. This automatic ‘mode-selection’ was intended to work by detecting the presence of the breath tube on the top. The design intent was that if the tube was attached when the device was switched on then it would initialise the unit ready for a breath sample. If the tube was not attached it would initialise the device ready for a blood sample. The participant wished to achieve this functionality using a micro switch (the style of which is shown in Figure 74) which would be depressed by the weight of a breathalyser tube.
Unfortunately StickIT did not feature a switch of this style, preventing this from being achieved in this manner. To overcome this the participant chose to mimic the intended functionality using Wizard of Oz prototyping (Maulsby et al., 1993), and use StickIT to achieve the rest of the interactivity. The participant added some additional controls to the Flash software UI prototype that could be triggered by the user depending on which sampling method they wished to trial (see Figure 75). The participant also used Wizard of Oz prototyping with StickIT to simulate the process of sampling blood. StickIT did not feature an I/O capable of sampling blood, instead the participant mounted one of the StickIT I/O’s into a piece of cardboard (see Figure 76 and Figure 77). The intention was that the piece of card acted as a single use (patient specific) blood sampling shield that would be clipped to the breathalyser body. Once attached, the software UI would prompt the user to place their finger on the ‘sensor’. In this case the I/O mounted inside the cardboard shield acted as the blood sampling point and triggered the UI to respond as if it were taking a blood sample (see Figure 78 & Figure 79).
Despite StickIT not being able to support the exact method of interaction, the participant felt it was superior to Paper Prototyping in allowing subtle differences in interaction to be prototyped. Consequently it was explained that this could improve user error detection during user trials. Specifically, the interview revealed that Paper Prototyping had previously been found to be often misleading or insufficiently flexible in its ability to test subtle differences in interaction such as holding a button down.

<Design Consultancy B>
“If someone is pressing and holding a button...you have to ask them ‘are you pressing and holding that button?’ which is a bit of a leading question, because you have told them that pressing and holding is an option...It’s good for high level stuff, but the details of how people are interacting and differences of press and hold, or pressing two buttons, or...you’re starting to miss out really.”

The noted improvement of StickIT in terms of ‘Effective Representation of Intended Physicality of Concept’ and ‘Level of Ergonomic Evaluation’ was also found to be supported by qualitative data. Since the RP models described by the participant typically would not feature raised details, this naturally reduces the physicality of the physical user interface. In turn this provides less of an opportunity for ergonomic evaluation.

Additionally, the participant devised a method of adapting the conductive substrate to allow it to feature a curved surface, achieving a closer representation of the design intent. The curvature of the substrate also allowed for a more accurate evaluation of the ergonomics and physical properties of the design. This was achieved by using a thin section of sheet aluminium that was curved by hand into the desired contour. The substrate was then taped to the aluminium, forming a curved surface that the StickIT I/Os were still able to penetrate (see Figure 80).

![Figure 80 - Curved substrate](image)

During the interview it was explained that due to the costs involved, formal user tests are rarely conducted during the early stages of a design project. Instead, early stage testing is usually conducted internally with other members of staff. StickIT was considered potentially useful at a similar point in Design Consultancy B’s design
process as *Paper Prototyping*. The participant explained that the use of *Paper Prototyping*, and likewise the envisaged use of StickIT, would not be limited to user testing but could be useful as a means of communication also.

<Design Consultancy B participant>

"it's in the same place as like I said about Paper Prototyping, where you've been sketching stuff on paper...this is kind of the same level of sketching interaction, it's a very like, oohh what if we did this, or why don't we do this...working with other people in the team like internally, just having those conversations. I think it's quite strong in that area"

As stated in Section 5.3.1, Design Consultancy B has both ‘in-house’ electronics and software engineers. Rather surprisingly, the participant describes the involvement of these specific disciplines during the very early stages of developing a computer-embedded device as uncommon and intentionally limited with regards to prototyping. The skills and involvement of such expertise will typically be something that takes place at a much later stage and would focus on engineering a design ready for production. According to the participant the limited involvement of such expertise during the early stages is largely driven by the rapid escalation of projects costs when additional people become involved. Occasionally a situation might occur where these expertise are required in order to produce an interactive prototype. However, due to commitments to other projects, engineers are typically unable to offer assistance immediately. Lead times of no less than a week can be expected, even for the development of rough low fidelity prototypes. This lead the participant to say they considered interactive prototyping methods which are accessible to designers to be equally as applicable and needed, in a company such as theirs with ‘in-house’ electronics and software engineers.

Finally, the participant felt that StickIT had the potential to extend beyond use strictly during the early stages. It was suggested that the substrate and I/O devices could be enclosed within a high fidelity RP prototype as it could potentially save a considerable amount of time in the fabrication of PCB’s and wiring inside the prototype.
5.3.3.2 What were the weaknesses of StickIT?

The data from the Rating / Weighting scale shows that the participant considered Paper Prototyping to provide a greater level of fulfilment in terms of ‘Ease of Iteration’ than StickIT. On a number of occasions the participant expressed a particularly positive attitude towards the speed and ease of iteration afforded by the hardware aspects of StickIT. This suggests that any perceived reduction in the effectiveness of the ‘Ease of Iteration’ by StickIT related to the software UI prototyping, and the iteration complexities that were experienced by the participant during the testing phase (as discussed in 5.3.2). Qualitative data also indicated that the perceived poorer level of fulfilment for providing a ‘Fit with Designers Skill Set’ was also related to the software UI prototyping side of StickIT.

The participant felt that although the hardware prototyping would be within the reach of other people within his team, the software UI prototyping could present them with more of a challenge. Simple UI prototypes which move between static frames were considered to be within reach, but the introduction for the need of logical statements or multiple sensor readings would begin to cause barriers in terms of prototyping.

Paper Prototyping combined with a block model was also believed to offer a greater level of fulfilment in terms of ‘Level of Visual Refinement’ and ‘Robustness of Prototype’ than that offered by StickIT. Analysis of the interview transcript highlighted that the participant fully understood that StickIT was not intended to be a final solution at the time of the study. Nevertheless, the roughness of components such as the common antenna connection and the soldering on the PCB’s for the I/O’s could have lowered their perception of criterion such as ‘Visual Refinement’ and ‘Robustness of the Prototype’ that StickIT was currently able to achieve. These points highlight areas of refinement for StickIT’s development as opposed to being critical flaws in the prototyping approach. The aesthetical attributes of prototypes constructed using both StickIT and Paper Prototyping were also found to be the leading cause for the participant considering neither method particularly well suited for use as a ‘Client / Managerial Persuasion Tool’. On a number of occasions the participant stated they considered both StickIT and the
current practice to be better suited to internal use as a development tool rather than prototypes that might be presented to a client.

The rating weighting data also indicated that StickIT was considered to be less suitable as a prototyping platform for user testing than the current practice of *Paper Prototyping* combined with an RP model. It is likely that the fact the participant considered StickIT to be better suited as an internal development tool contributed towards these scores being awarded.
5.4  **UCD Consultant Analysis**

5.4.1  **Introduction**

Table 14 provides a summary of the details describing *UCD Consultant*.

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Independent User Experience and Interaction Consultant</td>
<td>General</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

*Table 14 - UCD Consultant Profile Summary*

*UCD Consultant* specialises in the user experience and interaction design of devices and products. *UCD Consultant* has over 10 years experience of working in the area of computer-embedded device design, with a background in industrial design. They strongly believe in the use of applying a User Centric Design (UCD) ethos to all aspects of their work. Having a taught background in industrial design, they do not have specialist expertise in the areas of electronic and software engineering. However, in the event of a project requiring such skills *UCD Consultant* typically hires in additional resources on a short term contract. *UCD Consultant* offers the following services: *Design Research, Interface and interaction design, Prototyping, Usability Testing, User Research* and *Ethnographic studies*.

*UCD Consultant* conveyed a strong belief in the value early stage low fidelity prototyping can provide. Unfortunately the role of a consultant does not always afford opportunities to work in this manner. For example, a recent contract involved running a series of user studies for a major mobile phone manufacturer. The studies involved actual handsets being used to display software UI prototypes. This meant that *UCD Consultant* was only given scope by the mobile phone manufacturer to conduct testing on the software UI. They were instructed not to report any issues surrounding the design of the physical device. Nevertheless, the initial stages of the design process outlined in Figure 81 shows the process that *UCD Consultant* uses when managing a project.
In the 12 months prior to taking part in the study, UCD Consultant had begun to use a software application called AxureRP for developing rapid prototypes of software User Interfaces (UI’s). The adoption of AxureRP replaced their previously preferred tool, Paper Prototyping. UCD Consultant described many benefits of the use of AxureRP over Paper Prototyping, these benefits are summarised as:

- Working with an interactive prototype as opposed to non-interactive methods to improve client understanding of the process being used.
- AxureRP prototypes can be packaged into an online format that can then be sent to a client, Paper Prototyping does not afford such a use.

When required UCD Consultant stated that they would use non-interactive block foam or card models to represent the physical attributes of the product.

The outputs of the design exercise that UCD Consultant produced are shown below in Figure 82 and Figure 83.
5.4.2 Speed of Prototyping

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Minutes</td>
<td>1hr</td>
<td>45 Minutes</td>
<td>30 Minutes</td>
<td>1hr 45mins</td>
<td>2hrs 45 Minutes</td>
</tr>
</tbody>
</table>

Table 15 summarises the times taken by UCD Consultant to complete the specific stages of the design exercise. The data provides evidence that StickIT was able to provide a prototyping method for UCD Consultant to produce an interactive prototype in less than two hours.

A brief period of only 30 minutes was spent working on initial design concepts at the start of the study before moving onto the physical prototyping. During the interview it was identified that this approach did not match UCD Consultant’s typical method of working, and they would normally expect to spend longer sketching before exploring concepts in 3D. Nevertheless, spending a small proportion of time working on paper and quickly moving onto interactive physical modelling was in no way considered to be a bad thing in the eyes of UCD Consultant:

<UCD Consultant>
“I used to spend ages worrying about getting everything right and how it looks on paper, this [StickIT] helps get the ergonomics right...this is what it’s really about, getting down and doing it.”

The physical prototype was completed prior to beginning work on the software UI. However, the software UI was produced and ‘debugged’ without using the physical hardware. Interestingly, the two prototypes were only used in an integrated manner after both had been constructed.

Notably the physical prototype construction took the participant longer to complete than the software UI. Examining the outputs of the design exercise, evidence was extracted that provided further detail about how the time was spent for each stage of the exercise. The software UI featured only basic interactivity, with the functionality being prototyped entirely through the use of the StickIT keyboard library. During the development of the physical prototype the participant made an error when measuring the space required within the prototype for the conductive substrate. When they realised their error they felt the best option was to abandon the prototype and to start again. This repetition of the physical prototyping adding approximately 15 minutes to the total time required. It is likely that this contributed to the need for a greater length of time to complete the physical prototyping compared to the software UI. Nevertheless, the participant did not feel the time required to construct the physical prototype was unreasonable or pose a problem.
5.4.3 Comparison with Existing Practice

Based on a combined use of *AxureRP* and non-interactive foam models as being *UCD Consultant’s* current practice, the participant was able to complete the *Rating / Weighting scale*. The raw data and normalised scores are shown in Table 16.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Os)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>S</td>
</tr>
<tr>
<td>Representation of intended interaction</td>
<td>6</td>
<td>10.17</td>
<td>3</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>3</td>
<td>5.08</td>
<td>1</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>4</td>
<td>6.78</td>
<td>4</td>
<td>6</td>
<td>0.7</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>6</td>
<td>10.17</td>
<td>2</td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>2</td>
<td>3.39</td>
<td>1</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>1</td>
<td>1.69</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>1</td>
<td>1.69</td>
<td>1</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>1</td>
<td>1.69</td>
<td>1</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>3</td>
<td>5.08</td>
<td>4</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>6</td>
<td>10.17</td>
<td>6</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>2</td>
<td>3.39</td>
<td>6</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>6</td>
<td>10.17</td>
<td>4</td>
<td>6</td>
<td>0.7</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>6</td>
<td>10.17</td>
<td>1</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>6</td>
<td>10.17</td>
<td>1</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>6</td>
<td>10.17</td>
<td>5</td>
<td>6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

| Totals                                               | 59                   | 51% | 84% |

| Normalisation Factor (Nf)                            | 1.69                 |

*Table 16 - Rating / Weighting scale data for UCD Consultant – (Current Practice - AxureRP software UI prototype & block model)*
Figure 84 - Graph displaying a comparison between existing prototyping method and StickIT - UCD Consultant
The rating weighing data shown in Table 16 was used to plot a scatter graph, shown in Figure 84. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

Overall, *UCD Consultant* perceived StickIT to provide an improvement of 33% compared to their current prototyping practice.

### 5.4.3.1 What were the Strengths of StickIT?

The data from the *Rating / Weighting scale* indicates that *UCD Consultant* perceived StickIT to provide an improvement for many areas compared to their existing practice. These perceived strengths are explored in a greater depth using the qualitative data gathered.

Rather unsurprisingly the ‘*Level of Ergonomic Evaluation*’ afforded by StickIT was perceived as being a considerable improvement upon the current practice used by *UCD Consultant*. This can be attributed to the fact that using their existing method the software UI and physical prototypes are independent of one another. The participant explained that their current prototyping method’s effectiveness is very much dependent upon the recipient’s ability to imagine the design intent. The limitations imposed by the separation of the software UI and the physical prototype which exist in *UCD Consultant*’s current practice can also be considered accountable for the noted improvement in ‘*Representation of Intended Interaction*’, ‘*Richness of Interaction*’, ‘*Effective communication of design intent*’, ‘*Level of Prototype Automation*’ and also the value of the prototype for use as a method of ‘*Client / Managerial Persuasion*’.

*UCD Consultant* explained that in their experience it is important to ensure that the prototype ‘*speaks*’ the same language as the user or client is expecting. *UCD Consultant* had found that the use of prototyping methods that do not coincide with the client’s expectations carries a risk of introducing bias towards a particular design through lack of understanding. With these experiences in mind, *UCD Consultant* explained they felt StickIT offered more potential than simply a
prototyping platform. They also felt it could provide an extremely useful communication aid when presenting early concepts and ideas to clients and stakeholders. This was evident not only from the qualitative data, but StickIT also scored highly for the criterion ‘Client / Managerial persuasion Tool’ on the rating / weighting scale.

Interestingly, UCD Consultant explained that sometimes the value of the work involved in interaction and interface design can be misunderstood by clients and stakeholders. They stated that the use of high fidelity prototypes, particularly during the early stages, as a cause for exacerbating the problem further. Owing to this, they believed that StickIT could provide value in conveying project progress to others, particularly during the early stages, by providing a tangible discussion point that offers a level of interaction.

Without access to ‘in-house’ electronics expertise nor software engineers, UCD Consultant felt that they were extremely limited in their ability for producing interactive prototypes, without external expertise. UCD Consultant felt this lack of prototyping support can lead to a reduced level of understanding of user needs. However, StickIT looked promising as a possible method for breaking down some of the subject skill barriers, including basic skills such as soldering. StickIT was seen as a tool that could potentially increase UCD Consultant’s ability to explore the user needs in greater depth through the use of interactive prototypes which they could produce ‘in-house’.

The output of the design exercise reflects the scores given by the participant in relation to the rating weighting scale in a number of ways. Firstly, the software UI is highly representative of a ‘wire-frame’ prototype. It primarily focused on designing the flow and information architecture. This would seem to indicate that the participant was not concerned with spending time refining the visual design of the interface at this stage. But rather the focus appeared to be on the information architecture of the interface. Examining the software UI also indicated that the depth of functionality featured by the prototype was also relatively low. This very
much supports the perceived low level of importance relating to the ‘Richness of Interaction’ of a prototype.

Following the study, the participant requested further access to StickIT as they wished to trial it in conjunction with AxureRP as opposed to Adobe Flash. The experiment was successful in as far as they were able to combine the two methods. Unfortunately, in order to get the interface prototype to respond to keyboard events generated by StickIT, a number of additional steps were required when constructing the software UI prototype using AxureRP. It was felt that this somewhat detracted from the fast and fluid nature afforded by both StickIT and AxureRP when used independently.

UCD Consultant considered the approach offered by StickIT as being similar to that of the Agile methodology that is often used in software development. According to Shore and Warden (2008) Agile is a project management methodology focused on the rapid user centric development of software applications. Agile is formed around a number of basic principles that encourage the breaking down of a project into smaller stages, each adopting a high iterative approach to achieving its goal. UCD Consultant considered the rapid iteration and opportunity for a user centric approach offered by StickIT to fit in well with the principles of Agile in the context of industrial design.

5.4.3.2 What were the Weaknesses of StickIT?

According to the Rating / Weighting data StickIT was perceived by UCD Consultant as providing less of a ‘Fit within a Designers Skill Set’ than their existing practice. As it can be seen from Section 5.4.1 UCD Consultant currently use a software application called AxureRP. Consequently, although capable of doing so, they had not used Adobe Flash for a number of years. Whilst the outputs of the design exercise had shown they were capable of using Flash to produce basic interactive prototypes, they considered the use of Flash for a more complex interface would perhaps pose a greater challenge for them. This could suggest a possible reason for their current practice being perceived to offer a closer fit with their skill set than StickIT.
During the interview the participant highlighted that the conductive substrate had in fact made the exact intended position of one of the I/O’s impossible to achieve. The sketch work depicts the position of the on/off switch on one side of the product. However, as the substrate was positioned on the front surface of the prototype this intent was not possible. Figure 85 and Figure 86 show the design intent and the actual prototype produced.

![Figure 85 - Intended position of Button](image1)

![Figure 86 - Actual position of button on Prototype](image2)

This issue was not considered by the participant to reduce the potential of the principle of StickIT, instead simply highlighted an issue in need of refinement. Stemming from the limitations experienced with the conductive substrate, UCD Consultant described what they would consider to be the optimum solution. This was described as being a modelling material that offered the same modelling capabilities as the blue foam, but could also perform the duties of the substrate, therefore eliminating the need for two separate materials.
5.5 Film Industry Equipment Ltd. Analysis

5.5.1 Introduction

Table 17 provides a summary of the details describing Film Industry Equipment Ltd.

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 125</td>
<td>OEM</td>
<td>Digital Film Editing Equipment</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 17 - Film Industry Equipment Ltd. Profile Summary

Film Industry Equipment Ltd. provided an industrial designer from their ‘in-house’ design team as a participant for the study. The designer plays a major role in the design and development of all the New Product Development (NPD) activities that take place within Film Industry Equipment Ltd. At the time of the study, they had been working for Film Industry Equipment Ltd. for just over two years, having previously worked at the BBC as an interaction designer. The participant has a background in industrial design. Once again, using the information gathered during the study, a profile of the existing design process used by Film Industry Equipment Ltd. was established (see Figure 87).
Film Industry Equipment Ltd. typically undertakes new design projects for two reasons. Firstly if a new market opportunity is identified a product will be developed to fulfil the market needs. Secondly, if an existing product has reached the end of its life cycle it may be redesigned to incorporate new features and rejuvenate the product. The participant stated that a redesign does not always result in an entirely new product and sometimes only small iterations are made. Film Industry Equipment Ltd. not only design and produce hardware for film editing, they also produce software applications that are used in combination with their products. The participant stated that in their experience the software applications will continue to be developed even after release. Changes can be applied via version updates very easily, however the hardware does not benefit from such a luxury. This implies that there is a greater pressure to ensure the hardware design is correct prior to release as changes cannot be made so easily. The participant explained that prototyping therefore naturally plays a critical role in their design process.
As it can be seen from Figure 87 the current method of early stage prototyping that is used by Film Industry Equipment Ltd. involves constructing 1:1 scale physical models using either foam or foam board. *Paper Prototyping* is then used for producing overlays of different concepts for the physical user interface. The participant stated that their current choice of prototyping methods enables them to mock up several concepts within a short period of time whilst incurring minimal material costs. The ability to prototype concepts to full scale was explained by the participant as being essential to allow accurate evaluation of ergonomics and usability. The participant felt that *Paper Prototyping* lends itself very well to printing out full scale UI concepts for use with prototypes.

Other methods of prototyping had previously been considered and explored by the participant, but had failed to meet their needs for a number of reasons. ErgoDex (Anon, 2008) for example was briefly considered but thought to be too expensive and too limited in functionality and scale. ‘Hacking’ keyboards to create prototypes, effectively using a similar technique to the IE system (Gill, 2003a), had also been explored but too was found to have its limitations. The participant explained that wiring and coding quickly became complex and detracted their attention away from the actual design exploration. Instead, a greater length of time was spent trying to troubleshoot the prototyping tool and not the design. The participant also stated that they had previously used Flash to create Wizard of Oz (Maulsby et al., 1993) interface walk through. However, most commonly the early stages would not involve using interactive methods due to the investment in time required in constructing them.

Despite Film Industry Equipment Ltd. having ‘in-house’ software and electronic engineers, the participant stated that while they are available to assist with prototyping, lead times of at least one week occur due to their commitments to other projects and tasks. As a result the participant preferred to find ways to explore designs without engineering involvement, particularly during the early stages as it allowed for faster iteration.
The outputs of the design exercise that were produced by the participant from *Film Industry Equipment Ltd.* are shown in Figure 88 and Figure 89.

**5.5.2 Speed of Prototyping**

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hr</td>
<td>40 Minutes</td>
<td>1 hr</td>
<td>30 Minutes</td>
<td>1hr 40 Minutes</td>
<td>3hrs 10 Minutes</td>
</tr>
</tbody>
</table>

Table 18 provides a summary of the times taken by the participant to complete each phase of the design exercise. The data shows that in this case the participant was able to prototype their concept in a total time of one hour and 40 minutes. StickIT therefore successful provided a method for achieving a prototyping time of less than two hours. In this case the physical prototyping was achieved in two thirds of the time that the software UI prototyping had taken. During the interview the participant stated that it had in fact been some time since they last used Flash. They believed that if they had used it more recently then the prototyping time could have been reduced. Further examination of the prototypes produced revealed that the software UI prototype included animated sequences and logical programming and that it was not simply made up of static frames. The animations were used for providing interactivity, whilst the logical programming added a random “pass or fail” feature to the interface. The StickIT keyboard library was not able to provide
support for developing this logical programming. However, the participant did choose to use the keyboard library for triggering the animations, whilst they wrote custom *Actionscript* to provide the additional functionality required. The need to write *Actionscript* code naturally led to an increase in prototyping time required for the software UI as the participant searched online for sections of code.

