University of Technology, Sydney

A cooperative design approach to the design of interactive devices for small, specialized user groups.

by

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Declaration of Authorship

I, Stefan Lie, declare that this thesis titled, "A cooperative design approach to the design of interactive devices for small, specialised user groups", and the work presented in it is my own. I confirm that:

- This work was done wholly while in candidature for a research degree at this University.
- No part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution.
- When I have consulted the work of others, this is always clearly attributed.
- Where I have quoted from the work of others the source is always given. With the exception of such quotations, this thesis is entirely my own work.
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Abstract

This research considers a cooperative design approach to the design, development and implementation of interactive devices catering to small, specialised user groups. Conventional methods of mass production used in the manufacture of interactive devices demand medium to large volume production runs of 10,000 to 100,000 + units for products to remain cost effective. This drives the need for products to appeal to large user groups, which means product implementation catering to small user groups is limited. However there is a need for interactive devices catering to small user groups in industries that require specialised devices to do specific tasks. Such industries include mining, health care and aged care to name a few. Recent advancements in Additive Manufacturing technology combined with the availability of Open Source Hardware + Software offer the possibility to develop and implement interactive devices for low-volume production starting as low as one unit produced. Conventional User Centred Design approaches used in Industrial Design are tailored towards high-volume production, however for small-volume production a cooperative design (co-design) approach may be more relevant.

To investigate this a study was conducted by devising a co-design approach and applying it to the design, development and implementation of an Operator Control Unit (OCU). This OCU was designed to control a semi-autonomous robotic Grit-blasting Assistive Device (GAD) that was deployed on the Sydney Harbour Bridge (SHB). The purpose of the SHB GAD is to remove old paint and rust from the Harbour Bridge steel structure by blasting it with grit. The development of the SHB GAD, including its OCU, is a joint project between Roads and Maritime Services (RMS[1]) and the University of Technology Sydney's Centre for Autonomous Systems. The project was chosen for the study because the SHB GAD is a tool developed specifically for the Sydney Harbour Bridge and is to be used by a small user group of ten users. The study was conducted by designing and developing the OCU cooperatively with five users, who are employees of RMS.

[1] In November 2011 the RTA (Roads and Traffic Authority) of New South Wales, Australia, was renamed RMS (Roads and Maritime Services).

Upon implementation of the OCU resulting from the study, a review of the co-design approach was conducted, by interviewing the five users and asking them to reflect on the process. The results revealed that this research is able to make contributions that will assist in furthering knowledge in this area. Furthermore the results led to a set of conclusions, of which one is that a co-design approach adds value to a project at a personal, team and company level. The resulting OCU was also compared to two commercially available OCUs. This comparison demonstrated, that the resulting OCU could be identified as a robotic OCU even though the users involved in the co-design approach had no previous design or robotics experience. The contributions and conclusions may provide new ways of structuring Industrial Design and Human Robot Interaction approaches to the design of interactive devices for small, specialised user groups.

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Contents

List of Figures

Abbreviations

ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Design
Co-design	Cooperative Design
EOD	Explosive Ordnance Disposal
E-Stop	Emergency Stop (button)
GAD	Grit-blasting Assistive Device
HCI	Human Computer Interaction
HRI	Human Robot Interaction
IDE	Integrated Development Environment
IP Code	Ingress Protection rating Code
OCU	Operator Control Unit
PDA	Personal Digital Assistant
PPE	Personal Protection Equipment
RMS	Roads + Maritime Services
RTA	Road Traffic Authority
SHB	Sydney Harbour Bridge
SLS	Selective Laser Sintering
SWAT	Special Weapons And Tactics
UCD	User Centred Design
USAR	Urban Search And Rescue
UTS	University of Technology Sydney
3D	3 Dimensional

Glossary of Terms

Pot-master	Person controlling the supply of grit and compressed air to blast guns (the grit is supplied via large pots, hence the name).
Resistive	Resistive touch screen, reads input signals if pressure is applied.
Capacitive	Capacitive touch screen, reads input signals if an electric conductor such as bare human skin touches the screens surface.
Real-life	Life as it is lived in reality, involving unwelcome as well as welcome experiences, as distinct from a fictional world. In the context of this research the setting of the study is in real-life in that it is a real project and not an academically controlled study.
Dead Man Switch	A safety device that it used by grit-blasting Professionals to safeguard themselves against accidentally being hit by the blast stream of their blast gun.

Technologies utilized to conduct this research

Concepts Unlimited	CAD software used to create virtual 3D models of the OCU housing.
FDM	Fused Deposition Modelling was the Additive manufacturing technology used to manufacture OCU housing prototypes 1 and 2.
SLS	Selective Laser Sintering was the Additive Manufacturing technology used to manufacture the real OCU housing.
Qt Creator	Open Source IDE (Integrated Development Environment) software used to design and code the OCU GUI.
Nvivo 10	Qualitative data analysis software used to analyse interview data.
EndNote X3	Bibliography software used to manage the bibliography, citations and references.

Chapter 1. Introduction

Interactive devices are digitally enabled devices that are used by people for work and or entertainment. They are products that people interact with while using them and are generally portable such as a Global Positioning System used for navigation or an mp3 player (i.e. Apple iPod) for playing music. Interactive devices are ubiquitous to modern society and living without them is difficult to imagine.

To create an interactive device three main elements are necessary: (1) need, (2) design process and (3) manufacture. First the decision to create an interactive device must be made based on a need (1) after which it has to be designed (2) and then manufactured (3). These three elements are interdependent and using current methods of manufacturing are reliant on medium to high-volume production. In terms of volume this means a medium-volume production run is considered to be approximately 10,000 to 50,000 units produced and a large one 50,000 to 100,000 + units (Thompson 2007). Therefore products such as interactive devices are designed to appeal to a broad range of people and are designed with high-volume production in mind.

The cost of manufacturing the tools used for mass production, such as an injection moulding tool, is high and is almost the same regardless of the size of the production run (Thompson 2007). Therefore manufacturers of interactive devices want to produce (and sell) as many units as possible because this reduces the cost of the tooling per unit produced. Furthermore the cost of the materials and components that products are manufactured from should be as low as possible, again to keep the cost per unit down. Since it is more cost effective to purchase material in large quantities, producers of goods like to aim for medium to high-volume production. Add to this the costs of marketing and distribution it can be understood that the more products are produced the lower the cost per unit becomes, which leads to a higher financial return on the investment.