During the interview the participant stated that they considered the time taken to construct the physical interactive prototype could be split into two sub-tasks. The first task was considered to be the construction of the physical prototype. This was considered by the participant to account for the majority of the total prototyping time required. The second was to attach StickIT to the prototype in order to make it interactive. The participant considered the labour involved in achieving this was minimal compared to the investment of time and effort for constructing the prototype and literally took a matter of minutes to complete. This was considered to be a significant key strength by the participant. They perceived StickIT’s approach to required very little additional effort on top of their current prototyping approach in order to convert a rough prototype into a functioning interactive prototype. An increase in effort required to add interactivity to a prototype was something that the participant had previously emphasised as being a significant drawback with other prototyping methods that had been explored by them (namely the hacking of existing equipment such as computer keyboards).

Again, the physical prototype was constructed first but was not used during the development of the software UI prototype. The two elements were only combined at a stage when the participant considered them both to be complete and ready for testing.
5.5.3 Comparison with Existing Practice

The current practice of prototyping used by Film Industry Equipment Ltd. during the early stages, foam board physical prototyping combined with Paper Prototype overlays for various iterations, was used by the participant for the completion of the Rating / Weighting Scale. The raw data and the normalised values are shown in Table 19.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Os)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>S</td>
</tr>
<tr>
<td>Representation of intended Interaction</td>
<td>6</td>
<td>8.57</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>4</td>
<td>5.71</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>6</td>
<td>8.57</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>4</td>
<td>5.71</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>4</td>
<td>5.71</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Effective representation of intended</td>
<td>5</td>
<td>7.14</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>physicality of concept</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>2</td>
<td>2.86</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>5</td>
<td>7.14</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>6</td>
<td>8.57</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Interaction between designer and</td>
<td>6</td>
<td>8.57</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>2</td>
<td>2.86</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>4</td>
<td>5.71</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>4</td>
<td>5.71</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>6</td>
<td>8.57</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>6</td>
<td>8.57</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>70</td>
<td></td>
<td>55%</td>
<td></td>
</tr>
<tr>
<td>Normalisation Factor (Nf)</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 19 - Rating / Weighting scale data for Film Industry Equipment Ltd. (Current Practice = 1:1 scale foam board prototype with Paper Prototype Overlays)
Figure 90 - Graph displaying a comparison between existing prototyping method and StickIT - Film Industry Equipment Ltd.
The rating weighting data shown in Table 19 was used to plot a scatter graph, shown in Figure 90. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

The participant perceived StickIT to provide an overall improvement of being 28% more effective compared to the level of fulfilment offered by the existing practice used.

5.5.3.1 What were the Strengths of StickIT?

The greatest perceived area of improvement offered by StickIT according the participant was the Level of Prototype Automation. As with previous cases, since Film Industry Equipment Ltd. used a non-interactive prototyping method as a current prototyping practice this result was not surprising. Frequently during the study, the participant expressed their frustrations with using Paper Prototypes; whilst it provides a cheap and fast method of working, the resultant prototypes do not actually provide any level of functioning interactivity. The increase in prototype automation offered by StickIT was felt to be a significant benefit when using a prototype for user testing purposes. This therefore accounted for the improvement of ‘Suitability of Prototype for Conducting User Testing’. The participant also felt that having a working, albeit fairly rough, prototype would act as a particularly strong leverage tool when discussing design considerations with the software team in Film Industry Equipment Ltd. Expanding upon this point further during the interview, he explained that using Paper Prototyping on a foam model requires a certain degree of imagination relating to how the users will interact with the product, illustrated by the following quote:

"So the software team wants to do it a certain way, but you want to do it another way, and you have no way of proving which route. You've got no evidence...because it doesn’t do anything, you can only imagine."
The participant explained that this limitation has in the past led to conflicts of opinions between teams within *Film Industry Equipment Ltd*. In one case this resulted in a design opportunity identified by a designer being excluded from a final design as the designer was unable to fully convey its value using the available prototyping methods. Furthermore, the participant felt that the output of the design exercise clearly illustrated their point relating to the faults of relying upon a designer's imagination for identifying potential problems. The initial intention was to position the power button of the breathalyser on the bottom face of the product (Figure 91 and Figure 92).

![Figure 91 - Design Intent for Button Position](image1)

![Figure 92 - Actual position on physical prototype](image2)

This detail was prototyped using StickIT as the participant intended the design to be. However, during the testing phase of the design exercise the participant quickly noticed that the button could be accidentally pressed if the product was placed in an upright position, consequently triggering the Flash software UI unintentionally. The participant felt that had the prototype not been interactive, they might not have realised that the switch could be accidentally pressed.

The rating / weighting data shows that the participant perceived StickIT to offer an improvement in terms of ‘Effective communication of design intent’, ‘Representation of Intended Interaction’, ‘Richness of Interaction’ and also
'Immediate exploration of error solving'. It is plausible to suggest that the issue with the button on the base of the breathalyser and past experiences of limitations imposed by using non-interactive prototypes were contributors which lead to StickIT being perceived to offer an improvement in these areas.

The participant saw potential for StickIT to offer an improvement in the ‘Level of Technical Understanding’ displayed by a prototype. However, this would require some refinement of StickIT in order to fully fulfil the participant's needs. The participant explained that if StickIT could support the use of 'off the shelf' components, it would allow a variety of different switches to be rapidly tested. According to the participant the ‘feel’ of a switch is an important attribute that needs to be considered when designing products for the film editing industry. It was explained that if a product has a high value, then it is important that the interaction with that product does not feel cheap.

As previously discussed the participant had experienced barriers in the past when attempting to "hack" keyboards for the purpose of producing an interactive prototype. As a result of this, providing a close fit with the skills of a designer was considered to be one of the most important factors by the participant when considering a new prototyping method. The Rating / Weighting data indicates that the participant felt that both Paper Prototyping and StickIT provide an excellent fit with the skills of an industrial designer. Qualitative data was used to gain a greater understanding of how StickIT fulfilled this need. Interestingly it was found that although the software UI prototyping approach offered by StickIT was considered to be a good fit with the participant’s skills, it was felt that the hardware prototyping provided a closer fit. The participant explained that although he was able to use Flash, the need for writing Actionscript was the biggest barrier in terms of the software UI prototyping approach provided by StickIT. It was suggested that if the Flash element could be simplified then this would help to address the issue. Additionally if the software application used to programme the StickIT I/O’s could be incorporated into Flash this would also help to streamline the prototyping process.
5.5.3.2 What were the weaknesses of StickIT?

The Rating / Weighting scale data indicates that StickIT was perceived to be marginally poorer with regards to the Ease of Prototype Iteration than Film Industry Equipment Ltd.’s existing practice. ‘Ease of Prototype Iteration’ was considered to be one of the most important factors for early stage prototyping by the participant, therefore it was important to try to understand the shortcomings of StickIT. Examining the qualitative data quickly identified the reason behind StickIT being considered less fulfilling. The participant simply felt that as StickIT required the software UI to be prototyped using Flash, this would naturally be harder to rapidly iterate than Paper Prototype equivalents that did not require coding at all. This notwithstanding, StickIT was still regarded as offering a prototyping approach that would allow for rapid iteration with a high degree of ease and was not considered to be outside of the participants skill set.

As already stated, the participant considered the ‘Representation of Intended Interaction’ and ‘Effective communication of the physicality of a concept’ to be both very important areas for an early stage prototype to address. The participant felt that the spongy tactile nature of the conductive substrate used by StickIT could potentially lead to miscommunication of the intended design concept as it introduced a tactile sensation while interacting with the I/O devices that was not intended to be as in the final product. The participant considered this factor to be an important area for refinement if StickIT were to be further developed as a prototyping tool.

Although the design concept produced by the participant did not feature any I/O's on the curved surfaces of the product, the participant recognised that this may have been difficult to prototype using StickIT in its current form. However, they suggested that if the actual buttons for each I/O were on fly-leads, this would allow them to still connect to a single substrate but would allow them to be positioned anywhere on the prototype. Alternatively it was suggested that it would be useful to be able to connect sections of substrate together, therefore allowing it to be positioned on multiple surfaces and still work using the single antenna concept.
Finally, during the interview the participant stated that some of the products they
design are still considered to be computer-embedded devices, but do not feature
GUI's. Instead, some products rely on the use of LED indicators and segmented
numerical panels for conveying information to the users. Whilst appreciating that
StickIT did not intend to provide prototyping support for these kinds of output
devices, they felt that they would significantly benefit from having prototyping
methods similar to StickIT that did provide such functionality.
5.6 Multi-Platform Communications Corp. Analysis

5.6.1 Introduction

Table 20 provides a summary of the details describing Multi-Platform Communications Corp.

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 - 1250</td>
<td>OEM</td>
<td>Peer to Peer Communication</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 20 - Multi-Platform Communications Corp. Profile Summary

As described in section 3.3.3.5, Multi-Platform Communications Corp. develops and provides peer to peer communication technologies. Traditionally Multi-Platform Communications Corp. has worked largely in the software application market. However, recently they have seen a rapid increase in demand for device specific and compatible versions of their products for use on third party devices including mobile phones, television set top boxes, tablet PC’s and landline telephone handsets.

Multi-Platform Communications Corp. allowed for one of their senior interaction designers to take part in the study to trial StickIT. The participant had over 10 years industrial experience, including having previously worked for Yahoo as an interaction designer. At the time of the study the participant had been working at Multi-Platform Communications Corp. for 2 years. The participant's job focused on the interaction design relating to the development of the applications produced by Multi-Platform Communications Corp. Once again it was possible to use the data gathered during the interview to form a profile of the design process used by the participant from Multi-Platform Communications Corp. This design process is shown in Figure 93.
The participant from *Multi-Platform Communications Corp.* stated that during the early stages of a project, it will typically be impossible, and in their opinion unnecessary, to prototype every concept. Instead, an initial round of concept selection will take place, where ideas and concepts are either communicated using storyboards or just verbally described. The ideas that are considered to satisfy the brief best are chosen to be taken forward to a very crude and rough prototyping stage to explore them further. According to the participant a variety of prototyping methods are used within *Multi-Platform Communications Corp.* during this initial stage of rough prototyping. The choice of prototyping tool was described as being an individual preference for the designers involved and a choice of what they felt most comfortable using. The participant stated that their personal preference and tool of choice is *Adobe Flash*, although other people use tools including *Omni-Graph* and *AxureRP* for the same purposes. These early stage prototypes are tested using on-screen façade prototyping techniques only. The participant described two primary constraints being present within *Multi-Platform Communications Corp.*
Firstly, the company was initially formed as the result of a technological breakthrough which was utilised and developed into a product. Consequently the company is largely driven from a technical and engineering perspective. Secondly, budget and resources (*persons available for a project*) do not often present problems, but rather the largest constraint faced by employees is one of extreme time pressure resulting in short project deadlines.

It became apparent that whilst the applications that *Multi-Platform Communications Corp.* produced are being developed for use with an increasing number of computer-embedded devices and bespoke platforms, the interaction designers within *Multi-Platform Communications Corp.* have very little, if any control over the design of the physical devices. Whilst it could be argued that for this reason, *Multi-Platform Communications Corp.* may be outside the primary target user group of StickIT, it was considered that trialling StickIT with *Multi-Platform Communications Corp.* should continue and would remain a valuable asset to the research for two key reasons:

Firstly, existing literature in the field states that interactive prototyping is not solely a task undertaken by industrial designers. Research suggests that often disciplines other than industrial designers, including interaction designers, also face the same prototyping barriers and as a result prototyping tools should be equally as accessible across these disciplines (Gill et al., 2008a).

Secondly, the study would be of value to establish whether *Multi-Platform Communications Corp.* saw potential for prototyping software UI's in conjunction with a physical device. While *Multi-Platform Communications Corp.* may not be in a position to have a major impact on the physical device design for which their products are placed on, testing in conjunction with a physical prototype has been empirically proven by a number of authors to lead to a greater number of design issues being identified than testing on-screen only (Liu and Khooshabeh, 2003, Nam, 2005, Gill et al., 2008b).
The prototypes produced by the participant from *Multi-Platform Communications Corp.* are shown in Figure 94 and Figure 95 are examined in-depth in the subsequent sections.

![Figure 94 - Multi-Platform Communications Corp. Physical Interactive Prototype](image1)

![Figure 95 - Multi-Platform Communications Corp. Software User Interface Prototype](image2)
5.6.2 Speed of Prototyping

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 Minutes</td>
<td>55mins</td>
<td>1hr 25Minutes</td>
<td>15 Minutes</td>
<td>2hrs 20 Minutes</td>
<td>3 hrs 10 Minutes</td>
</tr>
</tbody>
</table>

Table 21 - Summary of Design Exercise Timings for Multi-Platform Communications Corp.

Table 21 presents a summary of the times taken by the participant to complete specific stages of the design exercise. A total prototyping time of two hours 20 minutes was taken by the participant to prototype their design concept. Therefore in this case StickIT was unable to provide a method of prototyping in less than two hours. Rather surprisingly, despite the participant being from an interaction design background as opposed to industrial design, the physical prototyping was completed 30 minutes faster than that of the software UI. The participant reported experiencing no difficulties in using StickIT to produce the physical prototype, neither were any problems observed during the study. It is possible that only a short period of time was spent on the physical prototyping due to a lack of experience in developing physical designs. However, the resultant physical prototype was close to the initial sketched concept so this did not appear to be a key reason.

The participant began by sketching some initial concepts for the physical design of the breathalyser, before choosing a single concept to develop. The next stage involved developing the flow of the software UI by sketching state transition diagrams on paper to get an overall idea of the UI design intent. In this case, the participant chose to prototype the software UI using Flash, before constructing the physical model. Although the participant considered their software UI prototype to be low fidelity and 'quick and dirty', it does display evidence of a relatively high degree of consideration having been given to the visual refinement and aesthetical attributes of its design. The participant was clearly very comfortable in the use of Flash for the purpose of prototyping in this style.
The software UI prototype featured a combination of animated sequences and programmed logical functions, (see Figure 96 for a storyboard displaying a sample of an animated sequence featured in the prototype). The participant from Multi-Platform Communications Corp. was confident in their coding ability to produce the software UI prototype, and therefore did not require the use of the keyboard library.

The relatively high level of visual refinement found within the software UI prototype created an interesting topic of conversation during the interview. The Rating / Weighting scale data shows that the ‘Level of Visual Refinement’ is not considered a highly critical attribute during early stage prototyping by Multi-Platform Communications Corp.'s participant. During the interview the participant explained that they fully appreciate that low fidelity prototyping can indeed save time, something that they repeatedly described as being the greatest pressure faced within Multi-Platform Communications Corp. However, the participant highlighted a problem in working in such a manner: they felt it is often difficult for someone who is visually trained not to consider details such as colours, fonts and GUI element placement when developing a prototype of a design. What is more, the participant felt strongly that in their opinion all of these factors contribute equally towards the overall user experience as much as the flow of a menu or the placement of a button. Consequently, they felt that the inclusion of such details can be important even for early stage prototypes. This opinion is interesting in that it is
contrary to numerous research findings including (Arnowitz et al., 2007, Goodwin, 2009, Buxton, 2007), which found that the use of high fidelity prototypes during the early stages of the design process can in fact be counterproductive.
5.6.3 Comparison with Existing Practice

The current practice of prototyping used by Multi-Platform Communications Corp. during the early stages of a design process were described as typically limited towards onscreen façade style prototypes. The participant stated that they will typically use Flash for this purpose, as such, Flash was used as the current practice when completing the Rating / Weighting Scale. The raw data and the normalised values are shown Table 22.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Os)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation of intended Interaction</td>
<td>6</td>
<td>10.34</td>
<td>4</td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>4</td>
<td>6.9</td>
<td>4</td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>5</td>
<td>8.62</td>
<td>4</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>5</td>
<td>8.62</td>
<td>4</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>6</td>
<td>10.34</td>
<td>4</td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>3</td>
<td>5.17</td>
<td>2</td>
<td>5</td>
<td>0.3</td>
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<tr>
<td>Level of visual refinement</td>
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<td>5.17</td>
<td>3</td>
<td>3</td>
<td>0.5</td>
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<tr>
<td>Level of technical understanding</td>
<td>3</td>
<td>5.17</td>
<td>3</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>2.5</td>
<td>4.31</td>
<td>4</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>3</td>
<td>5.17</td>
<td>3</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>3</td>
<td>5.17</td>
<td>6</td>
<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>5</td>
<td>8.62</td>
<td>5</td>
<td>4.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>5</td>
<td>8.62</td>
<td>5</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>2</td>
<td>3.45</td>
<td>2</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>2.5</td>
<td>4.31</td>
<td>4</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Totals</td>
<td>58</td>
<td></td>
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</tr>
<tr>
<td>Normalisation Factor (Nf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 22 - Rating / Weighting scale data for Multi-Platform Communications Corp. – (Current Practice = Onscreen Flash only Prototype)
Comparison between existing prototyping method and StickIT - Multi Platform Communications Corp.

![Graph displaying a comparison between existing prototyping method and StickIT - Multi Platform Communications Corp.](image)

Figure 97 - Graph displaying a comparison between existing prototyping method and StickIT - Multi Platform Communications Corp.
The rating weighting data shown in Table 22 was used to plot a scatter graph, shown in Figure 97. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

The data gathered from the Rating / Weighting scale indicates that the participant perceived an overall increase of around 10% in terms of level of fulfilment between StickIT and their existing practice.

5.6.3.1 What were the strengths of StickIT?

According to the participant from Multi-Platform Communications Corp. the areas in which StickIT offered the greatest level of improvement were ‘Effective Representation of Intended Physicality of Concept’, ‘Interaction between designer and prototype’ and the ‘Level of Ergonomic Evaluation’ afforded by the resultant prototypes. While an increase in these areas is not surprising, the degree of improvement appears to be somewhat modest considering the fact that the current practice used does not involve the use of a physical prototype at all.

Possibly the greatest strength demonstrated by StickIT in this case was that the participant was able to prototype the physical aspects of their design without difficulty despite not having a background in industrial design. The Rating /Weighting scale data indicates that the participant felt StickIT was equally accessible to their skill set as their current practice. This indicates a particular strength of StickIT as it introduced new design and prototyping considerations to the participant, yet achieved it utilising the participant’s current skill set. During the interview the participant noted that the actual construction of the prototype took the majority of the time. While adding the interactivity to the prototype, the area the participant admitted to knowing the least about and was also the most nervous about, took only 5 minutes. This time could potentially have been reduced further as the participant initially experienced a minor connection problem between the StickIT hardware and their laptop. The ease with which StickIT allowed the
participant to explore a working interactive physical prototype was of particular interest to them.

The participant stated during the interview that in their opinion the software UI prototyping was the most complicated aspect of the design exercise.

<Multi-Platform Communications Corp.'s participant>

"The most complicated part of creating the prototype was actually creating the logic and programming, programming the interactive prototype, and not, and making it then physical."

The participant felt that the use of StickIT could be beneficial in enhancing the user experience through prototype concepts, and stated during the interview: "it really help making this stuff feel more real".

The speed of prototyping provided by StickIT was considered to be a positive attribute by the participant, as they frequently felt that time pressures within Multi-Platform Communications Corp. forced them to work through ideas rapidly. However, the participant expressed a concern that the time needed to prototype a concept cannot be infinitely reduced. They stated that the need for 'thinking time' is often underappreciated; essentially presenting the argument that if things are rushed then quality can suffer. The participant explained that within Multi-Platform Communications Corp. there are some expert Flash users that can assist with prototyping if challenges arise, however it is largely a decision of importance versus time available.

Finally, it was found that the interaction design team do not have access to an area where physical prototypes could be constructed, such as workshop or model making facilities. Although this was the case, the participant was able to construct the physical prototype using the materials provided plus StickIT whilst working at their desk. This was due to StickIT providing a good fit with their skills, and did not require a designated workshop space or electronic prototyping equipment. Examining this further it demonstrates that the addition of physical prototyping into Multi-Platform Communications Corp.'s existing design process would not
require the development of bespoke model making facilities if using an approach such as StickIT.

5.6.3.2 What were the weaknesses of StickIT?
The participant from Multi-Platform Communications Corp. considered the overall concept of StickIT to provide a valuable method of prototyping. In terms of weaknesses, the participant felt that the fundamental principle of the system was good, however suggested a number of possible improvements to extend the system’s potential further.

Firstly, the participant considered that the biggest constraint of StickIT was that the screen was not on the prototype and instead the GUI displayed on a laptop. They explained that all of the products that they design will feature some kind of display and provide feedback through a combination of visual and audio. The participant felt that the feedback of a prototype was therefore as important as the inputs, and should also be supported by a prototype. Despite this opinion, the participant had previously described the early stage prototyping processes used within Multi-Platform Communications Corp. as being either scenario based or very quick on-screen interactive prototypes. The development of prototypes that could run on devices does not happen until much later when a single concept had been chosen for being developed fully. This therefore suggests that since StickIT is intended for use during the early stages, it supports embedded screens no less than the current practices used within Multi-Platform Communications Corp.

A further area for improvement suggested by the participant related to the conductive substrate material. The participant felt that the substrate made the operation of a button feel ‘weird’ and resembled pressing a cushion rather than the type of tactile sensation generally associated with interacting with consumer electronics. It was interesting that the prototype produced by the participant using StickIT had resulted in encouraging them to think of the user experiences associated with the physical interactions of the device in addition to the software UI. Although they appreciated that the purpose of StickIT was to investigate the concept and not a final solution, it was also suggested that the toolkit would pose a
greater value if it could support a wider range of inputs. The participant initially suggested the inclusion of a greater range of physical inputs including dials, sliders and rocker switches. However, they later stated that the ability to prototype touch screens rapidly could also be of value as more and more products they deal with are featuring touch screen technology.

As stated in section 5.6.2, the participant did not use the StickIT keyboard library when prototyping their software UI concept. This was due to it offering only partial support for the functionality needed to prototype the design, but also due to the participant feeling confident in their Actionscript ability to be able to sufficiently prototype the design. It was considered by Multi-Platform Communications Corp.’s participant that the predefined nature of not only the StickIT keyboard library, but also prototyping tools including AxureRP and Balsamic Wire framing, restricted flexibility. They felt the consequence of using predefined libraries can be limiting towards creativity. As a result they felt the flexibility offered through writing bespoke Actionscript outweighed the labour and learning curve involved. The participant felt that it was acceptable if a particular prototyping method required elements of learning prior to use. This was however, conditional on the investment in time spent learning resulted in prototyping abilities that could not have otherwise been achieved.