Consequently the need for a product to be brought into existence is driven by how many units can be sold and due to current methods of mass production the more that can be manufactured the better. For an interactive device to be produced in high volumes it must appeal to a broad range of people or users. Industrial designers therefore are required to design their products so they appeal, within reason, to as many users as possible. Thus the decision to put a product into production is more often than not driven by how many units are likely to be sold to the target user group. This is the case for the majority of products ranging from products such as a simple bottle opener to complex interactive devices such as a Global Positioning System. The requirement for a product to appeal to a broad range of users to make its mass production viable unfortunately means that many product solutions with good potential are considered unviable for production because the perceived target user group is not deemed broad enough and the production volume therefore too low to warrant production. The need cannot be justified. Examples of such unviable products are tools for specialized professions that require a degree of customisation or tools for professionals working in site-specific locations where the site may dictate specific requirements. In these cases user groups may be as small as ten users or even less. If it were possible to manufacture interactive devices in ways that do not rely on mass production then the need for products previously deemed unviable could be justified. For a more detailed definition of Small, specialized user groups please go to section 2.2.

Physically an interactive device can be separated into two main elements: the first being the external housing and the second being the internal electronic components. As stated earlier both of these elements have depended on large volume production to make interactive devices viable for production. However in recent years advances in Additive Manufacturing technologies such as Selective Laser Sintering (SLS) [to manufacture the outer housing] and the rise in popularity and availability of Open Source Hardware + Software in the form of microprocessors and sensors [for internal electronic components] are creating new possibilities to manufacture interactive devices without using mass production. Additive Manufacturing is well suited to manufacture parts in volumes as low as 1 unit, from materials such as plastics and metals and due to the steady decline of the costs associated with Additive Manufacturing technologies this is now feasible (Markillie 2012). More information on Additive Manufacturing can be found under section 2.3.

To build the internal components of an interactive device microprocessors, switches and in some cases sensors are incorporated depending on what the device is designed to do. And once the hardware has been assembled it needs to be programmed to execute its electronic functions. Until recently, designing, building and programming a microprocessor was a complex undertaking that had to be done with the assistance of specialised technicians. However in recent years, this type of technology has become more accessible to people who have no formal training in electronics. "Do It Yourself" Open Source Hardware microprocessor products such as Arduino[2] boards and websites such as Sparkfun[3] and Adafruit[4] that sell everything necessary to build electronic products combined with more accessible programming through Open Source Software, are creating new opportunities that allow interactive devices to be created without the need of large scale product development teams (Anderson 2011). More information on the subject of Open Source Hardware + Software can be found under section 2.3.

Thus by combining Additive Manufacturing [to manufacture the external housing] and Open Source Hardware + Software components [for internal electronic components] it is possible to manufacture interactive devices in very low numbers.

Prior to being manufactured a product needs to be designed. The conventional Industrial Design approach is generally referred to as User Centred Design (UCD) (Sanders & Stappers 2008). With UCD the designer assumes the role of a researcher who collects data about the potential users of a product by interviewing and or observing them. The collected data is then translated into a set of requirements that are used as guidelines to design the product. So the user is central to the process and is well considered but not directly involved in the design process. UCD has been successfully used by industrial designers for many decades and works well for products that are designed to appeal to large user groups.

However if the need to manufacture an interactive device for a small, specialized user group could be justified through utilizing Additive Manufacturing and Open Source Hardware + Software, UCD may not be the appropriate approach.

If a user group were between 1 and 10 users it would be feasible to work directly with most members of the user group and get them to actively participate in the design process. This method, known as cooperative design (co-design), invites all stakeholders, in particular end users, of a product to participate in the design process. Through taking a co-design approach mistakes made based on assumptions of the design team can be avoided and it enables all stakeholders involved to claim ownership over the project. A co-design approach is also likely to be more time efficient if the process is managed well and participants are

[2] www.arduino.cc
[3] www.sparkfun.com
[4] www.adafruit.com

accessible and eager to contribute. Section 2.1.3 provides more insight into User Centered Design and co-design approaches.

In Summary, to make an interactive device viable for production traditional methods of manufacturing demand medium to high-volume production. This in turn drives the need for interactive devices to appeal to a broad range of users and leads to User Centered Design as the most appropriate approach. This makes it challenging to justify designing and manufacturing interactive devices for small, specialized users groups.
However by utilizing Additive Manufacturing as the manufacturing method, making use of Open Source Hardware + Software and taking a co-design approach, designing interactive devices for small, specialized user groups may be viable.

1.1 Statement of the problem

Different product design areas demand different approaches to design processes. For instance a User Centered Design (UCD) approach is useful when designing an interactive device in an area that needs to appeal to a large user group (see section 2.1.3). However the focus of this research lies in the area of small, specialized user groups which presents the main research problem of what an appropriate design approach would be when designing an interactive device for such a user group. The researcher believes that, due to the user groups being small in size and specialized in their work, designing the device with them by taking a co-design approach is sensible. In this case all actual end users would design the device together using their professional knowhow and would likely end up with a solution most appropriate for them. To investigate this the following three areas were examined:

1. Design approaches

   Current approaches in relation to the design of interactive devices in the fields of Interaction Design, Human Robotics Interaction and Industrial Design (section 1.1.1).

2. Interactive devices for small, specialized user groups

   A definition and detailed explanation of what is meant by small, specialized user groups (section 1.1.2).

3. Additive Manufacturing and Open Source Hardware + Software

   An investigation into how Additive Manufacturing technologies and Open Source Hardware + Software will facilitate the manufacture of interactive devices in low volumes (section 1.1.3).

1.1.1 Design approaches

To understand why the suggestion of using a co-design approach in the context of this research is unusual and therefore warrants investigating it is helpful to explain what the most common approach Industrial Designers use today and why.