5.6.4 Specific Issues for Multi-Platform Communications Corp.

The participant expressed a very clear positive opinion towards StickIT overall and was able to relate to the intended benefits. Nevertheless, despite the participant’s personal views on StickIT, they felt that the time pressures of projects within Multi-Platform Communications Corp. might restrict the use of prototyping methods that explore designs in the context of a physical device to some extent. The participant explained that the interaction design team are actively trying to evangelise the value in adopting a UCD approach and the benefits of early prototyping with the involvement of users. The participant highlighted through the design exercise that they were also aware that the physical design of a device has as much of a role to play in the overall user experience as the elements which are displayed on screen. However, it was explained that UCD processes are considered by some people
within *Multi-Platform Communications Corp.* to be lengthy and time consuming and would further stretch deadlines. This therefore suggests that whilst the participant from *Multi-Platform Communications Corp.* is able to appreciate the value in StickIT’s overall concept, certain cultural barriers within *Multi-Platform Communications Corp.* could limit the adoption of physical prototyping tools at the time of the study.
5.7 **Global Mobile Phone Corp. Analysis**

5.7.1 **Introduction**

<table>
<thead>
<tr>
<th># of Employees</th>
<th>Type of Company</th>
<th>Primary Market</th>
<th>‘in-house’ Electronics Capabilities</th>
<th>‘in-house’ Software Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000 – 125,000</td>
<td>OEM</td>
<td>Global Mobile Phone Markets</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

A senior member of the ‘in-house’ interactive prototyping team was provided by Global Mobile Phone Corp. to participate in the study to trial StickIT. The participant had been working at Global Mobile Phone Corp. for approximately 8 months when the study took place. Despite being relatively new, the participant held a senior position within the team. Prior to working for Global Mobile Phone Corp. he had worked for a number of large multinational companies as an interaction designer. The participant has a taught background of industrial design, during which they developed a personal interest in the interaction design issues relating to consumer technology. Within Global Mobile Phone Corp. the participant’s job role is to work alongside the user interface, user interaction and user experience design teams to provide interactive prototyping support for both their hardware and software requirements. Using the data gathered during the study a typical design process used by the prototyping department emerged. This design process is shown in Figure 98.
Although *Global Mobile Phone Corp.* has ‘in-house’ electronics and software engineering teams, the nature of being a multinational corporation presents a problem. The core activities of the design are divided across a number of counties and continents. Consequently, handset design is undertaken in one country, whilst the software UI is designed in another. The participant stated that this meant the handset and software UI are designed independently of each other. As a result, the participant described the opportunities for the software UI designers to suggest changes to the hardware as being extremely limited, although not impossible. Hardware and software designers are able to contact each other with ease, however requesting changes to hardware designs was described as a long process that required going through numerous channels of bureaucracy. Nevertheless, according to the participant from *Global Mobile Phone Corp.*, the software UI teams felt strongly about testing UI concepts in conjunction with physical devices. Wherever possible the integration of software prototypes with physical devices is favoured. A further limitation faced by the software UI developers within *Global Mobile Phone Corp.* related to their physical environment. Access to model making facilities was limited at their offices and restricted to desk based activities, with even basic electronic prototyping tools such as soldering irons being scarce.
Prototyping of handsets was outsourced to an RP sub contractor company, typically incurring a lead time of around one week.

As can be seen from Figure 98, Global Mobile Phone Corp. uses a wide range of prototyping methods during the initial stages of concept development for the handset UI's:

- Paper Prototyping
- Storyboards
- PowerPoint Interactive Wireframes
- Flash Lite UI + Existing Handset
- ‘in-house’ UI prototyping platform + Existing Handset
- Disguised fully functioning handset inside "Black Box"
- Façade On-screen Only Prototypes

Initial prototyping by the participant was described as using Paper Prototyping which would be tested internally and externally with between 8-10 people. The participant explained that this process would generally be repeated as the design undergoes iteration, and has been found to be particularly useful at identifying key design requirements with minimal investment in time or effort. Once a clearer idea of the design exists, the team will move onto producing a rough interactive wireframe prototype or storyboard of the UI flow. Following the definition of the wireframe (essentially the basic information architecture of the UI), the next stage involves developing an interactive prototype that whenever possible will be combined with an existing handset. Two primary prototyping tools were described as being used within Global Mobile Phone Corp. for achieving this, Flash Lite being one, and a bespoke software application developed by Global Mobile Phone Corp. the other. In order to protect the anonymity of Global Mobile Phone Corp. this bespoke software package will be referred to as an ‘in-house’ Software Tool. The participant noted that while Flash Lite prototypes can be easily loaded onto some handsets, it offers only a very limited level of functionality in comparison to the full capabilities of Flash running on a PC.
In situations where neither Flash Lite or ‘in-house’ Software Tool are able to provide the required functionality for a software UI prototype to be loaded onto a handset, the interface prototype will be made using full Flash and displayed on a PC and operated via a mouse and keyboard in the fashion of a façade prototype. This will typically be required if the prototype features a higher degree of interaction than simply swapping between frames. The participant believed that façade prototyping was widely used within Global Mobile Phone Corp. for two reasons: Firstly, this method had been historically used by the company, and therefore it was very much a case of being difficult to change old habits. Secondly, they believed that a genuine lack of superior alternatives existed.

The outputs of the design exercise undertaken by the participant are shown in Figure 99 and Figure 100. The details of the prototypes produced during the design exercise are discussed in detail below.

![Image](image.png)

**Figure 99 - Global Mobile Phone Corp. Physical Interactive Prototype**

**Figure 100 - Global Mobile Phone Corp. Software User Interface Prototype**

### 5.7.2 Speed of Prototyping

<table>
<thead>
<tr>
<th>Concept Design</th>
<th>Physical Prototyping</th>
<th>Software User Interface (UI) Prototype</th>
<th>Testing</th>
<th>Total Prototyping Time</th>
<th>Total Design Exercise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Minutes</td>
<td>50 Minutes</td>
<td>40 Minutes</td>
<td>10 Minutes</td>
<td>1hr 30 Minutes</td>
<td>2hrs 10 Minutes</td>
</tr>
</tbody>
</table>

*Table 24 - Summary of Design Exercise Timings for Global Mobile Phone Corp.*
Table 24 shows a summary of the times taken by the participant from *Global Mobile Phone Corp.* to complete the design exercise. In this case StickIT was successful in providing a prototyping method that enabled the participant to prototype their design in less than two hours.

Qualitative observational and interview data was used alongside the prototypes produced to further examine the use of StickIT by the participant. During the design exercise it quickly became apparent that the participant was well practiced in the use of Flash for producing interactive prototypes. The software UI flow was initially sketched out on paper along with the physical prototype design, before moving onto the prototyping of both aspects. Interestingly and what cannot be seen from Table 24 is the fact that the participant developed the physical prototype UI and the software UI almost in parallel. Once the overall physical model had been developed they began by creating the basic functionality of the software UI prototype using Flash. They chose to write their own *Actionscript* for two reasons: firstly the keyboard library of StickIT was unable to provide functionality for all the UI features they wished to include, and, secondly, they felt very comfortable in their ability to write their own code. The design intent was for the software UI prototype to trigger a counter upon someone breathing into the testing tube mounted on the prototype. However, since StickIT was not able to support a pressure sensor interaction, the participant simulated this trigger using Wizard of Oz (Maulsby et al., 1993) prototyping. StickIT was however used to support the other functions of the device, whilst the triggering of a breath being given was achieved by pressing a key on the keyboard.

Having constructed the basis of the physical prototype and also the software UI, the participant began to add interactivity to the hardware prototype using StickIT, whilst also modifying the software UI to accommodate revisions in their design thinking. For example, at one stage they recognised that the design required a reset function, and therefore also a reset switch. Both elements were added to the prototypes before the participant continued with developing the design.
5.7.3 Comparison with Existing Practice

Unlike the other cases, the participant from *Global Mobile Phone Corp.* explained that an array of prototyping methods may be used during the early stages of their design process. When completing the rating weighting scale the participant based their current practice on all of the methods available to them as opposed to selecting a single prototyping approach to compare against StickIT. The raw data and the normalised values of which are shown in the table below:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting Factor (W)</th>
<th>Normalised Weighting (Nw)</th>
<th>Rating (R)</th>
<th>Normalised Rating (Nr)</th>
<th>Nw x Nr (Os)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>S</td>
<td>C</td>
</tr>
<tr>
<td>Representation of intended interaction</td>
<td>6</td>
<td>8.28</td>
<td>4</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>5</td>
<td>6.9</td>
<td>5</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Ease of prototype iteration</td>
<td>5</td>
<td>6.9</td>
<td>4</td>
<td>6</td>
<td>0.7</td>
</tr>
<tr>
<td>Immediate exploration of error solving</td>
<td>6</td>
<td>8.28</td>
<td>4</td>
<td>6</td>
<td>0.7</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>5</td>
<td>6.9</td>
<td>4</td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>5</td>
<td>6.9</td>
<td>2</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>4</td>
<td>5.5</td>
<td>4</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>4</td>
<td>4.14</td>
<td>3</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>4</td>
<td>5.5</td>
<td>5</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>5</td>
<td>6.9</td>
<td>5</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>5.5</td>
<td>7.59</td>
<td>4</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>4.5</td>
<td>6.21</td>
<td>5</td>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>4</td>
<td>5.52</td>
<td>4.5</td>
<td>4.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>5.5</td>
<td>7.59</td>
<td>2</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Client / Managerial Persuasion tool</td>
<td>5</td>
<td>6.9</td>
<td>4</td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>Totals</td>
<td>72.5</td>
<td>67%</td>
<td>79%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Normalisation Factor (Nf)                          | 1.38     |          |          |          |          |          |

Table 25 - Rating / Weighting scale data for *Global Mobile Phone Corp.* – (Current Practice = All of prototyping tools used by Company)
Figure 101 - Graph displaying a comparison between existing prototyping method and StickIT - Global Mobile Phone Corporation
The rating weighting data shown in Table 25 was used to plot a scatter graph, shown in Figure 101. The weighting which the participant gave to each of the 15 attributes is presented in order, ranging from the least important on the left, to the most important on the right. The graph also allows shows the ranking the participant gave for each attribute for both their current prototyping practice as well as StickIT.

The normalised data from the Rating / Weighting scale indicates that the participant considered StickIT to provide an overall improvement of 12% over their current prototyping practices used. The fact StickIT was considered to offer an improvement over the existing practice in this case is an important result. It is important due to the fact StickIT was not compared to just a single prototyping tool, but to an array of prototyping tools. Critically, this array of tools included highly sophisticated methods such as the use of fully functioning mobile phone handsets as a prototyping platform.

5.7.3.1 What were the Strengths of StickIT?

The greatest perceived strength of StickIT compared to the existing prototyping methods used by Global Mobile Phone Corp. was the ‘Level of Ergonomic Evaluation’ that was afforded through the StickIT prototype. The existing methods of prototyping were felt to offer a certain degree of support in terms of exploring the ergonomics of a design as many of the methods did feature the software prototypes being used with a handset. However, none of the existing methods allowed for the software UI to be tested in combination with the actual handset that the UI was being developed for. Consequently, the participant considered that StickIT would allow for a more accurate, albeit low fidelity, representation of the intended design to be combined with the UI concept. Interestingly the participant described the "Black-Box" prototype as being considerably bigger than a typical handset. The reason for which was explained as the "Black-Box" is essentially used to disguise the handset of another manufacturer and therefore needs to be large enough to accommodate the third party handset inside. The same reasons also provide justification behind a perceived increase in the ‘Representation of the Design Intent’. The participant recognised that using a prototype that does not
match the desired ergonomics of a design can influence user testing. They stated that the hardware department can be asked to produce a working prototype of the actual handset if it is essential, but in their experience time and budget rarely allow this to happen, particularly during the early stages. The problem was described as stemming from the fact that the prototyping methods mentioned in Section 5.7.1 have been used by the company historically, and seen to work to a certain degree, so they continue to be used.

The perceived improvement shown for the ‘Ease of Prototype Iteration’ by the Rating / Weighting scale data could be accounted for as being related to the level of iteration possible whilst using integrated handset/UI prototyping approaches. While the current practices used, such as Paper Prototyping provide a very easy method of prototype iteration, the hardware prototypes used by Global Mobile Phone Corp. do not support rapid iteration at all. The participant stated that they did not consider StickIT as a potential replacement for Paper Prototyping. Paper Prototyping does not require any coding knowledge, therefore the participant felt it would still be easier to iterate than StickIT which requires some Flash programming skills. However, he saw StickIT to be more like a stepping stone, or intermediate stage that would sit well between Paper Prototyping and any progression to full hardware prototypes.

The participant explained that the level of fidelity that is required by a prototype will generally be judged on a project by project basis. The integration of StickIT with Flash therefore provides a good platform for enabling the designers of Global Mobile Phone Corp. to work through a range of levels of fidelity.

During the interview the participant opined that the speed of prototyping afforded by StickIT in terms of the hardware came largely as a result of not needing to hollow out a prototype in order to embed the electronics required for its functionality inside. In particular this was thought to offer a key strength for working in an environment such as their office. The participant felt that the ability to prototype without requiring electronic equipment such as soldering irons was a strong feature.
Finally, it was explained that wherever possible, current practice will always try to integrate the software UI into a screen on a handset. The embedding of a screen to display the UI is something that StickIT did not set out to achieve. However, it would be possible to combined StickIT with a prototyping approach also being developed by PAIPR (Zampelis, 2009) that focuses on enabling software UI’s to be augmented onto the surface of a low fidelity prototype. This could potentially provide a method of prototyping an interactive device in less than two hours including the ability to display the UI in situ on the prototype.

5.7.3.2 What were the weaknesses of StickIT?

According to the data from the Rating /Weighting Scale the area where StickIT performed the least effectively in comparison to existing practices was the level of ‘Robustness of the Prototype’. It is probable that this was caused due to many of the existing practices made use of fully functioning handsets. These handsets would naturally feature a much higher level of prototype robustness than a prototype produced using StickIT. Qualitative data also indicated that whilst the participant saw nothing wrong with StickIT being used as an internal prototyping tool, the current aesthetics of the system trialled may be considered a little too "primitive and rough" for use with external stakeholders. The participant stated that working with "working" prototypes, whether that is a façade prototype, Flash Lite on a handset, or "Black-Box" prototype, carried the risk of a reduction in prototype robustness. The only prototyping method that was thought to be very robust was Paper Prototyping which features no technical aspects.

It became apparent from the conversations with the participant from Global Mobile Phone Corp. that the mobile phone industry is a highly competitive market. A challenge that the UI designers at Global Mobile Phone Corp. are currently facing is the need to prototype designs for gesture based interactions. The participant stated that they currently use another manufacturer's handset inside the "Black-Box" in order to prototype gesture based interactions. The reason for which is that

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5 Gesture input refers to a method of interaction that senses the movement of the user in order to trigger different events on a device. An example of gesture based input is the Nintendo Wii Controller.
it provides a more accessible platform for "hacking" than *Global Mobile Phone Corp.*'s own handsets. As a result of *Global Mobile Phone Corp.*'s current interest in gesture based interfaces the participant stated that it would be really useful if StickIT was able to support the prototyping of gesture based interactions with the same speed and ease that it offers for button based interactions.

As previously stated, it was observed during the design exercise that the StickIT keyboard library was not used by the participant for the prototyping of the software UI. This was found to be for two reasons; firstly the library was unable to support the full functionality desired, and secondly the participant felt more than comfortable in writing their own *Actionscript* code. This shortcoming of the StickIT keyboard library was also described as being a limiting factor in the use of the ‘*in-house*’ Software Tool also used by *Global Mobile Phone Corp.* The ‘*in-house*’ Software Tool was described as being a library of UI components that could be "dragged and dropped" to rapidly construct UI prototypes that could be loaded onto one of *Global Mobile Phone Corp.*’s existing handsets. The participant however, described the ‘*in-house*’ Software Tool as being somewhat limited in terms of flexibility.

### 5.7.3.3 Additional Information Relating to Global Mobile Phone Corp.

Since conducting the study, *Global Mobile Phone Corp.* has developed a further ‘*in-house*’ prototyping tool to assist their UI designers with the exploration of interactive prototypes. This new prototyping tool works in a similar "drag and drop" manner to the ‘*in-house*’ Software tool that was in use at the time of the study, however it also allows for exploration of some basic gesture based interactions. Like many of the other prototyping methods used by *Global Mobile Phone Corp.*, this new prototyping platform also only supports use on an existing handset, or by running "Façade style" on a computer screen. This therefore indicates that the rapid development of physical interactive prototypes during the early stages is still somewhat of a barrier for *Global Mobile Phone Corp.*’s designers, and further illustrates the potential offered by StickIT.
6 Cross Case Analysis

Examination of the individual case studies in Chapter 5 resulted in a number of interesting findings relating to StickIT’s use as an early stage prototyping tool. In all cases StickIT was considered to offer an overall improvement upon the existing prototyping methods. This included the participant from Global Mobile Phone Corp. who compared StickIT against all of their prototyping methods, rather than selecting a single approach. This highlights a significant finding that in all cases the participants acknowledged major weaknesses and limitations with their current prototyping practices and design processes. Reasons for the continued use of these practices varied between cases.

During the StickIT design exercises the participants from Design Consultancy B and Multi-Platform Communication Corp. both required longer than two hours to prototype their concepts. This was in contrast to the participants from the other companies who all prototyped their concepts in less than two hours. A difference in the fidelity of the software UI prototypes is evident between the two participants who required more time than in the other cases. Those who took a greater length of time opted to include a higher level of refinement towards the visual aesthetics and animations featured within their UI prototypes.

Critically, the potential of StickIT as a prototyping platform did not appear to be influenced by a company having ‘in-house’ electronics expertise. Design Consultancy B, Film Industry Equipment Ltd. and Global Mobile Phone Corp. all stated that the people with specialist electronic expertise had little involvement in interactive prototyping during the early stages. Consequently, StickIT was seen to offer value to the prototyping processes in all cases.

The scope of the participants’ job roles also revealed an interesting theme across the cases. None of the participants were found to be in positions that enabled them to influence the design of both the physical device and the software UI equally. In the cases of Design Consultancy B, UCD Consultant, Multi-Platform Communications Corp. and Global Mobile Phone Corp. the participants were more focused towards the interaction design issues. Consequently, their influence over the industrial
design was found to be either very limited or worse (as in the case of Multi-Platform Communications Corp.) with almost no input at all.

Using a cross case analysis method, these areas are examined in greater depth.

6.1 **Comparison with Existing practices**

<table>
<thead>
<tr>
<th>Company</th>
<th>Current Practice</th>
<th>Normalised Score</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Consultancy A</strong></td>
<td>Paper Prototype &amp; Foam Model</td>
<td>52</td>
<td>64</td>
</tr>
<tr>
<td><strong>Design Consultancy B</strong></td>
<td>Paper Prototype &amp; RP Model</td>
<td>56</td>
<td>71</td>
</tr>
<tr>
<td><strong>UCD Consultant</strong></td>
<td>AxureRP UI Prototype &amp; Block Model</td>
<td>51</td>
<td>84</td>
</tr>
<tr>
<td><strong>Film Industry Equipment Ltd.</strong></td>
<td>Foam Board model &amp; Paper Prototype Overlays</td>
<td>55</td>
<td>83</td>
</tr>
<tr>
<td><strong>Multi-Platform Communications Corp.</strong></td>
<td>Adobe Flash</td>
<td>66</td>
<td>76</td>
</tr>
<tr>
<td><strong>Global Mobile Phones Corp.</strong></td>
<td>Paper Prototyping, Storyboards, PowerPoint Wireframes, Flash Lite + Handset, ‘In-house’ UI platform + Handset, ‘Black Box’, Façade Prototype</td>
<td>68</td>
<td>79.0</td>
</tr>
</tbody>
</table>

**Table 26 - Summary of Comparison between StickIT and Current Practice (As per Rating/Weighting Data)**

Table 26 shows that in all the cases studied, StickIT was considered by the participants to offer an overall improvement compared to the existing prototyping methods being used. On average StickIT offered a positive improvement of almost 20% compared to existing practice. The fact StickIT was seen to offer an improvement in all the cases is interesting in a number of ways.

Firstly, the rating weighting scores awarded by the participants clearly indicates that the current practices being used for early stage prototyping of computer-embedded devices have a number of major flaws. The significance of this finding is in the fact that the participants from **Design Consultancy B, UCD Consultant, Film Industry Equipment Ltd, Multi-platform Communications Corp. and Global Mobile Phone Corp.** all admitted to being aware that the prototyping methods being used were not perfect yet continued to use them. What is more, many of the prototyping
methods used by *Global Mobile Phone Corp.* were significantly more sophisticated than the methods used by the other companies. More importantly, *Global Mobile Phone Corp.* has a distinct advantage over the companies in the form of a dedicated team focused on the development of prototyping tools to support the design of computer-embedded devices, yet still acknowledged StickIT to offer potential.

*Paper Prototyping* was revealed to be the most widely used prototyping method during the early stages of computer-embedded device design, often combined with a foam / block model. The technique remained, or had been, a prototyping method used by all of the participants. Interestingly, the limitations of using *Paper Prototyping* were recognised by the participants from *Design Consultancy B*, *UCD Consultant* and *Film Industry Equipment Ltd*. All three cases recognised a common limitation; the inability to provide an accurate representation of the actual interaction. However, it was only the *UCD Consultant* that had sought an alternative prototyping tool, AxureRP, because of those limitations. Participants from both *Design Consultancy B* and *Film Industry Equipment Ltd.* explained that the interactions with a paper prototype fail to provide any feeling or tactile feedback which can present serious limitations during user trials. However, in both cases physicality of the prototypes had been sacrificed for the flexibility and iteration offered by *Paper Prototyping*. A similar sacrifice in terms of the physical accuracy of a prototype in favour for ease of prototyping was also acknowledged by the participant from *Global Mobile Phone Corp.* whilst explaining the use of existing handsets and the ‘Black Box’ method. Conversely, the participant from *Design Consultancy A* felt that if a prototype was able to communicate the intended design then it was acceptable to sacrifice accuracy in terms of the physicality and ergonomics. Table 27 shows a summary of the limitations and reasons for continued use of the various prototyping methods used in each of the cases.
<table>
<thead>
<tr>
<th>Company</th>
<th>Prototyping Practice</th>
<th>Limitation(s)</th>
<th>Reasons for continued Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Consultancy A</td>
<td>Paper Prototyping &amp; Foam Model</td>
<td>Non integrated approach between physical and digital interfaces</td>
<td>Participant believed the approach’s efficacy to be a question of their ability to communicate the design intent</td>
</tr>
<tr>
<td>Design Consultancy B</td>
<td>Paper Prototyping &amp; RP Model</td>
<td>- Physicality details excluded from model</td>
<td>Provides platform for increased number of iterations from one prototype</td>
</tr>
<tr>
<td>UCD Consultant</td>
<td>AxureRP &amp; Foam Model</td>
<td>Non integrated approach between physical and digital interfaces</td>
<td>- Limited knowledge of electronic based prototyping methods that would support an integrated approach - Limited access to workshop for prototype fabrication</td>
</tr>
<tr>
<td>Film Industry Equipment Ltd</td>
<td>Paper Prototyping &amp; Foam Board Model</td>
<td>- Lack of physicality attributes associated with interactions - No link with working UI</td>
<td>- Rapid iterative exploration of UI’s in a participatory manner - Effort involved in electronic prototypes detracts from design of product</td>
</tr>
<tr>
<td>Multi-Platform Communications Corp.</td>
<td>Flash</td>
<td>- No integration or relationship with the design of the physical devices - Participant also has no knowledge of electronics or prototyping skills required for creating interactive prototypes.</td>
<td>- Company is more focused on the applications design - Almost no influence in physical device design from a UX or ID perspective (only technical)</td>
</tr>
<tr>
<td>Global Mobile Phone Corp.</td>
<td>Paper Prototyping, 'Black-Box', Flash Lite + Existing handset, Façade</td>
<td>Inaccurate representation of actual handsets that UI will eventually be used with, inhibits ergonomics and physicality evaluation</td>
<td>- Processes have been historically used by Company - Whenever possible, integration of screen is preferential - Limited access to prototyping tools and facilities by IxD designers</td>
</tr>
</tbody>
</table>

Table 27 - Summary of limitations and reasons for continued use of prototyping methods in each case

The design exercise showed that the physical interactive prototyping aspects of StickIT offered many of the key benefits which led to Paper Prototyping being a popular and widely used prototyping method. Furthermore, StickIT was able to
offer a means of addressing some of the limitations present with *Paper Prototyping*, such as the lack of real time interactivity, physicality of interaction and integration with a software UI prototype.

Table 28 provides a summary of the prototyping limitations for each case that StickIT addressed as well as identifying those areas which remain a barrier towards early stage prototyping.
<table>
<thead>
<tr>
<th>Company</th>
<th>Prototyping Practice</th>
<th>Reasons for continued Use</th>
<th>Addressed by StickIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Consultancy A</td>
<td>Paper Prototyping &amp; Foam Model</td>
<td>Participant believed the approach’s efficacy to be a question of their ability to communicate the design intent</td>
<td>Integration between prototypes addressed, StickIT may influence preconceived opinions through use.</td>
</tr>
<tr>
<td>Design Consultancy B</td>
<td>Paper Prototyping &amp; RP Model</td>
<td>Provides platform for increased number of iterations from one prototype</td>
<td>StickIT found to offer similar levels of flexibility and iterations possible with a single prototype as existing method.</td>
</tr>
</tbody>
</table>
| UCD Consultant                | AxureRP & Foam Model                     | - Limited knowledge of electronic based prototyping methods that would support an integrated approach  
- Limited access to workshop for prototype fabrication | Electronics knowledge constraints addressed. Case study demonstrated it is not always necessary to have access to dedicated prototype workshop in order to produce rough interactive models |
| Film Industry Equipment Ltd   | Paper Prototyping & Foam Board Model     | - Rapid iterative exploration of UI’s in a participatory manner  
- Effort involved in electronic prototypes detracts from design of product | StickIT found to address intricacies of electronics prototyping, whilst also addressing the need for rapid UI exploration. |
| Multi-Platform Communications Corp. | Flash                                      | - Company is more focused on the applications design  
- Almost no influence in physical device design from a UX or IXD perspective (only technical) | StickIT alone is unlikely to alter the current design process of company. However, it does provide a platform which could prove to be a valuable tool for facilitating collaborative design exercises between companies. |
| Global Mobile Phone Corp.     | Paper Prototyping, ‘Black-Box’, Flash Lite + Existing handset, Façade | - Processes have been historically used by Company  
- Whenever possible, integration of screen is preferential  
- Limited access to prototyping tools and facilities by IxD designers | StickIT combined with projection and augmentation prototyping tools could provide a rapid prototyping method which includes the screen being displayed in situ. |

Table 28 – Reasons for current prototyping methods and status of fulfilment through use of StickIT

Flash was also found to be a common prototyping platform for all of the participants. However, some variance in ability and comfort in its use was apparent. The participants from Design Consultancy B, Multi-Platform Communications Corp.
and Global Mobile Phone Corp. were all seen to be very comfortable in the use of Flash. Conversely whilst able to use Flash to prototype their concepts, the participants in the other cases displayed a lower level of comfort and confidence in its use. The participants from Global Mobile Phone Corp. and Multi-Platform Communications Corp. both explained that they use Flash almost on a daily basis. In contrast to this, the participants from Design Consultancy A and Film Industry Equipment Ltd. both described their use of Flash as irregular and periodic. This lower frequency of using Flash stemmed from an increased involvement in other aspects of the design development process. UCD Consultant explained that whilst they occasionally still use Flash, the platform they use most often is AxureRP. Interestingly, the participants from Multi-Platform Communications Corp. and Global Mobile Phone Corp. were the only two cases that chose not to use the StickIT keyboard library to support the prototyping of the software UI. Table 29 shows the use of the StickIT keyboard library and the use of custom Actionscript across the cases.

<table>
<thead>
<tr>
<th>Company</th>
<th>Use of StickIT Keyboard Library</th>
<th>Use of custom Actionscript</th>
<th>Frequency of using Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Consultancy A</td>
<td>✓</td>
<td>X</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Design Consultancy B</td>
<td>✓</td>
<td>✓</td>
<td>Moderate - Often</td>
</tr>
<tr>
<td>UCD Consultant</td>
<td>✓</td>
<td>X</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Film Industry Equipment Ltd</td>
<td>✓</td>
<td>✓</td>
<td>Infrequent - Moderate</td>
</tr>
<tr>
<td>Multi-Platform Communication Corp.</td>
<td>X</td>
<td>✓</td>
<td>Very Often</td>
</tr>
<tr>
<td>Global Mobile Phone Corp.</td>
<td>X</td>
<td>✓</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

Table 29 - Summary of StickIT Keyboard Library Use and Custom Actionscript with Frequency of Flash Usage

Examining the results of the rating weighting scales for each of the companies showed a number of interesting areas between the cases. All participants weighted ‘Representation of Intended Interaction’ highly. The same was true of ‘Ease of Prototype Iteration’ and ‘Immediate Exploration of Error Solving’ (See Table 30).
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Consultancy A</th>
<th>Consultancy B</th>
<th>UCD Consultant</th>
<th>Film Industry Equipment Ltd</th>
<th>Multi-Platform Communications Corp.</th>
<th>Global Mobile Phone Corp.</th>
<th>Mean Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation of Intended Interaction</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>5.8</td>
</tr>
<tr>
<td>Ease of Prototype Iteration</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5.3</td>
</tr>
<tr>
<td>Immediate Exploration of Error Solving</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>5.0</td>
</tr>
<tr>
<td>Suitability of prototype for conducting user testing</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>Level of Ergonomic Evaluation</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>Client or Managerial Persuasion tool</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>2.5</td>
<td>5</td>
<td>4.6</td>
</tr>
<tr>
<td>Level of prototype automation</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>Interaction between designer and prototype</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>Effective communication of design intent</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4.2</td>
</tr>
<tr>
<td>Richness of interaction</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>2.5</td>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>Fit within designers skill set</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>2.5</td>
<td>4</td>
<td>3.8</td>
</tr>
<tr>
<td>Effective representation of intended physicality of concept</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>Robustness of Prototype</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>Level of technical understanding</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>Level of visual refinement</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 30 - Weightings given for each attribute across the cases, including Mean weighting (criteria ordered top to bottom) in descending order based on mean weighting.

Interestingly, the criterion ‘Level of Ergonomic Evaluation’ was also weighted as being amongst the most important factors by all of the participants, except for the participant from Multi-Platform Communication Corp. It is possible that Multi-Platform Communications Corp’s limited involvement in the device design was a contributing factor in this result.

Table 30 also shows that 'Level of Visual Refinement' and 'Level of Technical Understanding' were awarded low weighting values in the majority of the cases. The participant from Multi-Platform Communications Corp. was the only participant to weight the 'Level of technical understand' as being an important attribute for an early stage interactive prototyping tool to provide.
Figure 102 - Graph showing the comparison between existing prototyping methods and StickIT based on the mean ratings across the 6 cases.
These criteria were not only scored as being of least importance in the rating weighting scales, but the outputs of the design exercise provided further evidence of these areas being of little importance during early stage prototyping.

StickIT offered an improvement or was measured to be equal to the current practice in all but two instances. The participants from Design Consultancy B and Film Industry Equipment Ltd. considered their existing prototyping methods to offer a better level of fulfilment in terms of ‘Ease of Prototype Iteration’. In both cases this was explained during the interview as being related to the ease of iteration for the software UI rather than the StickIT method as a whole. However, since a Flash interface is more difficult to iterate than one produced using Paper Prototyping, they felt StickIT offered a lower level of fulfilment.

Figure 102 shows the comparison between the existing prototyping methods and StickIT based on the mean ratings for each of the cases. The 15 attributes are also ordered along the horizontal axis in order of ascending weighting values (based on the mean across the 6 cases). A clear trend can be seen showing that StickIT was rating higher than the existing practices being used. It is also possible to see the distance between the trend lines is greater on the right hand side of the graph than it is on the left. This indicates that StickIT offered an improvement over existing practices for the attributes which were weighted the highest, and therefore the most critical, since the attributes are ordered left to right based on their mean weighting scores.

The rating weighting data also revealed that in all cases, StickIT’s greatest strengths were considered to come from its physical interactive prototyping capabilities.

6.2 Speed of Prototyping

It can be seen from the results of the individual case analysis that the participants from Design Consultancy B and Multi-Platform Communication Corp. required the greatest length of time to prototype their concepts. In both cases the participants
took longer than two hours. The mean time taken to produce a prototype using StickIT was one hour 58 minutes.

Figure 103 - Comparison of Total Prototyping Times for each Company

Figure 104 - Comparison of Physical Prototyping times and Software UI Prototyping Times
The data in Figure 103 and Figure 104 show that the time required for physical device prototyping is very similar in all cases. However, the participant from Design Consultancy B and Multi-Platform Communication Corp. can be seen to have spent a greater length of time than the other companies when developing the software UI prototypes. Crucially, it was observed that in these two cases the prototyping times were not in fact slowed by the use of StickIT *per se*. Nor was the increase in prototyping time observed to be caused by the participants encountering any difficulties whilst producing their prototypes. Rather the additional time taken was primarily observed as being the cause of an increased level of fidelity featured within their software UI prototypes. Interestingly, the prototypes produced in these two cases featured a similar level of functionality and depth to the software UI prototypes produced in all the other cases. The increased level of fidelity was found to be primarily related to the level of visual refinement and richness of interactivity incorporated into the resultant prototypes. In particular, animations were more developed and graphical icons featured a greater level of refinement than they had been in the other cases (See Figure 105, Figure 106 and Figure 107).
Although exceeding two hours to prototype their concepts, neither participant felt that the time taken was unreasonable, too long or impractical for integration with the early stages of the design process. What is more, both participants acknowledged and appreciated that had they in fact produced lower fidelity prototypes, a reduction in the time required would have been almost certain. So why did these participants choose fidelity over speed?

This question is of particular interest for two key reasons. Firstly, time was noted as being a common pressure faced by all the participants within their companies.
Therefore one would assume that every effort would be made to save time where possible. Secondly, a great deal of literature supports the use of lower fidelity refinement during the early stages, so why was this not the case?

The participant from *Multi-Platform Communications Corp.* provided some justification for the use of higher fidelity graphics and animation than had been expected, explaining that they are a visually trained person. Accordingly, they explained that they find it difficult not to consider attributes such as colour, font and iconography, even from a very early stage within the design process. The participant also stated that they consider the visual aspects of a UI to play an equal role in building the overall user experience to the position of the buttons. Consequently they believed that neither should be considered less important than the other.

The participant from *Design Consultancy B* on the other hand provided no rationale for their decision to use a higher level of fidelity, although they did state they would like to work in more of a ‘sketchy’ manner within Flash if it were possible. It is also possible that they simply wanted to demonstrate their prototyping capabilities during the design exercise, and therefore an element of pride may have influenced the level of desired refinement.

![Comparison of Total Prototype Times and Testing Times](image-url)

*Figure 108 - Comparison of Total Prototyping Times and Testing Times for each Case*
The time spent in each case testing their StickIT prototypes was found to be very short compared to the time invested in their construction (see Figure 108). The use of early stage prototypes which were described by the participants in each case provides a number of possible reasons.

<table>
<thead>
<tr>
<th>Company</th>
<th>Use of Prototyping during the early stages</th>
</tr>
</thead>
</table>
| Design Consultancy A                         | - Design/concept exploration and development  
- Communication tool for conveying design intent to other stakeholders and sub-contractors               |
| Design Consultancy B                         | - Platform for internal development and testing of UI’S, mental models and flows.  
- Formal user testing with external users is minimal during early stages due to costs involved         |
| UCD Consultant                               | - Communication tool for conveying concepts to clients  
- Platform for testing and developing concepts  
- Platform for involving clients and users in design in a participatory approach                      |
| Film Industry Equipment Ltd.                 | - Communication tool for conveying concepts to clients  
- Platform for involving clients and users in design in a participatory approach                      |
| Multi-Platform Communication Corp.           | - Communication and development tool for early stage concepts  
- Help ‘realise’ new innovative ideas in a form for others to understand                                |
| Global Mobile Phone Corp.                    | - Platform for testing concepts in internal and external based user tests  
- Platform for developing and communicating ideas and concepts                                           |

Table 31 - Summary of early stage prototype usage in each case

Table 31 shows that formal usability and user testing plays only a minor role in relation to the participants’ described use of early stage prototypes. In all cases, early stage prototyping methods were described as being methods for developing and exploring concepts as well as providing communication aids.

6.3 Company Constraints

One of the strengths of case studies over other research methods is that it takes into account contextual issues that exist within each case (Yin, 2009). The context in which early stage prototyping methods are used is an important factor that can influence the suitability of a method within a design process. The prototyping methods available to UCD Consultant, the participant from Multi-Platform
Communications Corp and the participant from Global Mobile Phone Corp. were found to be constrained by contextual factors relating to their individual companies. Table 32 provides a summary of these factors.

<table>
<thead>
<tr>
<th>Company</th>
<th>Prototyping Constraints</th>
</tr>
</thead>
</table>
| UCD Consultant                       | - Role as a consultant means no workshop facilities  
- limits prototyping capabilities to either outsourced RP bureaus or desk based methods                                      |
| Multi-Platform Communications Corp.  | - Open planned office environment with no workshop facilities.                                                                                           |
| Global Mobile Phone Corp.            | - Offices for IxD and Industrial design are based in different countries resulting in no workshop facilities for IxD and user interaction designers to use.  
- Prototypes of handsets can be sourced, although incurs lead-times and is rare practice.  
- Out-sourced RP bureaus sometimes used  
- Office regulations prohibit use of soldering irons due to H&S, therefore limited to desk based methods without need for prototyping tools. |

Table 32 - Summary of Contextual Constraints that influence prototyping options

Access to workshop facilities required to construct prototypes was a common constraint found in all three of these companies. However, the results of the design exercise show that StickIT was able to provide a successful solution. Participants were able to construct physical interactive prototypes within these critical constraints. Much of the UCD Consultant’s work is with companies similar to Multi-Platform Communications Corp. and Global Mobile Phone Corp. With that in mind, it is interesting that those facing a greater level of constraint relating to prototyping methods are those who work for the largest companies featured in this research.

Design Consultancy B, Film Industry Equipment Ltd and Global Mobile Phone Corp. are companies that all have specialist electronics and software engineering expertise ‘in-house’. However, a comparison of the results of the individual case analysis suggests that having such expertise provides little advantage in terms of prototyping capabilities during the early stages of developing computer-embedded devices. The results suggest StickIT was perceived to be of equal value by those companies with electronics and software engineering ‘in-house’ as it was by those without. It was revealed that the inclusion of such expertise during the early design stages can significantly increase projects costs. Furthermore, participants from
both Design Consultancy B and Film Industry Equipment Ltd. explained that the involvement of electronic and software engineers can often be very unsupportive of working in a rapid iterative manner during the early stages of the design process. Prototyping lead times of at least one week were common across the three cases when involving such expertise. Consequently those participants were strongly in favour of the development of tools which increase designers’ abilities to prototype interactive products, particularly during the early design stages.

Perhaps one of the most interesting and unexpected findings of the research relates to the profiles and roles of the participants featured. Firstly, despite matching the recruitment criteria “must have active experience of interactive prototyping within their current job role”, it was found that none of the participants were in a position within their respective companies to influence or control key elements of the computer-embedded devices they designed. Whilst certain limitations over design decisions were to be expected, two thirds stated that their influence over the industrial design of the product is extremely limited and their focus is more geared towards user interaction design. Moreover, even at the stage within their design processes when tools such as Paper Prototyping were described as being used, it was apparent that a great deal of effort had already been invested in the hardware development of the products. This immediately limited the level of changes possible, even if design flaws were found to exist. It was only the participants from Design Consultancy A and Film Industry Equipment Ltd. who described having what could be considered an active role in the industrial design of the devices they design. However, these participants consequently appeared to have a lesser degree of control over the interaction design.
7 Discussion

7.1 Introduction

The critical literature review presented in Chapter 2 identified the need for further research in the area of interactive prototyping needs for designers working on computer-embedded devices. In particular, the review indicated that there had been very little research which had focused on investigating the interactive prototyping needs of designers during the very early stages of the design process. StickIT was developed to facilitate an exploratory investigation into the potential for providing designers of computer-embedded devices with a method for rapid early stage interactive prototyping. StickIT was based on a number of suggested needs found within previous research (Gill et al., 2008, Hartmann, 2005, Hudson and Mankoff, 2006, Avrahami and Hudson, 2002, Bdeir, 2008, Lee et al., 2004). The case studies within this research provide a detailed insight into the potential offered by StickIT as a means of rapid early stage interactive prototyping. This chapter collates the major findings from the analysis chapters and discusses likely causes and implications of the results in the broader context of the original research aim and the relationship between the literature reviewed in Chapter 2.

Perhaps, most importantly, this research has found that the challenges and issues surrounding early stage prototyping for computer-embedded devices are more complex than the mere lack of prototyping tools required to overcome knowledge barriers. Whilst this research confirms a strong need for improving prototyping methods, barriers towards early stage interactive prototyping were found to exist in a number of other forms.

7.1 Who is responsible?

The premise for much of the literature reviewed in Chapter 2 is based on an understanding that industrial designers are ill equipped with suitable methods enabling them to prototype computer-embedded devices. In particular, the need for providing them with interactive prototyping methods for use during the early stages has been regarded as a key barrier towards successful computer-embedded device design (Gill et al., 2008a, Hartmann, 2005, Norman, 1998, Cooper, 2004,
A lack of prototyping tools during the early design stages has been described as a preventative factor in industrial designers’ abilities to fully explore the user interactions and human factor considerations required when designing these products. The research in this thesis supports the fact that there are indeed serious limitations in the prototyping tools available for early stage prototyping of computer-embedded devices. This was clearly demonstrated by the fact that StickIT was considered to offer an improvement over existing practice in all of the cases, including the wide array of prototyping methods used by Global Mobile Phone Corp. However, this research has identified a key issue relating to the design processes used for computer-embedded device design.

Much of the existing literature reviewed in Chapter 2 has been based on two assumptions: Firstly, Ulrich and Eppinger (2008), Heskett (1980) and Dreyfuss (1967) all define the role of industrial designer as being responsible for addressing the form and user interactions associated with a product’s design. This opinion, suggesting that industrial designers are ultimately responsible for defining the physical artefact as well as the user interactions, was also implied by many of the authors who wrote about developing toolkits. Secondly, it is assumed that the design of the user interactions and the industrial design occur at the same stage in the design process, and that it is due to a lack of tools or knowledge that prevent designers from exploring the two in an integrated manner.

This research did not find a concurrent approach to the industrial design and the interaction design in any of the cases studied. What is more, in all of the cases studied, the participants were found to have either a greater level of involvement in the interaction design or the industrial design. In none of the cases were the participants found to have an equal degree of influence or involvement towards both aspects, nor were they found to work intimately alongside the other discipline.

The design processes of Design Consultancy B and Film Industry Equipment Ltd. offered perhaps the closest level of integration between the two streams of work. The participant from Design Consultancy B was able to influence the industrial
design in terms of mappings (the positions) of controls, but explained that more
significant changes would be unlikely. This was explained as being due to the
industrial design already having reached a stage where CAD development had
begun. The participant from Film Industry Equipment Ltd. had control over the
physical device design. However, they had limited influence over the software UI
that the device was used in conjunction with, thus jeopardising the synergy
between the two aspects. The case study of design consultancy, Alloy, in Gill (2004)
emphasised the importance of prototyping speed in order to provide a fit with the
early stages of a consultancy's design process. However, the cases of Design
Consultancy A and UCD Consultant revealed a greater barrier, whereby they are
often only enlisted to work on certain stages of a product's development. This
highlights a serious issue with regards to the design processes of computer-
embedded device design when working in a consultancy type environment.

One might assume that an in-house design team would not suffer from such
exclusion from critical stages of a design process. However, the companies which
were studied that featured in-house design teams were still found to suffer from
barriers towards an integrated and concurrent design process. The challenges faced
by Global Mobile Phone Corp. were found to be similar to a case study of
Multinational Mobile Phone Corp. by Woolley (2008). The geographical separation
between the industrial design teams and the interaction design teams was found to
be very similar, as was the fast paced nature of dealing with newly emerging
interactions. At the time of the study by Woolley, interactions such as using styli,
scroll wheels and soft keys were presenting the UI design team with specific
prototyping barriers. Two years later, the study with Global Mobile Phone Corp.
featured many similarities, only now current market trends are interested in
interactions such as gesture and touch screen as opposed to styli and scroll wheels.
Although prototyping barriers were, without doubt, present in the other five cases,
it would appear that Global Mobile Phone Corp. faced the greatest challenge in
terms of interactive prototyping needs. The demand to deal with new methods of
interaction is evident in both the case of Global Mobile Phone Corp. as well as the
mobile phone company studied by Woolley (2008).
The separation of industrial design and interaction design poses a major barrier in the adoption of the suggested design processes of many authors (Norman, 1998, Cooper, 2004, Goodwin, 2009, Gill, 2003a). The significance of this is that the use and evaluations of interactive prototypes are not able to impact the design of computer-embedded devices in a broad sense covering all aspects of the design regardless of the speed, ease and stage at which they can be produced.