User Centered Design approach

The design of any interactive device requires that the person conducting the work employ a design process. Regardless of the approach taken (either UCD or co-design) the design process doesn't change. The design process can be described as the path that is followed by the designer in order to complete a design project. The design process can be broken down into four stages:

1. Research
2. Concept development
3. Design detailing
4. Implementation

In Industrial Design practice currently the most common design approach is User Centered Design (UCD) and it has been in use for over six decades (Sanders & Stappers 2008). During UCD the user is viewed as a *subject* and the designer controls all four stages of the design process. To begin with the designer takes on the role of researcher/investigator and conducts research (Stage 1) into the end user of the product that is being designed. This research may be conducted by interviewing several end users or through observation of end users performing tasks that relate to the product that is being designed. The designer then would use this research data to construct a framework within which to develop one or more design concepts (Stage 2) of the product in question. The type of user data required varies depending on the type of product that is being designed but it could include anthropometric data and research into behavioral patterns both in relation to the end user of the product. The central aspect of UCD is that end users are considered research subjects that provide data. The design work is then done by the designer without end users. Once the design concept has reached a stage in its development at which it needs to be evaluated the designer may conduct user trials with potential end users to obtain feedback on the product. This feedback would then be used by the designer to make adjustments to the design concept, after which more user trials would be conducted. This process of sample based user trialing would then cycle through several iterations, until no more adjustments need to be made and or a lack of funds forces the project to move on. The designer would then proceed to detailing the final design (Stage 3), which typically involves optimizing it for manufacturing. Once the design detailing is completed the design would be considered ready for implementation/production (Stage 4). UCD is particularly useful when designing products destined for high-volume production, products that will be used by thousands of users. Because such products need to appeal to many users the designer designing the product needs data that covers a large spectrum of users. For example a product such as the remote control of a television is likely to be used by various types of users, ranging from people with good eyesight to people that may not be able to see very well at close range and need reading glasses. Therefore the designer may decide to ensure that as many people in the user group as possible will be able to read the type on the buttons of the remote without needing their glasses. In other words when designing a product that must appeal to many end users designers need broad-spectrum user data.

Cooperative Design

When designing a product for a very small user group with as little as one or two end users UCD would work but may not be most appropriate. In this case the designer is likely to have access to all actual end users and this presents the opportunity to design the product with them. The design approach that is taken when designing together with end users is referred to as participatory design or co-design. The two terms, "participatory design" and "co-design", are equally valid, so to avoid confusion it will henceforth be referred to as co-design. During a co-design approach the user is viewed as a *partner* rather than a subject. Co-design has been in use for over three decades in areas such as local community project development (King et al. 1989) but particularly in Human Computer Interaction for the development of computer application systems (Bodker 1996). However co-design has not yet gained broad appeal in Industrial Design practice or in the field of Human Robot Interaction. During a co-design approach the role of the designer changes compared to that in UCD. The most notable change is that designers no longer make major design decisions themselves but rather rely on direct input from end users. In terms of the design process the stages remain the same:

1. Research
2. Concept development
3. Design detailing
4. Implementation

Elizabeth Sanders and Pieter Stappers use the term co-design to *"… refer to the creativity of designers and people not trained in design working together in the design development process"* (Sanders & Stappers 2008). This development process happens at the beginning of the design process during research (Stage 1) and particularly during concept development (Stage 2). During Stage 2 the designer no longer makes high-level design decisions but rather will rely on the expertise of end users. This means that the designer needs to take on the role of a mediator while designing cooperatively with end users (Manzini & Rizzo 2011). The evaluation of models and prototypes would again involve working cooperatively with end users, however the design detailing (Stage 3) and implementation (Stage 4) is done entirely by the designer and manufacturer.

Applying a Co-Design approach to a project

To investigate the application of a co-design approach to a project that involved designing an interactive device for a small, specialized user group a real-life project that fulfilled all necessary requirements was selected as the study. A detailed account of how the study was conducted can be found under section 3.3. This real-life project was the design, development and implementation of the Operator Control Unit (OCU) for a Grit-blasting Assistive Device (GAD), which is a semi autonomous robotic system designed to grit-blast old paint and rust of the Sydney Harbour Bridge (SHB). More background information of the SHB GAD project can be found under section 1.2. The SHB GAD OCU was selected for the study because it was an interactive device to be used by a small group of approximately ten end users in a site-specific work environment, namely the Sydney Harbour Bridge.

1.1.2 Interactive devices for small, specialized user groups

In the context of this research small, specialized user groups are defined by their size and their needs. In terms of their size a user group could consist of 1 to 20 users. The users needs could be professional where a group of users perform specialized tasks that are unique due to the specific nature of the site that they are working in, such as the Harbour Bridge. The users needs could also be personal such as their anthropometric requirements or the nature of the type of tasks they need to perform. An example of this is long term stroke victim rehabilitation where small groups of victims with similar rehabilitation needs could have an interactive rehabilitation device designed specifically for them. Indeed a recent real-life study titled “Interactivating Rehabilitation through Active Multimodal Feedback and Guidance” by Associate Professor Bert Bongers and Stuart Smith investigated the development of spinal cord rehabilitation tools for very specific patient needs (Bongers & Smith 2011). Amongst many interesting findings the resulting outcome of this study was a fully functional interactive device to be used by a small group of users in the spinal cord rehabilitation unit of the Prince of Wales hospital in Sydney, New South Wales, Australia.

It was discussed earlier that economies of scale of mass production dictate if an interactive device goes into production or not. Anything less than a production run of 10,000 units is rarely considered, the more end users are likely to purchase the product the better. Therefore if a user group had 20 users or less it is unlikely anyone would be interested in investing in tooling for a production run because manufacturing tools used to mass-produce products is expensive.

However there are small user groups that perform regular specialized tasks and have a need for a product or tool that would help them perform these tasks if it were available (Bongers in Stiles 2010, p. 47). The design and manufacture of products and tools for small, specialized user groups and individuals is not new. Tools such as surgical instruments used by surgeons and musical instruments for professional musicians have been tailor made to the specific needs of their users by specialized crafts people for over a century. “The Glove” designed and made by Bert Bongers (2007) is an example of such an instrument. Although it is important to note that these examples are more of a bespoke nature, where a product is made specifically for one user only.

Also along the same lines but at a more consumer product level, are mass produced products that users are able to customize themselves to a degree. In these cases there is generally a brand that offers a customization service via a website. An example of such a service can be found on the web page of NIKEiD[5], which allows users to "design" their own Nike shoe. Again these types of services are not new as Oya Demirbilek wrote in 2001:

> *Enabling end-users to design their own products is still in its infancy stage, and will most probably develop very rapidly in the coming years. Examples of such attempts can actually be found in some web pages where end-users can create online, their "own" shoes, for example, using a palette of different basic shoe types, different colors, textures and materials. The development of these web pages is closely related to marketing strategies and as a result of it end-users can purchase their own designs, once they have finished it. Some companies even provide a way to personalize the artifact by giving the user the option to write his/her name, or a personal identification onto it* (2001).