This also presents something of a barrier in terms of the design process shown in Figure 26, p.76. This design process was based on the suggested requirements for early stage interactive prototyping by Gill et al., (2008a), Hudson and Mankoff (2006), Avrahami and Hudson (2002). Rather interestingly, the separation of the two aspects did not appear to reduce the need for improved methods of early stage interactive prototyping, by either discipline.

The breadth of impact within a design process that an early stage interactive prototyping tool might provide was found to be more constrained than had been anticipated. However, the ability to rapidly construct working prototypes with little need for specialist skills was thought to provide leverage and strength when discussing ideas and concepts with other members of a project team.

Interestingly, it was noted that in all but one case, the participants had backgrounds in industrial design, despite some having more active roles in interaction design. This was clearly an advantage, as they had a greater awareness of the overall interaction design implications than someone with no background knowledge of the physical aspects of product design. However, without processes providing the opportunity for true concurrent integration between industrial design and interaction design the case studies show that knowledge and awareness are not always sufficient to solve the problems.

Given that in none of the cases studied was there an equal level of influence over the industrial design and the interaction design found, the question arises: 'what are the causes of this separation?'
According to Ulrich and Eppinger (2008) the greater the complexity of user interactions associated with a product, the greater the need for industrial design. The design processes seen across the six companies featured in this research suggests that industrial designers are in fact becoming less involved in the design of the user interactions for complex computer-embedded devices. Instead, IxD appears to be emerging as a discipline in its own right as part of the computer-embedded devices design process.

It is possible that this has been prompted by the increase in richness and level of dynamics found in many user interfaces today. The design exercises highlighted a very important factor relating to the user interfaces of computer-embedded devices. It demonstrated that user interfaces are often more complex than a series of static screens, or menu driven displays. Mohageg and Wagner (2000) stated that one of the fundamental problems with computer-embedded device design is the need for moving away from the confines of interactions associated with desktop computers. This need for developing new methods of interactions is a likely cause for the growth in the discipline of interaction design. The author speculates that more and more computer-embedded devices will seek to include much richer, more dynamic user experiences and interfaces over the next few years. Consequently, it is likely that the role of interaction designers will continue to gain strength and grow as a discipline in its own right. It is likely that this growth will continue to have an impact on the role that industrial designers play in the design of user interactions.

It is important to note that this research is not questioning the validity of the processes suggested by Gill et al., (2003), Goodwin (2009), Norman (1998) and Cooper (2004). However, it is suggesting that there is a need not only to address the issue of prototyping tool requirements, but perhaps an even greater need for a focus on addressing the separation between the industrial design and the interaction design and explore ways to establish true integration between those disciplines.
A further cause for concern relates to an increasing trend to use touch screens as the primary method of user interaction with computer-embedded devices. This trend increases the risk that user interfaces for touch screen devices will be developed without placing the UI in context with the physical product. This scenario of developing touch screen UI prototypes in isolation from the physical product was seen to be the case with *Multi-Platform Communications Corp.* where touch screen monitors were used for prototyping in isolation from the physical device. This increased the likelihood of missed opportunities to recognise the implications that a physical device may have upon the interactions.

### 7.2 Electronics Knowledge

The experimental prototyping methodology explored within this research was found to be successful at abstracting the necessary electronics knowledge associated with constructing interactive prototypes. The approach successfully facilitated a prototyping process in all cases, even for those who had little or no knowledge of electronics. In some cases, the design exercise exposed feelings of apprehension surrounding the topic of creating functioning interactive prototypes. However, contrary to their initial feelings, providing participants with a prototyping method that did not require electronics knowledge in fact led to an increased feeling of confidence. The process of constructing the interactive prototypes was even described as posing less of a challenge than creating the logic for the software UI. The approach facilitated by StickIT, which abstracted the necessary electronics knowledge, skill or use of equipment, was found to be a key strength for an interactive prototyping tool aimed at the early stages of design. The need for reducing the intricacies of creating electronic prototypes supports research by many of the authors featured in Chapter 2; (Avrahami and Hudson, 2002, Hartmann et al., 2006, Hudson and Mankoff, 2006, Cooper 2004, Gill et al., 2008a, Bdeir, 2008a).

Whilst the approach was successful in achieving its aim, the research also highlighted a number of interesting areas relating to electronic prototyping. These points are discussed below.
The literature reviewed at the beginning of this research stated that designers of computer-embedded devices lack electronics knowledge and this presents a major prototyping barrier. However, the cases studied in this research found this not to strictly be true. In half of the cases studied participants did in fact have some knowledge of electronic prototyping methods. Unexpectedly, this included competency and experience in the use of Arduino (Anon, 2007) and also familiarity with basic electronic skills such as soldering and PCB fabrication. This raises an interesting topic of discussion as a number of authors have described the need for electronics knowledge as being a key barrier between designers and interactive prototyping (Goodwin, 2009), (Norman, 1998), (Cooper, 2004), (Nam, 2005) (Gill et al., 2008a). Although half of the participants were found not to be comfortable with electronics prototyping, the fact half did have some knowledge suggests a possible increase in the number of designers becoming more interested in having some electronics knowledge. Although not specifically indicated by this research, it is possible that the growth of open source electronics platforms such as Arduino (2008) is encouraging a wider field of disciplines to develop an interest in “hobby electronics”. During the period in which this research has been conducted (2007 – 2011) there has been a significant rise in the number of online communities and meet-ups sharing experiences and use of Arduino as a prototyping platform.

Nevertheless, these participants still considered tasks like soldering, wiring and mounting PCB’s within prototypes, particularly during the early design stages, to be too time consuming and the cause of much frustration. This confirms limitations identified for existing tools in the critical literature review (Lee et al., 2004, Greenberg and Fitchett, 2001, Hartmann et al., 2006).

Critically, rather than these issues simply resulting in an increase in prototyping time, they were identified as leading to an altogether more serious problem. It was found that tasks such as wiring, soldering and mounting PCB’s inside prototypes often led to interactive prototyping methods being abandoned. In such situations, it was found that designers would revert to the use of non interactive prototyping methods such as Paper Prototyping (Snyder, 2003). The significance of this finding is the fact that this in turn increases the proportion of a design’s development
without being trialled in an integrated interactive manner. Or worse still, innovative design opportunities or features may be missed or rejected by stakeholders as a result of an insufficient ability to convey a design to others, as was the case in *Film Industry Equipment Ltd*.

Furthermore, in those cases where electronic prototyping skills existed, the intricacies associated with soldering and wiring was found to be unsympathetic and unsupportive of working in an iterative manner. Soldering and creating prototype PCB's were found to not only increase the prototyping time, but were considered by participants to offer very little in terms of flexibility. Iterations, like for example making small developmental steps such as relocating a switch, were described as tedious tasks, which hamper the fluidity of the design process. This justified the "solder-free" and "soft-wired" approach offered by StickIT which was consequently favoured by those participants who had previously faced issues of wiring and PCB fabrication.

For the participant from *Global Mobile Phone Corp.* it was not frustrations with circuitry construction, but rather health and safety regulations that restricted them from using equipment such as soldering irons. This indirectly placed limitations on the utilisation of their electronics knowledge when prototyping new designs. Consequently the participant was limited in prototyping options. This too led them to favour desk-based prototyping tools such as using existing handsets, 'Black-Box' techniques and *Paper Prototyping*. Effectively, these constraints pressurise designers into using prototyping approaches and methods which have been proven to be either limiting or which provide inaccurate information (e.g. usability data (Liu and Khooshabeh, 2003, Gill et al., 2008b, Hare et al., 2009, Sefelin et al., 2003)). This naturally makes approaches, such as the methodology explored with StickIT, a viable prospect. Such prototyping methodologies enable the exploration of physical interactions without the need to challenge the office regulations. They also allow designers to work with a closer representation of the intended physicality of the new design, albeit a rougher, cruder physical model.
Unexpectedly, the results also suggest that having electronic engineering expertise in the form of a multi disciplinary team does not necessarily solve the issues of early stage interactive prototyping. This is implied by the fact ‘in-house’ electronics expertise was not found to provide a substantial benefit to the process of early stage interactive prototyping. In fact, in the cases studied it was found that such expertise was typically excluded from being involved during the early stages and would instead focus on the later more detailed engineering stages. This finding suggests that whilst ‘in-house’ expertise certainly provides benefits in terms of downstream engineering and manufacturing support, a lack of tools and methods prevents even skilled electronics engineers from working in an iterative manner during the early stages to produce low fidelity prototypes. Consequently the development and use of toolkits that enable the prototyping capabilities to be placed into the hands of the designers themselves proved to be very popular.

### 7.3 Prototyping Facilities

The results also show that in some cases, early stage prototyping methods were influenced, not only by knowledge barriers, but also by access to workshop facilities and prototype fabrication methods available within their companies. As described in section 2.1 of the critical literature review, the use of modelling materials such as card and blue foam are commonly regarded as being standard materials used by industrial designers. These materials are often described as being common place during the early stages of development for low fidelity "sketch models" or prototypes, and widely taught as being common practice within industry (Myerson, 2001).

Previous research indicated that interactive prototyping tools aimed at the early stages of the design process need to provide a close fit with sketch modelling techniques such as foam and card modelling (Hudson and Mankoff, 2006., Avrahami and Hudson, 2002, Gill et al., 2008a, Bdeir, 2008a).

The research presented in this thesis does not suggest integration of interactive prototyping techniques with sketch modelling materials is in any way incorrect. However, the results do highlight a particularly interesting observation amongst
some of the cases. In only two of the six cases did the participants have access to a workshop area within their company intended for soft modelling / prototyping of this kind, (Design Consultancy A & B). UCD Consultant rents a small office space in central London which limits them to desk based activities, and therefore does not have a dedicated workshop area. Additionally, the role of a consultant means that much of their time involves being located at a client’s office. The participant from Film Industry Equipment Ltd had access to more space. However, the company still lacked what could be described as a traditional model making / prototyping workshop area. This led them to primarily use foam board material and card for prototyping, so that they could construct prototypes at their desks without large amounts of debris and dust or causing disruption to others. The environment in which the participant from Multi-Platform Communications Corp. works is a large open plan office area in which sit computers, desks, meeting tables and soft break-out areas. A similar setting was also the case at Global Mobile Phone Corp. Due to the company’s industrial design and interaction design teams being located in two different countries, those working on interaction design had no access to ‘in-house’ prototyping facilities suitable for making physical prototypes. The interaction designers of Global Mobile Phone Corp. were able to request prototypes from either the industrial designers, or through external prototyping contractors. However, these would typically be a 3D print of a handset, incurring a lead time of no less than a week and likely to communicate a higher level of fidelity than strictly required.

Interestingly, despite some participants having limited access to full prototyping facilities, all were able to successfully construct physical prototypes of their designs using the materials and tools provided. Nevertheless, the access to appropriate prototyping facilities within those companies studied highlights a significant issue in the processes of designing computer-embedded devices. This is of course dependant on the companies featured being representative of the wider field which can only be established through further research. It would be useful to conduct further research to establish an indication of the number of computer-embedded device designers that have limited access to basic prototyping
equipment. If the findings of a larger scale study indicate that more designers of computer-embedded devices experience similar constraints, then future interactive prototyping toolkits should perhaps look towards achieving desk based solutions to accommodate this.

7.4 Prototyping within one to two hours
This research found that speed of prototype construction is clearly an important factor for an early stage interactive prototyping method to provide. However, the results also indicated that the participants desired prototyping tools to offer rapid iteration and flexibility in addition to speed alone. The importance of prototyping speed had been one of the primary driving factors informing this piece of research. This need had been identified as being a key issue in the findings of previous research (Gill et al., 2008a, Hudson and Mankoff, 2006, Lee et al., 2004, Culverhouse, 2007, Culverhouse et al., 2009, Avrahami and Hudson, 2002). Additionally, the contention proposed by Gill et al., (2008a) was also a significant driving factor, stating that success would come from providing designers with a method for achieving early stage low fidelity interactive prototyping in a timescale of one to two hours. It was believed that this timescale was necessary to provide a similar prototyping speed to that of non interactive products, thus providing a close fit with the workflow of designers during the early stages of the design process.

The study proved that a prototyping speed of one to two hours was both achievable and also a desirable ability for designers involved in computer-embedded devices. This therefore supports the conclusions of Gill et al., (2008a). However, another key issue was also identified. An ability to rapidly make alterations to a prototype, essentially resulting in new prototypes in seconds rather than hours was found to be equally, and in some cases, more important than the time in which the initial prototype could be constructed. The results indicate that the time required for the initial prototype construction is less of a crucial factor, if a high level of flexibility and iteration can be achieved from a single prototype.

Interestingly, it was noted that a number of the participants commented on their biggest pressure being one of time. This further supports the findings of Gill et al.,
(2008a) whereby the need for a suggested prototyping speed of between one to two hours was informed by the realities of working against commercial pressures and deadlines.

The design exercise highlighted the importance for prototyping tools to offer a level of flexibility which enables them to be used alongside other methods, rather than relying upon a single tool to fulfil all requirements. In three of the cases StickIT was unable to provide full prototyping support for all aspects of the intended designs. In these cases the participants opted to use ‘Wizard of Oz’ (Maulsby et al., 1993) prototyping methods to provide the additional functionality.

One could view the need for supplementing StickIT with the use of Wizard of Oz prototyping methods as being indicative of a shortfall in StickIT’s suitability as a prototyping methodology. An alternative perspective could also be taken. StickIT successfully provided a method of prototyping for the foundation and the majority of the interactivity for each of the prototypes. However, it also provided the flexibility for the finer more bespoke prototyping requirements to be achieved using Wizard of Oz techniques. Examples of these bespoke requirements included a pressure sensor to detect a breath being taken and a micro-switch to detect the weight of a breath tube. Both of these requirements are very specific to the design brief that was set and therefore arguably difficult to incorporate into a pre-constructed set of tools. However, in neither case did the participant feel that using a combination of StickIT and Wizard of Oz triggers prohibited them from exploring their designs sufficiently. Much of the literature surrounding the use of Wizard of Oz prototyping relates to its use during the 1990’s for developing intelligent computer systems, often for the purpose of user testing (Maulsby et al., 1993, Gould et al., 1983). However, the study demonstrated that it also has the potential to be used alongside other prototyping methods, during a design’s early stages in an exploratory and evaluative manner.

At the time of the study StickIT was not able to prototype the types of gesture based interactions that Global Mobile Phone Corp. were particularly interested in. However, it does provide a level of flexibility that would make it possible to achieve
a low tech solution to this type of interaction. By replacing the "tactile dome switch" of a StickIT I/O with a ball bearing tilt switch, a very low tech gesture based I/O device could be achieved. Attaching a few of these types of I/O devices to a prototype would enable the designer to control a software UI prototype by altering the orientation of the prototype, similar to the type of control offered by a more complex gyroscopic sensor. A similar style ‘low-tech’ gesture based input using tilt switches was explored by an MSc student on the Advanced Product Design course at UWIC (Partington and Culverhouse, 2009).

Prototyping approaches such as the IE system (Gill, 2003), d.tools (Hartmann, 2006), The Calder Toolkit (Lee et. al. 2004) and VooDooIo (Villar, 2007) have in the past emphasised the need to support a wide range of off the shelf input devices in order to achieve adoption. Common examples given by these authors typically include sliders, dials, joysticks and switches. Limited access to electronic prototyping tools and also frustrations which arise when needing to modify circuitry, identified by this research, present potential barriers in the ability to develop prototyping tools capable of supporting a wide array of off the shelf components. However, the use of primitive input methods combined with Wizard of Oz prototyping techniques, as seen with the design exercises, shows value in the ability to 'mimic' more complex interactions without needing to match the exact intended interaction.

The importance of flexibility, iteration and speed was not only found to be associated with the physical interactive prototyping needs of designers. This research also identified that the approach to software UI prototyping also needs to provide support for these three elements in order to achieve successful integration with the early stages of the design process. In relation to interactive UI prototyping, StickIT aimed to provide a methodology similar in nature to an interactive version of state transition diagrams (Booth, 1967), based on a number of existing research recommendations (Woolley, 2006, Lin et al., 2002, Culverhouse et al., 2009). Previous prototyping toolkits including BOXES (Hudson and Mankoff, 2006), d.tools (Hartmann, 2005) and DENIM (Lin et al., 2002) have all attempted to use similar ‘interactive state transition diagram’ metaphors as approaches to UI
prototyping. However, the results of past research all indicated an industry preference towards the use of Adobe Flash rather than bespoke prototyping platforms. This is due to designers having a higher level of familiarity with Flash as a prototyping tool. Despite research indicating a preference towards Flash, it is unfortunately based around an integrated programming language, Actionscript. The need for programming knowledge had been identified (Gill et al., 2008a) as being outside of the reach of many designers. Gill et al., (2008a) suggested that because of the programming required, Flash was overly complex for use during the early stages of design. The StickIT keyboard library was intended to allow integration with Flash, but with the benefit of removing the need for programming knowledge needed to create the transitions between product states.

The research within this thesis supports previous findings which found Flash to be a common prototyping platform used by designers of computer-embedded devices. The use of other applications including AxureRP, OmniGraph and Balsamic was described in some cases, although such applications were not considered to offer the same level of flexibility as Flash. This was found to limit prototyping capabilities, making them less than optimal prototyping tools.

Although previous prototyping approaches such as d.tools (Hartmann et al., 2005), BOXES (Hudson and Mankoff, 2006) and the IE System (Gill, 2003), had recognised the same industry preference towards using Flash over other platforms, this had largely been attributed towards a level of familiarity. However, this research found that Flash is favoured due to the flexibility it can offer and not simply as a matter of familiarity.

This demand for flexibility within a software UI prototyping tool was evident in a number of instances. Firstly in a number of cases the interface prototypes were found to be much more complex than simple ‘interactive state transition diagrams’. This was despite the fact they were being produced during the early stages of a design process. Providing a simplified (‘programming free’) method of switching between states (facilitated by the StickIT keyboard library) was found to address only a minor part of the overall challenge of software UI prototyping. In a number
of cases, the participants included animations, programmed logical conditions and random events, which required them to write custom Actionscript. In particular, it was these tasks which were observed to present the greatest barriers to achieving a fast and fluid prototyping process. This implies that prototyping tools such as the many wire-framing applications available, including DENIM (Lin et al., 2002), offer a far less complete tool in relation to the design of computer-embedded devices than had previously been appreciated because of the poor level of flexibility and complexity they can offer. Whilst Flash does provide a platform which offers the flexibility to accommodate these requirements, the need for writing Actionscript clearly detracted from the overall fluidity of the prototyping process.

Furthermore, the process of creating the software UI prototypes using Flash was not found to be a simple case of replicating a design which had been already largely been resolved on paper. Instead, Flash was being used not only as a prototyping tool, but a development platform. Saffer (2010) states that ‘interface design’, as in the elements of a digital product that people see, hear or feel, only represent the tip of the iceberg in terms of the interaction design that exist behind them. The complexities in the development of the software UI prototypes very much support Saffer. The majority of the time spent constructing the prototypes dealt with the logic and flow of the interface rather than the visual design of onscreen elements. This level of complexity not only increases the time in which prototypes can be created, but the author also contends it can indirectly impact the ease of iteration and prototype flexibility that can be achieved. Additionally, as the design was effectively being tested throughout the prototyping process, it undoubtedly shortened the length of time required to test the design at the end.

In all but one case, the participants favoured the use of Actionscript 2.0 (AS2) over Actionscript 3.0 (AS3). In some cases the preference was explained as being due to AS2 supporting a ‘quick and dirty’ approach to coding. AS2 allows for code to be written in an unlimited number of places and movieclips (objects) within a Flash file. It is also more forgiving of minor syntax errors, for example forgetting to place a semi-colon at the end of a line of code. AS3 on the other-hand requires the developer to use a much stricter syntax and does not allow code to be placed
within objects or in multiple locations within a file. Instead, AS3 follows the conventions of a more formal object orientated programming language with functions, objects and libraries. Undoubtedly AS3 requires a greater understanding of programming. However, the structure and organisation that comes with it may in fact increase the ease and speed with which a prototype can be iterated and altered. Due to the increased programming knowledge required to use AS3, the author is not suggesting that it provides a suitable solution to early stage UI prototyping. However, there may be possible benefits that could be considered when developing prototyping tools for software UI’s that can be taken from the use of a more formal programming method. Stevens and Burley (1997) state that a key characteristic of working during the initial stages of the design process is a high failure rate and reliance on trial and error. Particularly during the early stages, it is likely that changes will not only be minor detail refinements, but rather much larger fundamental changes to a design. One approach that may increase the speed and ease with which early stage software UI prototypes can be iterated could be through a two layered construction method. The issues faced by the participant from Design Consultancy B when iterating their design came from the fact they needed to repeat the same alterations a number of times in order to achieve continuity throughout the UI. This was ultimately due to elements within the prototype being defined in multiple locations across the timeline. However, had they constructed the design using a combination of Global and Local attributes, elements such as the positions of controls could be defined in a single location, and therefore iterations would have been much simpler to implement.

- Global attributes - elements which carry across and affect an entire UI prototype, but are only defined in a single location
- Local attributes – elements specific to an individual state or object

Recognising the complexity associated with constructing even early stage interactive UI prototypes, and the desired level of flexibility, iteration and speed are likely key reasons for the common decision to use Paper Prototyping as a prototyping platform during the early stages. Interestingly, Paper prototyping was not being used without at least some awareness of limitations that can come from
its use. Many of the participants expressed frustrations with the lack of physicality, lack of real time interactions, and potential for misinterpretation by users. These limitations are not new, and many coincide with research findings of studies that have evaluated Paper Prototyping in the past (Liu and Khooshabeh, 2003, Sefelin et al., 2003, Hare et al., 2009). However, what this result does show is that factors such as physicality, real-time interaction, and communication of design intent are being sacrificed in preference for a prototyping method that can provide flexibility, speed and ease of iteration. Importantly, this choice is being made despite awareness of the potential implications on design communication and quality of evaluation when using such techniques. This suggests that failure to support these three factors either equally or more sufficiently than Paper Prototyping will prevent adoption of a technique during the early stages.

7.5 Application of early stage interactive prototyping within a design process

The use of StickIT within the design exercises was found to assist the designers' ability to think through ideas in a tangible manner. This was found to be particularly true for the time spent developing the software UI prototypes associated with each design. This period of the design exercises was found to be rich with trial and error, and the designers repeatedly altering the design as they progressively moved towards a complete prototype. Iteration during the early stages of the design process is described by many authors as a crucial element of the design process (Pugh, 1998, Ulrich and Eppinger, 2008, Lidwell et al. 2003). This suggests that prototyping tools such as StickIT provide enhancement to a designer's method of thinking through ideas, and very much fits within Ulrich and Eppingers (2008) first use of prototypes which is for the purpose of learning.

The actual time spent during the design exercises using the prototypes for testing was found to be relatively short compared to the time spent on their development. It could be suggested that the time required for testing was naturally short due to the designs of the products being fairly simple. However, the analysis of the data gathered suggests a number of other factors that may have influenced the time spent testing the designs.
Firstly, conducting formal usability and user tests was not found to be the major use of early stage prototypes. Instead existing tools, primarily *Paper Prototyping*, were found to be more commonly used as development aids. Such methods were found to be useful for facilitating working in small groups and rapidly working through ideas. The prototyping methodology enabled by StickIT was considered to offer a very similar developmental method of working to *Paper Prototyping*. The participant from *Design Consultancy B* was of the opinion that an early stage interactive prototyping tool should support a "*Let's try something and see how it works*" approach to design. Likewise, others likened StickIT to being a "*3D form of Paper Prototyping*" and "*like interactive paper prototyping*". Similarly, the participant from *Global Mobile Phone Corp.* stated that they did not believe such an approach would replace *Paper prototyping*, but instead be a useful stepping stone before progressing towards fully working prototypes.

The *UCD Consultant* and *Film Industry Equipment Ltd*, believed that rough, low fidelity interactive prototypes could be a valuable tool for use in a participatory design manner. These opinions were partially formed by the perceived simplicity of the physical prototyping facilitated by StickIT, affording an opportunity for users to get involved in the design. This view was not common across the cases. The participants in the other cases felt that prototypes such as those produced using StickIT, whilst valuable in terms of internal development tools were perhaps less suitable for use with external stakeholders. Additionally, the participant from *Global Mobile Phone Corp.* also felt that the use of such prototypes might also be too crude for some internal stakeholders, such as managerial roles. This highlights an interesting variation in the levels of confidence between designers surrounding the use of low fidelity prototypes. It also suggests that low fidelity prototyping might not always be appropriate, even during the early stages, depending upon on the audience receiving the prototype. To conclude, the matter of determining the appropriate level of fidelity for various stakeholders poses an interesting area for future research. A number of studies have compared the use of low fidelity and high fidelity prototypes for the purpose of usability testing (Lim et al., 2006, Arnowitz et al., 2007, Jim et al., 1996, Sá, 2006, Hare et al., 2009, Gill et al., 2008b).
However, there appears to be little research on the impact stakeholders have upon the requirements relating to prototype fidelity. Additionally, in the case of Design Consultancy B, it was found that the costs involved in setting up even informal user studies are often too high for consideration during the early stages of the design process.

The participants from Design Consultancy A and Multi-Platform Communication Corp. both explained that they will not always prototype concepts during every stage of the design process. Instead it is often only the more innovative and daring concepts that will be prototyped. Those that are considered less innovative or simpler will often be developed based on experience alone. This implies that early stage prototyping tools may be used to explore specific innovative and new facets to a design, rather than an entire solution. This application is highly supportive of Schrage’s ‘Serious Play’ (2000) notion. Schrage suggests that “Any tools, technologies, techniques or toys that let people improve how they play seriously without uncertainty is guaranteed to improve the quality of innovation”. The use of prototypes in this manner also suggests being supportive of Experience Prototyping (Buchenau and Suri, 2000). This focused use of early stage prototypes for specific features and innovations provides further possible reasons for why the prototypes within the design exercise were only tested for a relatively short period of time.

7.6 Fidelity of Prototypes

The findings of this research supports the work of McCurdy et al., (2006) and Houde and Hill (2004) and suggests that the use of a "low to high" scale to describe the level of fidelity featured by a prototype is insufficient.

Much of the work reviewed in Chapter 2 of the literature review reported a need for tools that support the very rapid development of low fidelity interactive prototypes during the early stages of design, (Avrahami and Hudson, 2002, Gill et al., 2008a, Hudson and Mankoff, 2006, Arnowitz et al., 2007, Culverhouse et al., 2009). The use of the term ‘low fidelity’ was broadly used implying that all aspects of a prototype should be low in fidelity. However, the prototypes produced in the
case studies of this research provide indications that a mixed fidelity approach may be of benefit to the early stage prototyping of computer-embedded devices.

For example, all cases considered the ‘Representation of the Intended Interactions’ of the design to be one of the most crucial areas for an early stage interactive prototyping method to fulfil. Conversely, ‘Level of visual refinement’, in terms of the physical prototype, was seen to be less crucial. Additionally, the focus of the physical prototypes appeared to be more towards producing a rough tangible interactive artefact that could provide an insight into the feel of a design, as opposed to exploring finer styling details.

The software UI prototypes on the other hand provoked mixed opinions regarding the appropriate level of visual refinement required for the early stages of the design process. UCD Consultant was very much in favour of and well practiced in the use of wire-frame prototypes during these stages. However, the participant from Multi-Platform Communication Corp. represented the opposite end of the spectrum and considered that the visual properties of a design are as important as the mapping usability issues. Although varied in terms of visual refinement, all the software UI prototypes featured a similarly high level of fidelity relating to the information architecture of the interfaces (the flow of an interface). This was highlighted by the rich process of trial and error that was observed during the construction of the UI prototypes.

This variance of opinion relating to the fidelity of various attributes within early stage prototypes strongly supports the adoption of a 'mixed fidelity' definition towards prototyping. McCurdy et al., (2006) suggest that such an approach would allow resources to be more efficiently managed and allow prototypes to have a clearer focus. This research would seem to confirm this.

7.7 Limitations of Research Approach

Limitations are inherent with all research methods and certain limitations will exist for all research studies. Therefore it is necessary for a researcher to acknowledge these limitations when discussing a piece of research. The limitations
The research was split into two sections; first, the development of an experimental prototyping tool, and secondly the exploration of the use of the tool in order to address the research aim. Six companies where selected for participation in the research, each working in a different market sector although all involved in the development of computer-embedded devices. The research strategy used a type of case study research. An inherent limitation of this type of research is the fact that it does not produce results which can be generalised across the field. However, this approach was taken for specific reasons over the use of an approach which may have led to more quantitative results. The aim of the research was to explore the needs of designers relating to interactive prototyping during the early stages of the design process. Exploratory research of this kind aims to develop in-depth and detailed understandings of a particular topic. Furthermore, the six companies selected for participation in the research were deliberately chosen to cover different market sectors of computer-embedded devices. This was chosen to provide insights into the interactive prototyping needs over a broad range of companies, rather than focusing on a single product type.

The number of participants featured within this research is an important limitation to acknowledge. Firstly, it is important to acknowledge that the findings of this research are based entirely on the use of StickIT by practicing design professionals. Previous research reviewed in chapter 2 often evaluated, or explored the needs of designers through the use of design students and recent graduates. This was not considered to be an acceptable approach for this research due to such participants having very limited, if any, experience of working in a commercial design environment. It was felt that this would significantly limit the quality and validity of the results gained. Furthermore, it was essential that each participant closely matched specific criteria, and were experienced with interactive prototyping methods. Gaining access to practicing designers for an entire day, without covering the costs of their time, proved to be challenging during this research. However, the
insights gained from those involved in this research are considered a valid justification of the approach taken.

A further limitation of the research strategy relates to the representative design brief that was used during the design exercises. Its purpose was to provide the designers from each company with an opportunity to trial StickIT within the context of a design process. The opportune scenario would have been to allow the participants to implement StickIT during the early stages of an actual 'live' project. However, this was in reality found to be unfeasible for a multitude of reasons. The issue of confidentiality and appropriate timing of projects presented insurmountable barriers towards trialling StickIT in this manner within the realms of a PhD. The use of a fictional design brief not only provided a way to overcome these issues, but also brought with it some additional benefits. Careful consideration was given when choosing an appropriate product area to ensure it did not favour or bias one case in particular. As well as addressing the commercial constraints of trailing StickIT in a live project, a fixed design brief also provided a commonality between the cases, allowing for the use of StickIT to be compared across the cases.

Additionally, upon reflection, the author recognises that there were some limitations with certain aspects of the data gathering and analysis approach which was taken. In particular, the use of a formal behavioural coding scheme may have been beneficial for recording the observations made during the design exercises. This may have allowed for a more rigorous analysis of the behaviours observed to have been undertaken. However, the nature of an exploratory investigation would have made it difficult to anticipate behaviours to observe prior to the observations taking place.

Furthermore, had the opportunity been available for formal training in the use of NVivo this may have allowed the author to use NVivo for analysis of the data in a more formal manner.

7.7.1 Limitations of StickIT

The StickIT approach was not without shortcomings. Although its use was only intended as a temporary measure to provide a connection between the individual
I/O's and the antenna for the purpose of the research, all of the participants felt that the substrate was limiting in one way or another. Not least of these constraints were caused by its '2.5 dimensionality traits'. In some cases, this resulted in the participants having to stray from their design intent slightly and alter the placement of the I/O's. However, in the case of the participant from Design Consultancy B, the use of some creative thinking resulted in the substrate being modified, allowing it to be given the same desired curvature as the surface of the blue foam model, allowing them to achieve three dimensionality whilst using the substrate (see Figure 109).

Despite the ingenuity displayed by this particular participant, the limitations imposed by the substrate clearly present an area in need of further work. A possible direction for this future work would be from a materials perspective, looking to combine the model making properties of the blue foam with the necessary conductive properties of the substrate. A possible starting point for this may include 'Squishy Circuits' developed by Johnson and Thomas' (2010). 'Squishy Circuits' describe the use of 'Play-dough' for constructing conductive electronics circuits as educational tools.

In the case of Global Mobile Phone Corp. one of the primary reasons for using the 'Black Box' method which utilised existing handsets, was that it provided them with a prototyping platform which allowed the screen to be integrated within the physical device. The use of such techniques was recognised within the company as not being perfect as it offered little accuracy in terms of ergonomics and physicality relating to the actual design intent. However, despite these limitations, an
integrated hardware and software approach was favoured and used over façade prototyping whenever possible. The participant from *Global Mobile Phone Corp.* felt that the integration of a screen was a key requirement for their early stage prototyping needs. Whilst StickIT on its own does not support the integration of a screen, it would be perfectly feasible (and has even been informally tested) to combine the tool with a type of augmented reality prototyping tool described by Gill (2008a). The system creates an *Augmented Reality (AR)* window allowing a Flash UI prototype to be superimposed onto the surface of any object which has an AR barcode attached to it. Similarly, the projected augmented reality system developed by Nam and Woohun (2003) may also be suitable for combining with StickIT if used with a high definition projector to overcome the resolution issues they had previously experienced. Both options would provide a prototyping system with the proven prototyping speed and flexibility of StickIT that also integrates the UI onto the surface of the prototype as opposed to being displayed on a PC screen.
8 Conclusions & Future Work

8.1 Introduction

This research investigated the interactive prototyping needs of designers involved in the development of computer-embedded devices during the very early stages of the design process. The development of the prototyping tool, StickIT, facilitated the investigation by providing an intervention to the existing design processes. It has shown that it is possible to produce interactive prototypes within a timescale of one to two hours without the need for electronics knowledge. Perhaps more importantly, it has also found that the ease with which prototypes can be iterated and the flexibility of the processes used are equally, if not more important attributes required during the early stages of the design process than just speed alone. Furthermore, the investigation has identified that the challenges and barriers which exist towards early stage interactive prototyping extend beyond a lack of tools. This chapter summarises the extent to which the research within this thesis has addressed the research objectives.

8.2 Research Aims and Objectives

The work within this thesis has been conducted in order to address the following research aim:

Explore the interactive prototyping needs of designers during the very early stages of the design process, when developing computer-embedded devices.

This research aim was approached by the undertaking of a critical literature review, development of a novel prototyping tool and an evaluation of the novel approach’s suitability through deployment with six key industrial collaborations. The findings of the critical literature review resulted in three research questions being identified which were intended to address the overall research aim. These questions are reviewed below in light of what has been learnt through undertaking the work within this thesis.
8.2.1 Research Questions

Question 1:

Is it possible to produce an interactive prototype during the early stages within a timescale of one to two hours, and if so is this appropriate?

This research has concluded that it is possible to produce interactive prototypes during the early stages of the design process in less than two hours. StickIT was used within the context of a design exercise and shown to successfully facilitate interactive prototyping during the early stages of the design process.

The pressures faced by designers within the commercial design industry supports the need for the ability to prototype ideas quickly and easily during the early stages. However, whether it is appropriate to define an actual timescale to this process is questionable. Early stage interactive prototyping tools should not look to simply reduce the time required to create a prototype in the first instance. Rather, it was found that the ability to rapidly make changes to a single prototype, thereby increasing the return on investment that can be gained from a single prototype is also highly important for the early stages.

Question 2:

How does a prototyping method of this nature and capability compare with existing methods used within industry?

A major finding of this research found that in all cases, participants acknowledged weaknesses with their existing prototyping processes and stated that StickIT provided improvements over their current methods. In all cases, the rating weighting scales resulted in StickIT being scored higher than the current prototyping practices being used. The importance of this result is that StickIT was considered to provide a positive improvement in all cases.

The research identified that paper prototyping, often combined with a soft blue foam model, as the most common prototyping process used amongst the participants. None of the participants currently use an integrated approach to
prototyping computer-embedded devices during the very early stages of the design process. In all cases, integrated interactive prototypes were only found to be used at a later stage in the design process. This presents a serious flaw in the design processes with an increased risk of failing to identify design flaws at a stage when changes can be made.

The use of paper prototyping as a prototyping tool was not without an apparent awareness for the limitations inherent with the approach. However, despite this, participants were not deterred from using it due to limited choice of comparable prototyping methods in terms of prototyping speed, ease of use and ease of iteration.

The need for an improvement in the availability of suitable prototyping methods for use during the early stages of the design process is still in need of several developments.

**Question 3:**

- How does StickIT meet the interactive prototyping needs of designers involved in prototyping computer-embedded devices during the early stages of the design process?

A major finding of the research is the fact that the barriers towards the adoption of interactive prototyping techniques were found to exist beyond a simple lack of tools and knowledge. Serious limitations and flaws were identified in the design processes being used for the development of computer-embedded devices.

A concurrent and closely integrated approach towards the industrial design and the interaction design was not found to exist in any of the design processes used by the participants. In none of the cases were the participants in a position to equally influence both the industrial design of a product and the design of the user interactions. The emergence of interaction design (IxD) as a discipline in its own right was evident from the companies studied.
Despite this separation of disciplines, the research still identified there to be a strong need for improvements in prototyping tools. Prototyping methods should be available to both industrial designers and interaction designers during the early stages when developing computer-embedded devices.

The research found that even during the early stages of the design process, interactive prototypes of software UI’s are often more complex than a series of static frames. This aspect of the prototyping processes exhibited through the design exercises was regarded in all cases as the most challenging facet of prototyping a computer-embedded device.

This also highlighted the fact that even during the very early stages of a design process, when prototyping computer-embedded devices, a mixed fidelity approach is more appropriate. Varying levels of fidelity were found to be used across the different facets of the prototypes.

The need for interactive prototyping during the early stages of the design process was found to be more closely related to the need for supporting a designers’ ability to rapidly try ideas and learn from the experience. The use of a tool such as StickIT for the development of prototypes for the purpose of formal usability testing was not found to be the primary role an approach of this nature would provide.

8.3 Contribution to Knowledge

In working towards the aim and objectives of this research, new knowledge has been developed in the area of early stage interactive prototyping for the design of computer-embedded devices. Through this research the following areas of knowledge have been developed:

- The development of a prototyping methodology which has been proven to facilitate tangible interactive prototyping, within a timescale of one to two hours. A solution allowing interactive prototyping of this nature has previously not been achievable.
• In all cases studied, the prototyping methodology, facilitated by StickIT, was found to offer a number of improvements and strengths in comparison to existing prototyping methods.

• The barriers towards early stage interactive prototyping for computer-embedded devices have been found to extend beyond being a simple lack of appropriate prototyping tools. A shortfall in sufficient prototyping tools was found to contribute in part to the challenges. However, this research has also found a growing separation between the industrial design and the interaction design processes of computer-embedded devices presents a significant flaw in achieving an integrated and effective early stage prototyping approach for computer-embedded devices.

8.4 Future work

A clear area for future research relates to the continued development of interactive prototyping methodologies, in particular ones suitable for use during the early stages. Over the course of the work undertaken within this thesis the Arduino prototyping platform has continued to grow in popularity and use. Some design based courses have begun to include modules which introduce the use of Arduino as a prototyping tool to students. Encouraging design students, across disciplines, to gain basic programming and electronics knowledge could ultimately be a crucial step in providing designers of the future with the skills required for developing computer-embedded devices. It seems inevitable that the number of products being designed which fall into the category of computer-embedded devices will continue to rise, and therefore designers’ educations must evolve in parallel.

Prototyping software UI’s in relation to computer-embedded devices has been identified as an area which remains a major challenge, particularly for the adoption of interactive prototyping during the early stages. Tools which simplify, or remove the need for coding can limit the flexibility of the tool. Whilst those which offer a higher level of flexibility, such as Adobe Flash, require knowledge of programming in order to make use of such features. This therefore suggests a need to research ways to maximise the flexibility of UI development tools, without the need for extensive programming knowledge.
In addition to further research surrounding the development of prototyping tools, it is clear that the barriers in terms of separation within the design processes of computer-embedded devices need further investigation. Without addressing the separation between the industrial design and the interaction design, it is likely that any advances in prototyping techniques for computer-embedded devices will be unable to reach their full potential. A possible starting point would be to undertake a larger scale quantitative piece of research to better ascertain the extent to which a separation exists.

Tools and prototyping methodologies such as those demonstrated by StickIT show great potential for use within participatory design methods. Stemming from the 1970’s, participatory design is an approach to gaining knowledge through the involvement of users in the design process (Steen et al., 2007). Particularly in relation to the design of complex products such as computer-embedded devices, prototyping tools which feature low technical thresholds are likely to be a critical component for enabling users to become involved in the design process. The role of interactive prototyping in relation to participatory design methodologies presents an interesting area for future research.

Another area for potential future research could be to examine the differences between market sections in relation to interactive prototyping requirements. Recently there has been an increase in the need for medical device manufacturers to demonstrate efficacy and consideration of user needs and safety in relation to their products (ANSI HE75:2009, BS60601:2008, BS62366:2008). This is likely to increase the need for interactive prototyping methods suitable for use during the development of medical devices. Future research relating to interactive prototyping should perhaps examine the needs and issues related to specific product sectors.

Finally, it is the intention to disseminate the findings of this research to a wider audience through journal and conference publication. The Journal of Design Research would be a logical choice since the work within this thesis has built upon that of Gill et al., (2008a) which has previously been published in this journal.
9 References

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10 Appendices

10.1 Appendix 1 - Medynskiy Python Script

Python Script published by Medynskiy for establishing a connection between Bluetooth Serial Port and a PC, and then reading in RFID values from Son Micro RFID module.

```python
#!/usr/bin/python
# Written by Yevgeniy Medynskiy (eugenem@gatech.edu)
# Date modified: December 2006
# No copyright. No warranty. Distributed as-is.
# http://www.gvu.gatech.edu/ccg/resources/wearableRFID.html

import time
import Bluetooth
#
### Change to your device's Bluetooth address
#
device = "00:13:E0:67:23:08"
port = 1
#
### Read command and request for acknowledgement.
#
cmd1 = \"\x72\x65\x33\x36\x02\x07\x01\"
cmd2 = \"\x61\x63\x6B\x6E\x77\x6C\x67\x65\"
socket = bluetooth.BluetoothSocket(bluetooth.RFCOMM)
print "Attempting to connect to " + device + ":" + str(port) + "...",
socket.connect((device, port))
print "done."
socket.send(cmd1)
socket.send(cmd2)
print "Receiving data..."
data = ""
try:
    while True:
        try:
            data = socket.recv(255)
        except bluetooth.BluetoothError, b:
            print "Bluetooth Error: ", b
        if len(data) > 0: print data
except KeyboardInterrupt:
    print "Closing socket...",
```

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socket.close()
print "done."
10.2 Appendix 2 - Design Brief

With the rise in the number of drink driving offences being committed each year in Britain, Police officers are finding themselves using breathalysers more frequently. However, results from breath tests are not always straightforward and can often require the suspect being taken to the police station for a blood sample. Recent reports have suggested that providing Police officers a method of blood sampling at the side of the road could save Police time and resources.

A client has recognised this as an opportunity for the development and launch of a new product for the breathalyser market. Your design brief is to develop a concept for the new breathalyser, and produce an interactive prototype using the experimental toolkit. Your design process should focus on exploring the interaction aspects of the concept and how this affects the form of the design. Your thought process should be informed through the use of the prototyping toolkit.

You are not expected to have reached the correct concept at the end of the exercise, but to have simply gained experience of how early rapid low-fi prototyping can affect the design process, for good and for bad. You are also not expected to create a large in-depth prototype of the interface, a simple simulation of a couple of the concepts features are sufficient for the purpose of the study. The level of completeness is not the focus of the study; rather the emphasis is on the prototyping experience and how it affects the design process.

It is anticipated and understood that the introduction of interactive prototyping at such an early stage within the design process may not match your current methods of working. The reason for enforcing a specific design process, in which interactive prototyping is brought to the very front end of design, is to allow you to explore how you believe the design process is affected by doing so.