Demirbilek (2001) made this statement over ten years ago and was correct in her assumption that "*Enabling end-users to design their own products … will most probably develop very rapidly in the coming years"*. NIKEiD for instance was launched in 1999 and is still going, which may prove that users enjoy "designing" their own shoes.

Another example is the purchase of a new car. Most car manufacturers offer their customers the option to choose the colour of the paint, the type and colour of fabric or leather used to upholster the seats plus a multitude of optional extras. Both of those examples fall into the category of mass-customization, where a mass-produced product such as a running shoe or car can be customized to a degree. It needs to be made explicitly clear at this point that this research is not about designing for mass-customization. This research is about designing devices for users with specialized needs and due to these needs being special the user groups are very small in numbers.

Both the example of the shoe and that of the car only allow choice of surface finishes. In other words the surface of the shoe/car can be changed but not it's 3D shape. Additive Manufacturing is now changing this through businesses that provide services such as Digital Forming[6]. The mission statement on the Digital Forming website states:

> *"Our team has developed an online customization interface and platform (comprised of software and a supply chain), which can be licensed to brands allowing them to 'open' up their product ranges to customization in a way that*

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[5] www.store.nike.com/us/en_us/?l=shop,nikeid

[6] www.digitalforming.com

> *has never been done before. The idea builds upon customization interfaces currently seen in the market place, but is more revolutionary as it allows for a far greater means of customization – in full 3D experience."*[7]

So Digital Forming licenses their software to brands (manufacturers) of products. This software allows customers (end users) of the brands to change the 3D shape of the product they want to purchase. End users do this via websites and once they are satisfied with the product they can have it manufactured using Additive Manufacturing. Therefore this is a service that is similar to that offered by NIKEiD but in 3D. Lisa Harouni, a co-founder of Digital Forming, states that:

> *"It is actually a reality today, that you can download [3D] products from the web, [3D] product data I should say, from the web, perhaps tweak it and personalize it to your own preference to your own taste and have that information sent to a desk top machine that will fabricate it for you on the spot. We can actually build for you very rapidly a [3D] physical object. And the reason we can do this is through an emerging technology called additive manufacturing or 3D printing."* (2011)

To put the above in context: By using Additive Manufacturing (and Open Source Hardware + Software, see following section) as the enabling manufacturing technology it will be possible to manufacture products with complex 3D shapes in very low numbers. This in turn will allow designers, as this research will demonstrate, to consider designing products and devices for small users groups with special needs.

1.1.3 Additive Manufacturing and Open Source Hardware + Software

An interactive device cannot exist without the parts that embody its form and function. A few years ago it would have been difficult to consider designing an interactive device for a user group as small as 20 users because the external and internal parts could not have been manufactured in such low numbers. However two types of technologies now may make it possible to design, develop and implement interactive devices in numbers as low as one unit. The first is Additive Manufacturing to manufacture the housing and the second can be broadly described as Open Source Hardware + Software components such microprocessors, sensors, switches and software used to build the internal hardware. Until recently both of these technologies were predominantly used to build prototypes rather than fully functioning products.

[7] www.digitalforming.com/our-mission.html

Additive Manufacturing

Additive Manufacturing technologies have been in use for approximately 30 years but due to the high cost of both machines and produced parts have until recently predominantly been used for rapid prototyping only. Additive Manufacturing works by first creating a virtual 3D model of a part on a computer using Computer Aided Design (CAD) software. This virtual 3D model is then automatically sliced horizontally into layers of around 0.01mm thickness (layer thickness varies from machine to machine and materials used). These virtual layers are then sent to an Additive Manufacturing machine that deposits the material in the form of these layers starting from the bottom and working to the topmost layer. The material used can be a polymer such as nylon or a metal such as stainless steel. Two important aspects need to be noted: The first is that manufacturing a part in this way does not require a dedicated tool such as an injection mould to be made. The second aspect is that the part does not need to be designed with a dedicated tool in mind so undercuts and variation in wall thicknesses do not matter. Harouni (2011) takes even this a step further: *"[With 3D printing,] we can actually create structures that are more intricate than any other manufacturing technology — or, in fact, are impossible to build in any other way"*. The cost to produce parts through Additive Manufacturing is steadily decreasing and the part quality increasing to a point where for example Selective Laser Sintering is being utilised for actual part production rather than just prototyping.

Open Source Hardware + Software

Open Source Hardware + Software components are another type of technology that in recent years has transitioned from being used predominantly for prototyping to being utilised as actual electronic components to build products for everyday use as the following project demonstrates:

In 2010 an Australian based company called Breseight approached the Industrial Design program at UTS and offered their Additive Manufacturing technology in exchange for product concepts that would utilise Selective Laser Sintering machines for actual part production rather than just part prototyping. The Industrial Design program were willing to collaborate with Breseight and invited seven designers, of which this researcher was one, to participate and design products to be manufactured by Breseight. The resulting project was presented as an exhibition titled "Digifacture" (Stiles 2010). One set of products [designed for "Digifacture"] titled "Individual Interfaces" (Stiles 2010, pp. 45-52) designed by Associate Professor Bert Bongers and team became the impetus for this research. Bongers and his team designed three different products that function as interfaces designed to control domestic music players. By combining Additive Manufacturing [to make the external housing] with Open Source Hardware + Software microprocessor components and sensors [for internal components] Bongers and team produced three interactive devices of which one was fully functional. Bongers states that:

> *Almost all the electronic and digital technology around us is mass-produced, due to the complexity of manufacturing digital systems combined with the ease of replication. This is in contrast to older technologies, which are often custom made, in some cases highly individual (musical instruments, jewellery, clothes, cars). Recent developments in rapid manufacturing techniques and new insights in design practices can lead to a new trend of 'mass-customization'. The part of the electronic system that has the most need for customization is the interface, through which users can control and interact with the electronic systems. Computer systems over the past decade have shown many different ways of customizing the interfaces, mainly in the software. With rapid manufacturing techniques it becomes possible to create custom interfaces for physical interaction.* (in Stiles 2010, p. 47)

For detailed explanations of both Additive Manufacturing and Open Source Hardware + Software components please refer to section 2.3.

1.2 Background on the project and the researcher

UTS Center for Autonomous Systems

The Centre for Autonomous Systems (CAS) is a research centre that is part of the Faculty of Engineering & Information Technology (FEIT) at UTS. CAS conducts research into the creation of autonomous systems capable of interacting with the complexities of the real world. The centre consists of 40 staff and students working on various aspects of sensing, data fusion and control in relation to robotics. This researcher conducted the research presented here while he was a student with CAS. In recent years the CAS team made several major theoretical breakthroughs of which one was sensing and perception in unknown environments and applications of autonomous robots in infrastructure maintenance (Liu et al. 2008). Such infrastructures include bridges, which led to the development of enabling methodologies and system development of a Grit-blasting Assistive Device (GAD) for assisting bridge maintenance workers. The feasibility of this device, the developed methodologies and a proof of concept device were tested in the Sydney Harbour Bridge maintenance site from March to May 2010 (Paul et al. 2010). This test was so successful and impressed RMS

(Roads & Maritime Services) sufficiently for them to agree to enter into a partnership with UTS and commissioning them to build two Grit-blasting Assistive Devices (GAD) for deployment on the Sydney Harbour Bridge (SHB). The project that resulted from this partnership is a real-life project that was named SHB GAD.

The Sydney Harbour Bridge Grit-blasting Assistive Device

The SHB GAD project is about introducing automated technology to a manual labor work environment. The predominant reason for initiating the project was to reduce health risks to RMS workers. Bridges are essential in transport infrastructure worldwide. There are over 30,000 road and rail bridges across Australia. Bridge maintenance or replacement is one of the biggest expenditure items in traffic infrastructure development and maintenance. Corrosion is the primary cause of failure in steel bridges (Hare 1987), and is minimised by painting the steel structure. Periodical inspection and maintenance of these bridges is an expensive undertaking due to the associated environmental and employee health and safety issues.

Steel bridge coating maintenance consists of two procedures: rust/paint stripping and repainting. The most effective and efficient method of large scale paint stripping is grit-blasting, and herein lies the critical problem. Grit-blasting is extremely labour intensive and hazardous (RSA 2000), and is the most expensive operation needed during steel bridge maintenance. Workers have to not only spend long periods of time handling forces of 100 Newtons and above (Joode et al. 2004) but also need to take precautions to avoid exposure to the dust containing hazardous chemicals. In the case of the Sydney Harbour Bridge the hazardous chemicals include red lead and asbestos. In an article published in the Sydney Morning Herald in October 2010 titled "Bridge workers fear cancer cluster" Paul Bibby wrote:

> *"A cluster of cancer cases has been discovered among Sydney Harbour Bridge maintenance workers, a union says." – "The workers include riggers, painters, carpenters and crane operators who continually maintain the structure, which is the world's widest long-span bridge." – "It is feared lead paint may be the cause of the cancers."* (2010)

Furthermore, as the long-term health damage due to exposure to dust and fine particles is now obvious, the parts of the bridge being maintained need to be fully enclosed to avoid contamination of the environment and potential health risk to the general public. Thus supplementing manual labour in grit-blasting with assistive devices will have a significant health, safety and economic impact. Such devices will be able to reduce human exposure to hazardous and dangerous dust containing rust and paint particles, relieve human workers from extremely labour intensive tasks such as grit-blasting, and reduce costs associated with infrastructure maintenance.

The SHB GAD system has two main components. The first is the Grit-blasting component, which consists of the robotic manipulator that holds the blast nozzle and scanner and is mounted on a frame that sits on rails. The second is the Operator Control Unit (OCU), which as its name suggests, is the Unit that allows the Operator to control the Grit-blasting component.

The SHB GAD is used as follows:

1. The Grit-blasting component is set up in front of a section of the harbour bridge that requires grit-blasting (see Figure 1.1 below).
2. Via the OCU the Operator issues the "Scan" command, which will prompt the Grit-blasting element to 3 dimensionally scan the bridge section. It then uses the scan data to calculate a blast path.
3. Again via the OCU the Operator then issues the "Blast" command and the Grit-blasting component will commence blasting.
4. Once blasting of that section is completed the Operator can move the Grit-blasting component to a new section and repeat the process.

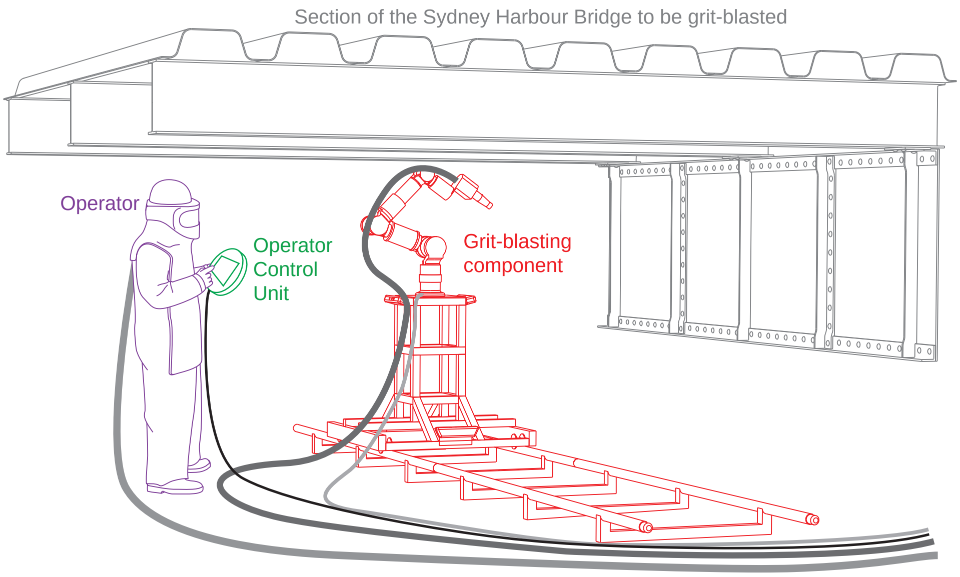

Figure 1.1:
Illustration of the complete SHB GAD system set up on the Sydney Harbour Bridge.

This researcher joined the SHB GAD project team as the interaction designer charged with the task of designing the OCU (Operator Control Unit). This was in September 2010 at which point the project was moving into the prototyping stage. He soon identified that this project was situated in the area of interactive device design for small, specialized user groups and proposed that a co-design approach be the most appropriate and all stakeholders agreed (also see section 2.1.6).

The project as a whole was the first of its kind in the world and technically highly demanding both in terms of software, mechatronic and mechanical engineering. As the prototype of the entire SHB GAD was being developed there was still a high degree of research and development being conducted by UTS engineers (Paul et al. 2011). This made the design and development of the OCU an interesting challenge because new possibilities were constantly being explored and concrete concepts could therefore not be developed until all technological aspects were finalised.