Recommended timing

1-2hrs concept and interface development

1-1.5hrs prototyping and testing
10.3 Appendix 3 - Interview Guide

- Identify existing early stage prototyping practices, and compare with experimental approach
- Difficulties that are faced within organisation
- Degree to which such a system would be successfully adopted by industry
- What benefits the system provides in context of their work & where it falls short

**Introduction**

This research is being conducted as part of a PhD being undertaken by Ian Culverhouse at UWIC. The aim is to investigate the potential for rapid low fidelity prototyping techniques on the design development of information appliances. By now, you will have been asked to take part in a formal design brief where you will have gained firsthand experience of using an experimental prototyping toolkit that aims to provide designers with the ability to create interactive prototypes within a time scale of 1-2 hours. The study requires honest opinions; do not just provide positive answers for the sake of it.

_N.B - Study aim is to investigate the effectiveness of experimental prototyping toolkit. Three aspects are key to this: usefulness to designers, flexibility & speed._

**Organisation Basics**

- Company Size
- Structure
- Market Sectors and Strengths within

**Process**

- What activities are included under the banner of interaction / user experience design?
- Where does prototyping and user testing fit into this process?
- Does interactive prototyping take place?
- Project examples – where has it been effective and crucial?

**Skills**
• What skills are needed to support the prototyping activities?
• Size of teams?
• Internal / External?
• Reasons for or against answer for above?
• Any constraints that caused problems that would be repeatable on future projects?

Value to company

• How is interaction design and interactive prototyping viewed within the organisation?
• Is this view equally shared within the design team?
• What benefit is it seen to bring?
• Why is it considered important?
• How is this value conveyed to the client?
• Is the importance changing?

Feedback on experimental approach

• What were their overall first impressions before use of the system?
• Has this changed through use? What are overall thoughts and feelings now?
• How does the process compare with current practice and experience?
• Would such ability bring value to the service offered by organisation?
• As the conversation develops, if not already covered, try to steer towards the following points:
  o First impressions - instincts
  o Overall impressions - did their first impressions change through use?
  o Usefulness at design development
  o Speed of prototyping
  o Flexibility of prototype
  o Importance of speed and flexibility of prototyping
  o Identify existing methods used
  o Current stage when interactive prototyping is thought about
  o Value of introducing it at such an early stage
  o What are interactive prototypes used for within their work?
  o Features that are most important
  o Features that are least important
- Features that are missing
- Realise potential for current projects?
- Adoption of such a system by industry?
- Fit within current skills of a designer

Any Questions they might have for you?

Rating / Weighting Scale

Thank them for their time, invite for a drink and some food?
## 10.4 Appendix 4 - Participant Rating / Weighting Form

<table>
<thead>
<tr>
<th>No.</th>
<th>Objective</th>
<th>Weight Factor (w)</th>
<th>Rating (r)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1-6</td>
<td>1-6</td>
</tr>
<tr>
<td>1</td>
<td>Representation of intended Interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Richness of interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ease of prototype iteration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Immediate exploration of error solving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Effective communication of design intent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Effective representation of intended physicality of concept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Level of visual refinement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Level of technical understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Fit within designers skill set</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Interaction between designer and prototype</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Robustness of Prototype</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Suitability of prototype for conducting user testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Level of prototype automation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Level of Ergonomic Evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Client or Management persuasion tool</td>
<td></td>
<td></td>
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<tr>
<td>16</td>
<td></td>
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<tr>
<td>17</td>
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</tbody>
</table>

**Total**
10.5 Appendix 5 - Participant Information Sheet

Researchers PhD Title

Investigate the effectiveness of rapid low fidelity prototyping techniques on the design development of information appliances

Why is the research being undertaken?

This study will form part of the research towards Ian’s PhD. This study is part of a larger evaluation plan for investigating the effectiveness of a novel experimental prototyping tool for product designers. As a result of research to date on existing methods and previous efforts at bridging the gap designers face when prototyping information appliances an experimental toolkit has been developed. The experimental prototyping tool aims to provide designers with the ability to rapidly create interactive prototypes within 1-2 hours.

Aim of this Study

To gather professional practicing designers’ opinions on the potential of the experimental prototyping approach developed as a result of research to date. The study aims to allow designers to gain first hand experience of using the prototyping toolkit by undertaking a short design brief and providing feedback on their experiences. The study also affords designers the opportunity to compare the experimental approach with their current practices and provide comparative feedback.

Who is undertaking the research?

Ian Culverhouse will be undertaking the research. Ian is currently in his final year of his PhD study at The National Centre for Product Design & Development Research.

Who is funding the research?

Ian Culverhouse’s PhD is funded by the University of Wales Institute Cardiff as part of the Programme for Advanced Interactive Prototyping Research group, based within The National Centre for Product Design & Development Research (PDR).

How will Data be gathered?

Observational and ethnographic case study research methods will be used for the study. A mixture of observational and semi structured interview techniques will be used to gather
data. Data will be recorded using a mixture of video recording, audio recording and note taking.

Permission will be sought before any recording of video, audio or note taking takes place.

**Timescale of the Study**

The overall timescale for the study is expected to last between 2-3 months, running between December 2009 and March 2010. This includes the pre-study organisation, piloting the study design and refining it, conducting the one on one session with practicing designers, collating the data and analysing the data.

Actual time that each participant will be involved in the study will be 1 day each in total.

**Your Participation in the Research Project**

**Why you have been asked?**

You have been invited to participate in this research because of your skills as a designer.

It is considered that to make any progress in breaking down some of the barriers designers face, the opinions of practicing professional product designers are vital to the development of any new approaches. This is where your professional expertise, experience and opinions are invaluable to this research.

It is entirely voluntary – there is absolutely no obligation of any kind to join the study, you will not discriminate in any way against if you decide not to take part.

**What happens if you want to change your mind?**

If you decide to join the study you can change your mind and stop at any time. We will completely respect your decision. There are absolutely no penalties for stopping.

It is important to remember that the study is not testing your abilities in any way, you will not be judged or marked. The studies aim lies wholly at investigating the potential for the experimental approach that has been developed.

**What would happen if you join the study?**

If you are willing to take part in the study you will be given the opportunity to trial the use of a developing interactive prototyping toolkit.
The study will require a total contribution of 1 day (possibly less, no more) of your time that will be split into various stages that make up the study.

The study will begin with a session aimed at giving you a brief overview of the research behind the development of the experimental toolkit. During this session, you will also be given an opportunity to familiarise yourself with using the toolkit and make sure you are comfortable in its use.

Following the initial introduction session, you will be presented with a short design brief to design and produce an interactive prototype of a concept breathalyser, working within the specified timescale. (See Design Brief for more details.)

The design exercise will be videoed to capture your process and development of the concept throughout the allotted time. You will also be given a diary that you can use to write in to describe key points and thoughts as you are working.

Once the design exercise is complete (when the allotted time is up) you will be interviewed using a semi structured interview style. The purpose of this interview session is to gather as much insight into your experiences of using the experimental toolkit as possible. During the interview you will be encouraged to make comparisons between the experimental approach and current methods that you may use. In addition to semi structured questions you will be asked to use a ranking/weighting scale to provide a quantifiable set of data as to how effective you perceive the experimental toolkit against your current practices.

**Are there any risks?**

We do not foresee any immediate risks to the participants of the study.

**What happens to the data collected from the study?**

The data from the study will be disseminated in an international conference paper and or journal paper as well as being in Ian Culverhouse’s PhD thesis.

**Are there any benefits from taking part?**

By taking part in this study you will be given the opportunity to use and feedback your opinions on an experimental prototyping approach that has been aimed at improving the processes of product designers.
You will also have an opportunity to see some of the other research currently being conducted within the research group, and potentially incorporate into your future projects.

**How we protect your privacy**

All data collected from the study is will be handled in accordance with the Data Protection Act. Any consent forms and written documents will be retained by the principle investigator for a period of at least 5 years in a secure location within UWIC. The documents will be made available for the purpose of inspection. Digital data, such as audio recordings and video and notes taken will be kept on a password protected computer.

*YOU WILL BE GIVEN A COPY OF THIS SHEET TO KEEP, TOGETHER WITH A COPY OF YOUR CONSENT FORM*

Contact Details:

**Ian Culverhouse**

Tel: 02920 41 7009

Email: iculverhouse-pdr@uwic.ac.uk

**Gareth Loudon**

Tel: 07796956054

Email: glouden@uwic.ac.uk

**Important! – You may take a break at any point during the study and are able to withdraw from the study at any time.**
10.6 Appendix 6 - Participant Consent Form

Participant Name:

UWIC PARTICIPANT CONSENT FORM

Title of Project: Investigating the Effectiveness of Rapid Low Fidelity Prototyping Techniques on the Design Development of Information Appliances

Name of Researcher: Ian Culverhouse

Participant to complete this section. Please initial each box.

1. I confirm that I have read and understand the information sheet dated ........................ for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my relationship with UWIC, or my legal rights, being affected.

3. I understand that relevant sections of any of research notes and data collected during the study may be looked at by responsible individuals from UWIC for monitoring purposes, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.

4. I provide consent for the taking of photos and video recording of my participation within the study.

5. I agree to take part in the above study.

______________________________________                             ___________________   
Name of Participant                                                                                   Date

____________________________________                     ___________________   
Signature of Participant                                                                                   Date

____________________________________   
Name of person taking consent                                                                                   Date

____________________________________   
Signature of person taking consent
10.7 Appendix 7 - Ethical Approval Application

UWIC APPLICATION FOR ETHICS APPROVAL

All Principal Investigators (PI) undertaking a research project which involves human participants should complete and sign this application form.

The document Guidelines for obtaining ethics approval gives full details of how to complete this form and is available via the research pages of the UWIC website. You should refer to this document in order to avoid unnecessary delays with your application.

As a PI, you are responsible for exercising appropriate professional judgement in this review and for operating within UEC (and any School and professional) guidelines in the conduct of the study.

Participant recruitment or data collection must not commence until ethics clearance has been obtained.

<table>
<thead>
<tr>
<th>Principal Investigator:</th>
<th>Ian Culverhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervisor (if student project):</td>
<td>Dr. Gareth Loudon</td>
</tr>
<tr>
<td>School:</td>
<td>PDR</td>
</tr>
<tr>
<td>Type of researcher:</td>
<td>Post graduate Research Student (PhD)</td>
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<tr>
<td>Programme enrolled on:</td>
<td>Research Programme</td>
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<tr>
<td>Project Title:</td>
<td>Investigating the Effectiveness of Rapid Low Fidelity Prototyping Techniques on the Design Development of Information Appliances</td>
</tr>
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</table>

PART ONE – ETHICS REVIEW CHECKLIST

| ERC1: Will the study involve NHS patients or staff? | No |

If YES, you do not need to complete Part Two of this form. Instead, an application for ethics approval must be submitted to the appropriate external NHS Research Ethics Committee. Complete Declaration A overleaf and forward a copy of your NHS application plus Part One of this form to your School Ethics Committee for information.
**ERC2:**

Does your research fall *entirely* within one of the following three categories:

- Paper-based, involving only documents in the public domain
- Laboratory based, not involving human participants or human tissue samples (e.g. electronics, chemical analysis)
- Practice-based, not involving human participants (e.g. exhibitions, curatorial, reflective analysis, practice audit)

<p>| | | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

If **YES**, you do not need to complete Part Two of this form. Instead, complete Declaration B overleaf and send the completed form to your School Ethics Committee for information.

If **NO**, you must complete Part Two of this form and submit your application (Part One and Part Two) to your School Ethics Committee for consideration.
**DECLARATION A**

I confirm that the information contained in this form is correct

My research involves human participants and ERC1 indicates I must obtain ethics clearance from the appropriate external health authority ethics committee.

Signature of Principal Investigator:

Date: 25 January 2012

---

**DECLARATION B**

I confirm that the information contained in this form is correct

My research falls entirely within the categories described in ERC2 and I do not need to take further action to obtain ethics clearance.

Signature of Principal Investigator:

Date:

---

**Brief synopsis of project:**

The project continues research by the Programme for Advanced Interactive Prototyping (PAIPR) into methods and processes surrounding the issues product designers face when prototyping interactive products. The work forms part of a PhD undertaken by Ian Culverhouse. In particular the research investigates very rapid low fidelity prototyping techniques for information appliances.

---

**FOR STUDENT PROJECTS ONLY**

I confirm that I have read and agreed the information contained in this form

Name of Supervisor: Dr. Gareth Loudon  
Date: 25 January 2012

Signature of Supervisor:

---

**School Research Ethics Committee use only**

☐ Considered and supported  
☒ Considered and not supported

Name: Click here to enter text.  
Date: Click here to enter a date.
**PART TWO – APPLICATION FOR ETHICS APPROVAL**

<table>
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<th>Expected Start Date:</th>
<th>01/11/2009</th>
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<tbody>
<tr>
<td>Approximate Duration:</td>
<td>2-3 Months</td>
</tr>
<tr>
<td>Funding Body (if applicable):</td>
<td>Ian Culverhouse is funded by The University of Wales Institute Cardiff as a Bursary Awards Research Student (BARS).</td>
</tr>
<tr>
<td>Other researcher(s) working on the project</td>
<td>N/A</td>
</tr>
<tr>
<td>Does your project require ethical approval from an NREC or other body?</td>
<td>No</td>
</tr>
<tr>
<td>If yes, please name the NREC or other body</td>
<td>N/A</td>
</tr>
<tr>
<td>Does your project use Human Tissue?</td>
<td>No</td>
</tr>
<tr>
<td>Has CRB clearance been given?</td>
<td>N/A</td>
</tr>
<tr>
<td>If yes, which organisation holds details of the check?</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**DECLARATION**

I confirm that the information contained in this form is correct  
Signature of Principal Investigator:  
Date:  

**FOR STUDENT PROJECTS ONLY**

I confirm that I have read and agreed the information contained in this form  
Name of Supervisor: Dr. Gareth Loudon  
Date:  
Signature of Supervisor:  

**Research Ethics Committee use only**

<table>
<thead>
<tr>
<th>Decision reached:</th>
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<tbody>
<tr>
<td></td>
<td>Project approved in principle</td>
</tr>
<tr>
<td></td>
<td>Decision deferred</td>
</tr>
<tr>
<td></td>
<td>Project not approved</td>
</tr>
<tr>
<td></td>
<td>Project rejected</td>
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</tbody>
</table>

Project reference number: Click here to enter text.  
Name: Click here to enter text.  
Date:  
Signature:  

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6 In cases where a CRB check has been sought by an external organisation, confirmation from that organisation that a satisfactory check has been received is required by UWIC at application stage.
### A – PROJECT DETAILS

**A1** In order to give members of the ethics committee some idea of the nature of your research, please answer the following questions with regard to this project:

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will you take blood or tissue samples from participants?</td>
<td>No</td>
</tr>
<tr>
<td>Will the study involve prolonged or repetitive testing OTHER THAN repetitive training exercises of a type which form part of the participants normal activities (such as athletics or music training)?</td>
<td>No</td>
</tr>
<tr>
<td>Are drugs, placebos or other substances (e.g. vitamins) to be administered to participants?</td>
<td>No</td>
</tr>
<tr>
<td>Could the study induce physiological or psychological stress or anxiety significantly greater than the participants are likely to experience in their daily lives?</td>
<td>No</td>
</tr>
<tr>
<td>Does the study involve participants who are unable to give informed consent?</td>
<td>No</td>
</tr>
<tr>
<td>Will the study involve children? (NB: Projects in professional practice involving groups of children in a public place in school, with the permission of the school, are exempted)</td>
<td>No</td>
</tr>
<tr>
<td>Is pain or more than mild discomfort likely to result form the study?</td>
<td>No</td>
</tr>
<tr>
<td>Will financial inducements, other than reasonable expenses and compensation for time, be offered to participants?</td>
<td>No</td>
</tr>
<tr>
<td>Will deception of participants to necessary during the study?</td>
<td>No</td>
</tr>
</tbody>
</table>

**A2** Briefly describe the rationale behind your project

As a result of the research undertaken by Ian Culverhouse to date, an experimental prototyping toolkit has been developed. The experimental tool is intended for use by product designers during the early stages of the design process, allowing them to rapidly create interactive prototypes within a timescale of 1-2 hours. Such a goal is currently difficult to achieve, or requires designers to go beyond their current working practices and learn new skills.

**A3** What are the aims of the research?

The aim of this study is to gather professional practicing product designers’ opinions on the experimental toolkit that has been developed as a result of research to date. The study aims to allow designers to explore the potential of the system through the means of undertaking a short design project where they will be able to use the experimental toolkit. Through first hand experience of using the experimental toolkit, designers will be encouraged to make a comparison between the new approach and their current practices. The study will also uncover information regarding the designers opinions of the toolkit through the use of semi-structured interviews.

**A4** Will you be using an approved protocol in your project?  Not applicable
A5 If yes, please state the name and code of the approved protocol to be used

| Not applicable |

If your project does involve the use of an approved protocol, please indicate when answering the following questions, which areas of your study are covered by the protocol

| A6 What methods of data collection and analysis will you adopt? |

The design exercise carried out by the groups will be video recorded. The video data collected will be later analysed to observe how the designers used the tool to complete the design challenge. Additional notes may be taken during the study in parallel to the videoing to record any key observations or comments made from the designers. It is anticipated that the design task will last approximately between 2-3 hours, based on the aim of the research to investigate rapid low fidelity prototyping within 1-2 hours.

Following the completion of the design brief, the participant will be interviewed using a semi structured interview process to gather feedback on their experiences and opinions on using the experimental approach. The questions for the semi structured interviews have not yet been fully devised, however they will aim to mine for information regarding the following points:

- Designers experience of using the prototyping techniques,
- What strengths and weaknesses each technique possessed,
- What was gained in terms of design development by using the prototyping technique.
- Compare and contrast how the system performed against their current practices they use.

A ranking/weighting scale will also be used to gather quantitative data from the designers on how they rate the performance of the experimental toolkit.

Data gathered will be analysed and coded thematically to identify common themes and opinions that arise from the data.

| A7 What remuneration (if any) will be offered to participants? |

There will be no direct remuneration offered to the participants.

However participants will be gaining access and have the opportunity to use an experimental prototyping tool that could benefit their working practices. Participants will be providing in-valuable feedback that will feed directly back into the development process for the experimental toolkit.

---

7 An Approved Protocol is one which has been approved by UWIC to be used under supervision of designated members of staff; a list of approved protocols can be found at [INSERT LINK]
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A8 From which group(s) will participants be recruited and what sampling method and criteria will be used?</td>
<td>The most crucial factor involved in recruitment for this study is that the participant is or has recently been a practicing product designer, involved in the development of interactive products. MSc students and BA/BSc product design students may be recruited to pilot the studies design, any data gathered from these pilots will only be used to refine the study design. Gender, age, ethnicity, disability or economic factor will not affect any aspect of the recruitment strategy for this study.</td>
</tr>
<tr>
<td>A9 How many participants will be involved?</td>
<td>The study aims for 6-8 participants will be needed to gather sufficient data.</td>
</tr>
<tr>
<td>A10 Where and how will the participants be recruited and what method of initial contact will you use?</td>
<td>Initial attempts to recruit participants will be made by contacting existing relationships between practicing designers within industry and PAIPR. If insufficient numbers of participants cant be found using existing relationships then a process of cold calling design consultancies will take place.</td>
</tr>
<tr>
<td>A11 What previous experience of research involving human participants relevant to this project do you have?</td>
<td>As part of my MSc I designed, organised and ran a set of user studies to conduct usability evaluations on product concepts. I have also organised and conducted an ethnographic study and informal interviews at a Parent and Toddler group as part of research into the design and use of pushchairs and baby strollers. More recently I have sat in on interviews between design consultancies and a researcher from PDR working on a feasibility study.</td>
</tr>
<tr>
<td>A12 Student projects only What previous experience of research involving human participants relevant to this project does your supervisor have?</td>
<td>Dr. Gareth Loudon has a long standing history of research involving human participants within the product development field. He has worked for Apple Computers, where he worked as the principle designer of the Asian Language handwriting recognition technology. Gareth has also worked for Ericsson Research where he developed new and innovative mobile devices and services for 3G networks based on in-depth customer research. Gareth has since run his own company called Light Minds that specialised in providing a consultancy based ethnographic research service. Now he runs a consultancy company called Innovation Forum, and is also a part-time lecturer at UWIC.</td>
</tr>
</tbody>
</table>
**B – POTENTIAL RISKS**

**B1 What potential discomfort or inconvenience to the participants do you foresee?**

It is not foreseen that the participants of the study will experience discomfort during the research. It is possible that the 1 day total study time, per participant, may be considered an inconvenience to some.

During the design exercise part of the study, participants will be using blue foam modelling material. It is expected that they will use hand tools such as formers and knives to shape their designs, as well as potentially using hot wire cutter. The improper use of these tools presents a risk to the participants’ safety.

**B2 How do you propose to deal with the potential risks?**

To minimise the inconvenience that the study may cause it will be designed in a way that the study can be spilt over more than one day. It is expected that each participants involvement in the study will be reviewed on an individual basis to ensure their participation in the study causes minimal inconvenience.

Risks presented through the use of sketch modelling techniques will be dealt with by providing the participants with an introduction to the tools they will be using and appropriate safe methods of use. Participants will be asked to sign a form, agreeing that they have received suitable training.

**B3 Do you intend to use a questionnaire to ascertain an individual’s level of physical fitness or health before accepting them as a participant? If yes, please give details.**

No – not applicable

**B4 What potential risks to the interests of the researchers do you foresee?**

No potential risks to the researcher are foreseen with the proposed study

**B5 How will you deal with these potential risks?**

Not applicable

**C – CONSENT**

**C1 Will informed consent be sought from participants?**

Yes

**C2 IF NO, explain why informed consent will not be sought**

Not Applicable

**C3 IF YES, describe how informed consent will be obtained and attach copies of relevant documents**

Prior to individual participant’s involvement in the study, consent will be gained from the relevant persons within their organisation to carry out the research. The purpose of the study, intended methods of data collection, how the data will be disseminated will all be explicitly described to ensure that all parties are fully informed about all aspects of the study.