It has to be noted at this point that it is possible to purchase commercially available OCUs (commonly know as teach pendants) and the project team at UTS did consider this. However none of the commercially available ones were deemed suitable because they were either not compatible with the system (in terms of the operating system) or would not have been able to withstand the harsh work environment (see section 2.1.5). It became clear early on in the project that all stakeholders wanted an OCU that was simple to use and very rugged and robust and there was nothing available at the time that fulfilled those requirements.

To appreciate the results of this study it is important to understand that all stakeholders involved, in particular the grit-blasters that participated in the co-design approach (more on the participant selection process under section 3.3), were working under highly constrained real-life conditions. There were safety constraints, which ranged from very stringent RMS work safety regulations for working on the Harbour Bridge to Australian Standards safety regulations (see section 2.4) in relation to working with industrial robots. There were conceptual restraints in that it was challenging for participants to imagine what a machine that didn't yet exist may be capable of doing. And there were technical constraints because the work environment of grit-blasting, which is like working in a toxic sand storm, is extremely hostile to any equipment exposed to it.

The Researcher

The researcher completed his undergraduate degree in Industrial Design at the University of Technology, Sydney (UTS) in 1998 and, since then, has been a practicing industrial designer in the field of design for manufacture. Since graduating he has designed many products for Australian and international clients in areas such furniture, footwear, home wares, office accessories and personal protection equipment. However the foundation for his career in Industrial Design was laid ten years earlier, in 1988, after completing an apprenticeship in Switzerland as toolmaker and specializing in the manufacture of injection mould tooling and sheet metal fabrication. While working as a qualified toolmaker for six years from 1988 to 1993 the researcher became aware of the role that industrial designers play in the manufacture of products, which led him to his undergraduate studies in Industrial Design.

Since graduating in 1998 the researcher has also been working as a part time academic lecturing and tutoring undergraduate and masters by course work students at UTS and at the University of New South Wales (UNSW) in Sydney. Due to the researchers background in manufacturing his teaching expertise lies in the area of manufacturing processes and materials in relation to Industrial Design. Other teaching areas are the supervision of 4th year industrial design Major Project students and Furniture Design.

Three aspects of the researchers professional background are relevant to this research. The first aspect comes from his knowledge in manufacturing for mass production and his experience in Industrial Design. Due to this experience he understands exactly how the mass production of products is linked to production volumes, user group sizes and design approaches. The second aspect, which is also due to his knowledge of manufacturing, is that he is well aware of, and looking forward to, the new possibilities that Additive Manufacturing and Open Source Hardware + Software are certain to offer designers such as himself in the future. And the third and final aspect is linked to the researchers work as a part time academic at UTS. The supervision of 4th year industrial design Major Project students involves guiding the students through their final project as undergraduate students. The relevance of this will be further explained under section 2.2 Small, Specialized User Groups.

Interdisciplinary project work

It is important to note that the framework of this research is interdisciplinary. This is due to the fact that it extends into three different professional areas, all with their own backgrounds and all well established in their own right. The first is Human Computer Interaction (HCI) due to the fact the research is about interactive device design. Anyone designing an interactive device should spend a good amount of time learning about the background and history of HCI (see section 2.1.2) and how it applies to interactive device design. The second area is Industrial Design due to the background of the researcher (see preceding paragraph) and the context within which the device is to be used. The third is Human Robot Interaction (HRI) because the background of the device to be designed is a robotic system (see section 2.1.4). Section 2.1 will provide a more detailed overview of how these three areas connect and form a basis for the study.

1.3 Need

Change in design approaches

In the field of Industrial Design current physical product outcomes are developed using dated design approaches governed by the expectation that the product will be mass-produced for very large markets. This research is attempting to bridge a gap between less traditional methods (in this case co-design) of establishing performance criteria in product designs and physical product outcomes.

As new manufacturing technologies such as Additive Manufacturing move from the fringe to the mainstream they begin to offer designers new opportunities (see section 1.1.2 and 2.3). These new opportunities can have a lasting effect on how designers work and whom they design for. It is therefore useful to investigate how Industrial Design practice could change to accommodate new manufacturing technologies and the design approaches that relate to them.

The impact of new manufacturing technologies

Understanding the possibilities that Additive Manufacturing offers gives rise to the question of how it may change the profession of Industrial Design. The most obvious impact is that the designer no longer is constrained by limitations that traditional means of mass production such as injection moulding bring with them. For example undercuts and draft angles that allow a part to be removed from a mould or die no longer need to be taken into consideration if a part is produced using Additive Manufacturing and much interesting research has already been conducted in this area (Hague et al. 2003); (Campbell et al. 2003).

However the research presented here seeks to investigate how current Industrial Design processes geared towards mass production could change to facilitate designing interactive devices for small, specialised user groups via the use of Additive Manufacturing combined with Open Source Hardware + Software microprocessors and sensors. Paul Markillie is the innovation editor at *The Economist* and compiled a special report on manufacturing and innovation, which was published in the April 2012 edition of *The Economist*. He states that *"As there are barely any economies of scale in additive manufacturing, the technology is ideally suited to low-volume production"* (Markillie 2012). With this statement Markillie is indicating that Additive Manufacturing will open up new avenues for low-volume production in areas where high-volume production is not viable.

1.4 Research questions

Under section 1.1 and 1.1.1 it was explained that this research is focusing on an appropriate design approach in the area of interactive device design for small, specialized user groups. To achieve a successful outcome for any design project it is important that an appropriate design approach is taken and the researcher is of the opinion that a co-design approach may be the most appropriate in this area. This leads to the following problem:

> *Would a co-design approach be appropriate when designing an interactive device for a small, specialized user group?*

To find answers to the problem, two research questions were formulated:

1. How is the co-design approach viewed from the perspective of participants involved in the study?

2. How does the OCU resulting from this study compare with commercially available robotic OCUs?

The research questions were answered by conducting a study in the form of a real-life design project (for a detailed account of the study go to section 3.3).

1.5 Purpose of the Study

Co-design approaches are not common practice in Industrial Design or HRI (Human Robot Interaction) so to get a better understanding of a co-design approach it is useful to conduct a real-life design project with real users. This type of research is referred to as action research, during which a practicing professional conducts a real design project in the real world and publishes the results as research (Pedgley 2007). According to the late Professor Bruce Archer, research through practitioner action, despite its being highly situation-specific, can advance practice and can provide material for the conduct of later, more generalizable, studies, provided the research is methodologically sound, the qualifications are clearly stated and the record is complete (Archer 1995).
In order to evaluate how well a co-design approach would work when designing an interactive device together with a small and professionally specialized group of users a study was conducted in the form of a real-life project. This project was the design, development and implementation of the OCU that allows human operators to control the SHB GAD. Two of the SHB GAD systems were built and therefore only two OCUs were required which constitutes a production number of two units produced. There were to be approximately ten users trained to operate the SHB GAD, which constitutes a small group of users. RMS is in charge of maintaining the Harbour Bridge and the ten end users are professional grit-blasters employed by RMS, forming part of the Harbour Bridge maintenance team. RMS management selected five of the ten grit-blasters to be part of the co-design team. The OCU was then designed cooperatively with those five grit-blasters of which none had any design experience nor had they ever used a robotic system. The co-design approach was conducted as a series of meetings, interviews and a workshop and the OCU was manufactured using Additive Manufacturing and Open Source Hardware + Software components. More detail in relation to the study can be found in Chapter 3.

The outcome of the study was evaluated through analysing data obtained by interviewing participants about their experience and by comparing the physical end result of the OCU to commercially available ones.

Summary of contributions

The contributions are explained in detail under section 5.6.

1. Employer driven participant selection

2. Non-linear interview map
3. User group specific co-design

Summary of conclusions

Full explanations of the conclusions are under section 5.7.

1. A co-design approach may increase participants/users understanding of and support for the project.

2. If participants of a small, specialized user group are involved in a co-design approach they are likely to enjoy the process.

3. The OCU resulting from this study is comparable to commercially available OCUs if viewed in context.

4. To ensure the success of a co-design approach under real-life circumstances it is necessary to build good relationships between all participants and stakeholders.

5. Proof that small, specialized user groups exist and that manufacturing an interactive device using Additive Manufacturing and Open Source Hardware + Software in low volumes is achievable.

1.6 Significance to the field

This study is important both to the Industrial Design profession and to the development of research into design approaches associated with contemporary design practice. The approach described in this study represents a sequence of events that could be generalized to have application in practice and in academic research. Action research is considered as an option for knowledge building (Archer 1995) partly because in the field of Industrial Design it has the potential to mirror the actions of a practitioner, which may more effectively forge links with industry. For the past three decades research in the field of Industrial Design has been dominated by studies that seek to understand what design is and how designers think (Cross 2006). Discoveries in this area, combined with a need for the professional practice of Industrial Design to move beyond product design into areas such as service, systems and interfaces has led to the development of new design approaches. However there are not yet many examples of how these approaches will manifest in Industrial Design practice and this study seeks to address this.

1.7 Limitations

The timeline and scheduling of the study is in correlation to that of the entire SHB GAD project. This means that the pace of the study needs to be instep with that of the SHB GAD project.

1.8 Ethical considerations

An application for ethics approval for this project was lodged with the UTS Human Research Ethics Committee (HREC) on the 20th of October 2010. Approval was granted on the 10th of February 2011 and the clearance number for this research is: UTS HREC REF NO. 2010-422A (Appendix A)

A letter of consent was provided by RMS (formerly RTA[8]) management giving the researcher permission to interview RMS personnel for this research (Appendix B).
All RMS workers that were participants of the co-design approach consented to being part of the project by signing a consent form (Appendix C).

With the exception of UTS staff and students, any person involved with this research is guaranteed 100% anonymity in any material published in relation to this research and particularly the study.

Additionally one needs to appreciate the wider impact the SHB GAD may have on people that will come in contact with it in their line of work. And although the intention of the project is to reduce the workers exposure to harmful substances such as red lead and asbestos while grit-blasting, it is conceivable that the workers will view the SHB GAD as a threat to their livelihood, possibly causing anxiety and stress. It is important to be mindful of this and to try to understand the reasons behind opinions and points of view that people will put forward while discussing this project.

[8] All correspondence regarding ethics approval was conducted prior to the RTA changing its name to RMS in November 2011, therefore all material under Appendix A, B and C is in reference to the RTA.

Chapter 2. Literature Review

To present the literature relevant to this research in a clear manner this literature review is comprised of four sections. The first section (2.1) investigates what interaction design is, the historical context of interaction design and current design approaches in relation to interaction design, Human Computer Interaction and Human Robot Interaction. The second section (2.2) will focus on small, specialized user groups and the third section (2.3) will discuss Additive Manufacturing and Open Source Hardware + Software technologies. The fourth and final section (2.4) reviews the current Australian Standard recommendations in relation to industrial robots.
Please refer to section 1.1 for a detailed outline of the research problem, section 1.2 for background information and section 1.5 for the research questions.

2.1 Interaction Design and Human Robot Interaction

The design of interactive devices falls into the category of interaction design, therefore this section seeks to contextualises interaction design by identifying what interaction design is, how it developed into a design discipline and investigates current design approaches relevant to interaction design. This section also investigates existing research in Human Robot Interaction for the design of OCUs comparable to the one proposed for the SHB GAD.

2.1.1 What is Interaction Design?

According to Bill Moggridge (2007) the term *"interaction design"* was coined by himself and Bill Verplank in 1984. At the time Moggridge was assembling a team of people in the Silicon Valley area to cater for the rapidly growing demand for electronic interface design on computers and software. His team was made up of professionals from different backgrounds such as information, industrial and graphic design and he needed a term to describe what they were doing so he called it interaction design.
To understand the term interaction design it is necessary to consider the meaning behind the words. The Oxford English Dictionary[9] defines interaction as

[9] www.oed.com

reciprocal action in response to a human action. So for a human to be able to interact with a product or service it needs to have a degree of intelligence, for instance in the form of a microprocessor, that enables it to provide reciprocal action.

There are many definitions of design and although the following one by Kim Goodwin is broad, it is clear in its meaning and can be applied to most professions that practice some form of design. Goodwin (2009) states that *design is the craft of visualizing concrete solutions that serve human needs and goals within certain constraints*. Interaction design is encompassed in this definition of design but a more specific definition is needed to allow for a clear understanding of what interaction design is.