**C4 If you are using an approved protocol, has the approved wording for participants been included in your Participant Information Sheet?**

Not Applicable

**C5 If NO, why not?**
| C6 | If there are doubts about participants’ abilities to give informed consent, what steps have you taken to ensure that they are willing to participate? | Not Applicable |
| C7 | If participants are aged under 18, describe how you will seek informed consent | Not Applicable |
| C8 | How will consent be recorded? | Each participant agreeing to take part in the study will be asked to sign two copies of a Participant Consent Form, one copy will be theirs to retain for personal records, the other will be kept in a secure place with the other participants consent forms taking place in the study. |

| D1 | Will participants be informed of their right to withdraw without penalty? | Yes |
| If no, please detail the reasons | Not Applicable |
| D2 | How will you ensure participants’ confidentiality and anonymity? | Participants will be asked prior to the study taking place if they agree to provide consent for photos and video to be used after the study. Data collected may be used in conference papers, journal articles, presentations and the final PhD thesis. Prior consent will be sought by participants before the commencement of video filming and photos that may disclose the participant’s identity. |
| D3 | How will issues of data storage be addressed? | To comply with the Data Protection Act, participants will be informed of what personal information will be held about them and who will have access to it. In the case of sensitive personal data, explicit consent will be gained from the participant. Any written forms, including consent forms, participation information sheets and questionnaires will be retained by the Principle Investigator in a secure location at UWIC that will remain accessible for audit purposes for at least 5 years. After the 5 years the data will be destroyed. Any digital data collected, video, photographs, will be kept on a password secured computer at UWIC. The password of which will be changed at least once every 3months (every 72 days). After the completion on the thesis, all digital video and photographs will be destroyed. |
| D4 | Are there any further points you wish to make with regard to the proposed research? | IMPORTANT: All participants will be explicitly reminded that their participation in the study is not compulsorily and that they may withdraw from the study at any time. |
NB: When submitting your application, in addition to this form your School Ethics Committee will expect to see copies of the documentation you will use during your project. Depending on what your project entails, this may include:

- Participant information sheet (See Section C)
- Participant consent form (See Section C)
- Parents information sheet (See Section C)
- Parents consent form (See Section C)
- Participant questionnaire (See A6)
- Health questionnaire (See B3)
- Letter to the organisation at which research will take place

Refer to the document *Guidelines for obtaining ethics approval* for further details on which documents you should provide and exemplar forms for your reference when compiling this information.
10.8 Appendix 8 - Ethical Approval

UWIC APPLICATION FOR ETHICS APPROVAL

DECLARATION A
I confirm that the information contained in this form is correct.

My research involves human participants and ERC1 indicates I must obtain ethics clearance from the appropriate external health authority ethics committee.

Signature of Principal Investigator:

Date: 27 October 2009

DECLARATION B
I confirm that the information contained in this form is correct.

My research falls entirely within the categories described in ERC2 and I do not need to take further action to obtain ethics clearance.

Signature of Principal Investigator:

Date:

Brief synopsis of project:
The project continues research by the Programme for Advanced Interactive Prototyping (PAIPR) into methods and processes surrounding the issues product designers face when prototyping interactive products. The work forms part of a PhD undertaken by Ian Culverhouse. In particular the research investigates very rapid low fidelity prototyping techniques for information appliances.

FOR STUDENT PROJECTS ONLY
I confirm that I have read and agreed the information contained in this form.

Name of Supervisor: Dr. Gareth Loudon

Date: 27 October 2009

Signature of Supervisor:

School Research Ethics Committee use only
☐ Considered and supported ☐ Considered and not supported

Name: Click here to enter text.

Date: Click here to enter a date.

Application for ethics approval v7 July 2009
Bringing Concepts to Life: Introducing a rapid interactive sketch modelling toolkit for industrial designers

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ABSTRACT

This paper presents the results of work in progress aimed at answering the challenges faced by industrial designers creating information appliance prototypes at a very early stage in the design process. A new system centred on a hardware unit called an IE5 is described in detail. The authors argue that the new method offers a potential solution that will allow prototyping in the critical 1 – 2 hour timeframe which would allow genuinely iterative hardware prototyping integration in the design process’ early stages. The system utilises passive RFiD embedded controls that can be attached to a sketch model without the need for any wiring or soldering. It solves the problems encountered by previous RFiD based toolkits in flexibility, footprint size, and range / connection reliability. While the system is still in development, the concept has been proved by a basic prototype. The paper identifies the system’s strengths and weaknesses before discussing areas for further development.

Keywords

Interactive prototyping, low fidelity, rapid iteration, RFiD. Common RFiD Antenna

INTRODUCTION

So called information appliances present industrial designers with a series of challenges. Not least of these challenges is the fact that these products are so complex that designers are unable to prototype them adequately. This paper presents work in progress which suggests a possible way of enabling industrial designers to rapidly create interactive sketch models of information appliances at an early stage in the design process.

Nam (Nam, 2006) recognised the difficulty industrial designers of information appliances face when trying to integrate all design elements in the early stage of the process. Creative ideas rapidly evolve during the early stages of a design but the lack of tools available that supplement and support traditional sketching and prototyping skills means that effective exploration of integrated design concepts becomes a major challenge. The system described in this paper is centred on a unit called an IE5, the intention of which is to provide a rapid and fluid method of creating 3D interactive prototypes. The system supports the iterative nature of the product design process, paying close attention to the scale of both the prototype and its interactive elements. These factors are frequently ignored, but are in fact crucial to an effective and accurate prototyping methodology.

A number of groups have been working in the area of interactive prototyping methodologies for some time, dTools (Hartman, 2001), Phidgets (Greenberg and Fitchett, 2001), IE system (Gill, 2003b), Calder Toolkit (Lee,
These proposals have all sought to provide ways to allow industrial designers to produce interactive prototypes more easily. While they have successfully identified a number of critical considerations in the design development of information appliances, a number of important factors have been overlooked. Gill et al. (Gill, 2008b) found that for a prototyping toolkit to achieve successful adoption by industry it should empower the designer to create a low fidelity interactive prototype within 1 – 2 hours. Furthermore, they recommended that this be achieved by utilising a toolkit that required no electronics or programming knowledge on the part of the designer, and which was easy to learn. They carried on to recommend that it should also support a wide varied range of analogue and digital input devices including push buttons, dials, sliders, touch sensitive buttons etc. They recommended that the system should be capable of utilising off the shelf components to offer a greater range of flexibility, and, lastly, they suggested that a wireless solution would be ideal, while noting the technical challenges that a totally wireless system presents (component footprint, internal power requirement, the need for “smart” components, problems of range). Gill et al. (Gill, 2008b) also demonstrated that the ability to rapidly create an interactive prototype to scale is also a highly critical factor. A prototype that does not accurately represent the intended scale of a design does not allow the designer to fully evaluate the physicality of interaction between the appliance and the user.

Experimental work by Culverhouse et al. (Culverhouse, 2008) combining DENIM (Newman et al., 2003) and VoodooIO (Villar and Gellersen, 2007) proved it was possible to create a fast and fluid sketch based system of prototyping information appliances. However, promising though the concept was, it was only achievable on a 2D surface, the prototype’s scale was wrong and the device was tethered to a PC by a wire. The results were nevertheless interesting enough to inspire the development of a new concept, the IE5, which the authors hope will eventually solve a number of the problems mentioned above.

**THE IE5**

![Image of the IE5](http://uk.youtube.com/watch?v=Yl0oYl8S-bU)

The IE5 has 4 main components (see Figure 1):

- a wearable passive RFID reader
- a conductive material which is embedded into a foam sketch model
- a common passive RFID Antenna
- passive RFID embedded buttons

### Figure 1: The IE5

The wearable reader has 3 main components:
- a 125kHz passive RFID reader
- a Bluetooth to Serial Modem
- a power supply

The RFID reader detects RFID tags on the 125 kHz frequency. 125kHz RFID tags are readily available from a wide range of suppliers at low cost and come in a variety of forms, for the work described in this paper “clamshell” style RFID cards are used as they are relatively easy to remove the chip from (see below). These chips feature an internal antenna which makes for a smaller unit thereby allowing a smaller control input footprint, the importance of which is noted above. To interface the passive RFID reader to a PC and report RFID events, a Bluetooth Modem was used, capable of transmitting data to a PC up to 30 meters away. To power both reader and the Bluetooth modem a 9v battery was used with a 5v voltage regulator. Later versions will probably replace this set up with a rechargeable battery to provide a more user friendly system.

All the components except the 9V battery were mounted on a PCB approximately 60mm x 60mm, that was produced “in house”. An additional LED was also incorporated into the circuit to provide visual indication as to when an RFID tag had been detected. The LED also provided assistance with software debugging at a later stage. The battery was housed in an “off the shelf” battery holder and was secured...
to the back of the wrist via an elastic strap. The PCB with the mounted components was secured to the back of the glove, also with elastic straps.

As scale has been identified as a key area of importance it was critical that the footprint of input controls be kept to an absolute minimum. Switcheroos (Avrahami, 2002) utilised modified passive RFID tags to make them switch-able by inserting a switch or button between the tag and its antenna. One of the key issues of this system however was that because each tag required an antenna, the footprint of the buttons made them unsuitable for creating true scale prototypes of most information appliances. The authors recognised the power of Switcheroos because each tag possesses a unique identity, requires no wiring and can be positioned freely on the surface of a model. Nevertheless they were also aware of the challenges. As well as the issue of the control input’s footprint, the range of an RFID reader is so short and the angle of the aerial so critical that the result was a very short, unreliable and invisible tether to the PC.

The first challenge then was to reduce the size of the footprint. The IE5 system sought to achieve this goal by removing the need for each RFID embedded button to have its own antenna, instead providing a common antenna for all the controls. This would mean that the control size would no longer be dictated by the necessity of having individual antennas, but rather by the size of the chosen control plus the (very small) passive RFID tag. But how could this be achieved in a flexible fashion?

The solution chosen utilises a conductive substrate to act as a conductor between each of the RFID embedded controls and the antenna. The substrate can be directly embedded in the surface of an early sketch model concept and controls can then be attached to it, giving the sketch model flexible and reconfigurable interactive elements.

Each control in this early, proof of concept setup comprises of four components (see Figure 2).

1. an RFID chip
2. a printed circuit board
3. a push button
4. a co-axial pin

On the underside of each push button is a small coaxial pin. This pin provides a method of attaching the push button to the conductive substrate, and also supplies a means of connection between the RFID chip embedded in the button and the common antenna (see Figure 3).

The push button is mounted across the RFID tag’s circuit in such a fashion that when the contact is closed the tag becomes discoverable. One side of the push button’s terminals is connected to the outer core of the coaxial pin, one side to the inner core. The circuit is completed each time the button is pressed, connecting the chip to the antenna through the substrate, thus enabling it to become powered up when in range of the reader. In such a way were the authors able to maintain the small form factor of each control while giving each RFID access to an aerial. The other major issue was one of range. The authors were convinced that a solid, reliable connection over a range of metres rather than centimetres was vital to any practical system and this was why the Bluetooth module was included in the system.
When a push button is pressed, its ID is passed from the RFID reader to the Bluetooth modem which connects to the PC using serial data. The data packets contain 10 digit ASCII strings, with the tag’s unique ID. Software extracts the 10 digit string from the data packet and compares it against a series of conditional statements identifying which button has been pressed. At this early stage in the work only a handful of RFID enabled buttons had been created, making it feasible to hard code an ASCII interrupt for each of the tags IDs. Outputting ASCII interrupts means that the system can be utilised with any software which may be used to create an interface simulation thus maintaining critical flexibility.

Conclusions and Future Work
This paper has presented a work in progress, describing a tool to will potentially enable rapid low fidelity prototyping of information appliances, the IE5. Whilst still being at a very early stage in its development, the IE5 has already demonstrated strong potential for enabling industrial designers to rapidly create low fidelity interactive prototypes whilst addressing areas of weakness within existing prototyping methodologies.

As well as maintaining key benefits of previous IE System iterations, the IE5 offers some new benefits of its own. The system offers the ability to incorporate interactive elements into a sketch foam model rapidly, giving a high degree of flexibility to modifying the interactive prototype. The authors argue that the flexibility of producing prototypes using the IE5 strongly supports the iterative nature of prototyping within the design process, as it allows the interactive elements of the design to be modified rapidly. Using the IE5 to create an interactive prototype does not require any electronics knowledge and eliminates the need for soldering and connecting components together and this brings with it the possibility of prototyping at low fidelity within the critical 1 – 2 hour range.

The early prototype results have been encouraging, but more work is needed. In addition to being able to prototype the physical aspects of an interactive product within 1-2 hours, a method of prototyping the software aspects of interactive product needs to be developed that is equally intuitive for industrial designers. Nam (Nam, 2006) speaks of the difficulty in finding a common sketching tool that industrial designers are familiar with when faced with the challenge of prototyping the software aspects of an interactive product. This is due to the skills needed to prototype the software aspects of an interactive product are similar to those of computer programming, a skill most industrial designers are not familiar with. The experimental work by Culverhouse et al. (Culverhouse, 2008) mentioned above explored using DENIM (Newman et al., 2003) for sketching early interactive interfaces. Unfortunately, despite early promise, reliability and response issues were encountered as soon as the design grew to any appreciable size and complexity. Whilst this in itself presents a problem, the concept of sketching interface prototypes by sketch based software shows potential for providing an appropriate fit within common practices of industrial designers. However Gill et al [3] suggested that rather than designing bespoke software, plug-ins for popular programmes might be a better route. Multimedia authoring software such as Adobe Flash and Director are commonly used by designers to create software concepts. Unfortunately, interactive concepts are sometimes difficult to implement with the storyboards and timeline metaphors used by these software packages. It could be that a sketch based state transition metaphor plugin could exploit and supplement some of the powerful features these stable, well known commercial packages provide. Whatever route is taken the software component of the system needs a lot of development to give it greater flexibility for adding new input devices. Development is needed to make it possible to change the ASCII value associated with a tag’s ID, improving the flexibility of the keyboard interrupts that control the interface simulation.

It is also critical that the system is capable of prototyping a much wider variety of inputs than simple push buttons. Later work will explore the potential for supporting rapid low fidelity prototyping of both digital and analogue inputs such as dials, sliders, touch sensitive buttons etc. The system will also need development to support the ability to prototype emerging technologies encompassing new methods of interaction.

Other hardware issues include development of the wearable reader to improve reliability of connection between the antenna in the wearable glove and the common antenna in the prototype and development of the conductive substrate which connects the individual RFID embedded buttons to the common antenna. Although the substrate
currently being used proves the systems feasibility, it needs a lot of development to make it thinner, potentially giving it the ability to wrap around a sketch model prototype, as opposed to the current method being used of embedding the substrate in a recess within the sketch model. In summary then, the system shows great promise but is still a work in progress.

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Construct, Deconstruct and Reconstruct: Exploring interactive sketching of information appliances

Ian Culverhouse *, Steve Gill **, Alex Woolley *** and Gareth Loudon ****

1. Introduction

This paper examines the potential of combining VoodooIO, a “Softwired Flexible User Interface” (Villar and Gellersen, 2007), with interface prototype authoring software vehicles including DENIM, an informal web site design tool (Lin et al., 2003), as a means of creating early interactive prototypes of information appliances. While there has been much work on the development of design methodologies for information appliances, including Phidgets (Greenberg and Fitchett, 2001), Switchoos (Avrahami and Hudson, 2002) and Paper Prototyping (Snyder, 2003) and while projects such as d.Tools (Hartmann et al., 2006) have approached the hardware and software elements in tandem, there are none that allow the speed and flexibility designers really need. Gill et al. (Gill, 2008b) found that for a prototyping system to achieve successful adoption by industry it must provide a good fit into the designer’s process and allow low fidelity prototyping in between 1 and 2 hours. Further, they found that users should require no electronics knowledge, no knowledge of...
programming and that the system should be very easy to learn. Through the case study below this paper suggests some possible routes towards this goal. The work took place during a 3 month industrial placement by the lead author at The National Centre for Product Design & Development Research (PDR). The brief was to develop a conceptual digital camera into a final design, partially informing the design through the implementation of interactive prototyping methodologies developed within one of PDR’s research groups, the Programme for Advanced Interactive Prototyping Research (PAIPR).

2. Background

VoodooIO (Villar and Gellersen, 2007) was developed by Lancaster University, based on their Pin & Play ad hoc networking technology. Developed as a flexible physical user interface, VoodooIO allows users to re-position user interface controls by pushing them into a networking substrate. Each control has a unique ID allowing the user to assign an input value via the VoodooIO software interface.

DENIM (Lin et al., 2003) is a software development tool for sketching website outlines quickly and intuitively. DENIM uses a state transition diagram metaphor to construct interface prototypes that can be interacted with as if inside a web browser. The potential of DENIM in the information appliance development field was identified by PAIPR, and in 2004 they had an open source version of DENIM customised to allow state transitions to be triggered via the keyboard. This made DENIM compatible with the IE System (Gill, 2003a) - an information appliance prototyping system based on translating a prototype model’s control inputs into computer keyboard inputs. VoodooIO was also supplemented with code to allow it to interact with the modified version of DENIM9, and although the system had been tried via a proof of concept demonstration and showed promise, it had not been trialled in a real design project. The lead author elected to use these techniques on the project described below.

3. Method

A design project undertaken during an industrial design placement by the lead author afforded an opportunity to trial the technique in a real design project. Early state transition diagrams of the user interface were created using DENIM (See Figure 1a). The resulting interactive software prototype was used in conjunction with VoodooIO to create a software interface triggered by a tangible interactive prototype (See Figure 1b). The interaction between the two was facilitated by a programme written by Nicolas Villar, who developed VoodooIO. This programme allows VoodooIO to be easily programmed to output ASCII codes which in turn allow its controls to trigger the modified version of DENIM. The potential for this system was clear; it allowed for very fast prototyping and was a good fit for designers’ traditional sketch development-based techniques. Unfortunately, DENIM quickly became increasingly unstable as the interface grew. The principle of its potential however had been demonstrated, but as a practical design tool the DENIM - VoodooIO combination was not yet

9 (see http://uk.youtube.com/watch?v=Yl0oYl8S-bU)
ready for use. Unfortunately this lead to the need to use traditional methods of creating state transition diagrams by using post-it notes to complete the early iterations of the user interface.

![DENIM interface design](image1.png)  ![VoodooIO](image2.png)  ![Flash & VoodooIO](image3.png)

**Figure 1a.** – DENIM interface design  **Figure 1b.** – DENIM – VoodooIO  **Figure 1c.** – Flash & VoodooIO

The stability issues with DENIM meant that a replacement software platform was needed to work with VoodooIO. Adobe Flash 8 was chosen for a number of reasons including its capabilities, familiarity to PAIPR, and more importantly, its high level of use by designers within industry. The very fast sketch methodology linked to a state transition metaphor was unfortunately now lost. However Flash combined with VoodooIO would still help to explore the concept of interactive sketch prototyping at an early stage in the design process albeit that some programming was now required to allow the interface to respond to specific keyboard interrupts. At this stage in the design process a low fidelity level was used to ensure the focus of development remained on the intended issues of navigation and interaction (See Figure 1c). The decision was heavily influenced by informal understanding within the group of the relative importance of physicality and fidelity, since proven in empirical trials (Gill et al., 2008b).

4. Discussion

A successful design process was facilitated by both VoodooIO - DENIM and VoodooIO - Flash hybrids. It was clear that a toolkit with the very fast and fluid sketched state transition elements of DENIM, coupled to a system that allows for a similar approach at the physical prototyping end of the process to that offered by VoodooIO, has great potential to fit with designers’ methods and required timescales. DENIM’s sketch based method of interaction eliminated the need for programming. This is an important asset of a tool for use by designers. Such a tool allows designers to be flexible in representing the design. VoodooIO enables the interactive input elements to be quickly added, removed and replaced. It also eliminates the need for electronics knowledge. For all their plus points however, there are also features of both DENIM and VoodooIO that would require significant alteration to make them ideal for information appliance design.

Although it showed great promise, DENIM quickly became unstable as the interface grew beyond the first few states. Additionally, Hartmann _et al._ (Hartmann _et al._, 2006) noted the importance of being able to extend a low fidelity interface towards higher fidelity levels as the design develops. DENIM does not support this ability, whereas Flash does. Flash also has the twin advantages being a design
industry standard and very stable, although it does require some programming knowledge for the application described here.

Although VoodooIO allowed very fast and flexible physical prototyping, it too had limitations in this particular type of application. The first of these was scale. Both Hartmann et al. (Hartmann et al., 2006) and Hudson & Mankoff (Hudson and Mankoff, 2006) emphasised the importance of a small form factor in interactive prototyping systems and also backed by PAIPR’s findings on physicality. The scale of a handheld product critically influences the user’s interaction experience, although this is often overlooked by researchers. VoodooIO was not designed for this type of application and so its controls are oversized. As a result the prototype was around twice the intended size of the concept. As well as ergonomic analysis limitations, this also increased the chance of errors based on user test data because the size of the product influences the way it is held and operated. Another major limitation of VoodooIO in this type of application is that it is essentially a two dimensional product. Fortunately the designs being explored in this case only featured input controls on one face of the product but many information appliances feature controls on multiple surfaces and in some cases do not feature flat surfaces. Attempting to “wrap” the VoodooIO substrate around a small organic form would be problematic. Finally, the authors’ noted that VoodooIO’s limited component library imposed limitations on the designer. A vastly more varied library of controls at a variety of scales would therefore be a minimum requirement of a toolkit for information appliance development.

5. Conclusions & Future Work

The DENIM – VoodooIO hybrid toolkit demonstrated great potential in fitting seamlessly into current prototyping practices of designers, however, neither are currently suited for information appliance design. The Flash – VoodooIO combination offered stability and also allowed progression of fidelity, but also had limitations of its own. Among these was the need for programming knowledge and the timeline metaphor which was not as well suited to this type of work when compared to a state transition metaphor. Future work should examine some of DENIM’s positive attributes and consider a DENIM-like plug in for Flash. Regarding VoodooIO’s potential for this type of application, the speed and ease of configuring controls and replacing elements are major benefits, whilst the scale, range of controls and even greater, the 3D adaptation of the substrate are key challenges. The lessons learned from this work have led to a PhD study undertaken by the lead author which aims to investigate the effectiveness of rapid low fidelity prototyping techniques on the design development of information appliances.

6. References


### MPhil/PhD to PhD TRANSFER REPORT

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Previous Name</td>
<td>Ian</td>
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<td>Family Name</td>
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<tr>
<td>Director of Studies</td>
<td>Dr. Gareth Loudon</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Steve Gill</td>
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<td>Advisor</td>
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#### Declaration by the Supervisors and Independent Assessor

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<td>13 August 2010</td>
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<td>Steve Gill</td>
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<td>Independent Assessor: Alan Lewis</td>
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#### Declaration by the Candidate

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<td>Ian Culverhouse</td>
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#### School Research Degrees Sub-committee

- Considered and supported
- Considered and referred to RDC

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#### Research Degrees Committee

- Approved
- Approved subject to recommended changes
- Rejected

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The programme of research

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