Gillian Crampton Smith defines that, *"interaction design is about shaping our everyday life through digital artifacts-for work, for play, and for entertainment"* (2002 in Moggridge 2007). Crampton Smith's definition is apt for two reasons: 1) she refers to interaction design *shaping* our everyday lives which becomes evident if we consider the way that interactive devices such as mobile phones, web browsers or e-readers drive many of the decisions we make while going about our daily activities; 2) this shaping process is happening through the use of digital artifacts or in other words a product or service enabled by a microprocessor/computer.

2.1.2 A brief history of Interaction Design

David Kelly sums up how interaction design got started:

> *"Interaction design started from two separate directions, with screen graphics for displays and separate input devices, but it got more interesting when the hardware and software came together in products"* (2004 in Moggridge 2007).

The beginning of interaction design can be traced back to the 1960s when the first computers were being developed for desktop use. At the time the main input device was the keyboard, however it soon became evident that more efficient input devices were needed to move cursors around the Graphic User Interfaces (GUI) on computer screens.

By the mid 1980s PCs (Personal Computers) were fast establishing themselves as professional tools and task specific software was being developed such as software for word processing. This brought with it the need for HCI (Human Computer Interaction[10]) engineers working on the design of GUIs for the

[10] The beginnings of Human Computer Interaction were referred to as Human Factors Engineering.

software to consider the end users needs more specifically. Bill Moggridge and Bill Verplank had recognized this growing need for design work driven by interactive products in 1984 but they were not the only ones to recognize this at that time. People such as Alan Kay, Don Norman, Gillian Crampton Smith, Terry Winograd, David Kelly and Jakob Nielsen to name a few (and there are many more), all began doing design work specifically for interaction design around that time. The resulting design approach used in interaction design that Moggridge et al. developed is now commonly known as User Centered Design (UCD). The predominant aspect of UCD is that end users of the interactive product or service are considered in the design process.

Interaction design for HRI (Human Robot Interaction) has its roots in the field of robotics engineering. This is due to the fact the engineers designing the robots also designed the systems through which their robots were to be interacted with. Examples of such applications are robotic systems used on assembly lines in car manufacturing that were first introduced in the early 1970s (Thrun 2004). This "design the robot, then the HRI" approach was adequate as long as robotics engineers or highly trained technicians were doing the programming or teaching of the tasks to be carried out by the robots. In other words there was no need for operating interfaces being operated by engineers or technicians to cater for a broader user group that did not have the knowledge and skill to program and control robots.

Today robots cover a wide range of applications, which brings with it a diverse group of users that need to be able to interact with robots efficiently and safely. This includes robots designed to assist people with their work such as remote controlled Urban Search And Rescue (USAR) robots that are guided via a televised link to robots that are designed for domestic use such as robotic vacuum cleaners. In both cases the user will want to start using the robot as quickly as possible therefore the device and or interface through which the user interacts with the robot needs to make sense to them and be easy to learn. For this reason, as in the case of HCI, it is important that the user is considered and consulted during the design process of the user interface. Julie Adams (2005) who has conducted research in the area of HRI-Design approaches from the perspective of Engineering states that HRI must move beyond the engineering design approach that designs the robot and then designs an HRI to a User Centered Design (UCD) approach that considers the human's workload, vigilance, situational awareness, etc. Adams (2005) also draws attention to timing stating that UCD needs to be employed at the earliest point in the [robotics] system design.

2.1.3 User Centered Design and Cooperative Design

User Centered Design

User Centered Design (UCD) approaches have been in use for approximately six decades and place the user that will use the product or service at the center of the design process. UCD [is practiced] from an 'expert perspective' in which trained researchers observe and/or interview largely passive users, whose contribution is to perform instructed tasks and/or to give their opinions about product concepts that were generated by others (Sanders & Stappers 2008). It is utilized when the designers of a product need to gain a clear understanding of whom they are designing for. In other words the designer of a product almost never belongs to the user group, which brings with it the need for the designer to research and consult the user. UCD is especially appropriate when designing products for large volume mass production - products designed for mass consumption. According to Terry Winograd product design [Industrial Design] has had some influence on interaction design:

> *One of the biggest influences [on interaction design] is product design. I think that interaction design overlaps with it, because they [product designers] take a very strong user-oriented view. Both [product and interaction design] are concerned with finding a user group, understanding their needs, then using that understanding to come up with new ideas. They may be ones that the users don't even realize when you begin. It is then a matter of trying to translate who it is, what they are doing, and why they are doing it into possible innovations. In the case of interaction design it is the way that the system interacts with the person* (in Sharp, Rogers & Preece 2006).

Cooperative Design

As new design disciplines such as interaction design began to emerge the meaning of the product to the user started to change. Co-design sees knowledge making as occurring through the interaction among people, practices, and artifacts - knowledge doesn't just reside in the head; it's a condition of a certain context (Spinuzzi 2005). According to Sanders & Stappers (2008) we are no longer simply designing products for users. We are designing for the future experiences of people, communities and cultures who now are connected and informed in ways that were unimaginable even 10[11] years ago (Sanders & Stappers 2008). In the field of computer systems development this shift from thinking of a product as an experience was recognized almost over four decades ago and led to new ways of developing or designing such products/experiences through co-design approaches. According to Sussane Bodker (1996), they were pioneered in Scandinavia, where research projects on user participation in systems development date back to the 1970s. One of the first projects in this area took place in the 1970s and was the so-called collective resource approach that developed strategies and techniques for workers to influence the design and use of computer applications at the workplace; the Norwegian Iron and Metal Workers Union project took a first move from traditional research to working *with* people, directly changing the role of the union clubs in the project (Ehn & Kyng 1987).

However according to Doug Schuler and Aki Namioka (1993) the co-design approach only started to gain recognition in the United States in the early 90s. In their introduction to the Conference on Participatory Design (PDC-90) Paul Czyzewski, Jeff Johnson and Eric Roberts explain how co-design differs from User Centered Design:

> *It rejects the assumption that the goal of computerization is to automate the skills of human workers, instead seeing it as an attempt to give workers better tools for doing their jobs.*
>
> *It assumes that the workers themselves are in the best position to determine how to improve their work and their work life. In doing so, it turns the traditional designer-user relationship on its head, viewing the users as the experts - the ones with the most knowledge about what they do and what they need - and the designers as technical consultants.*
>
> *It views the users' perceptions of technology as being at least as important to success as fact, and their feelings about technology as at least as important as what they can do with it.*
>
> *It views computers and computer-based applications not in isolation, but rather in the context of a workplace; as processes rather that as products (1990).*

Perhaps because early advances in co-design occurred in computer systems development and design, current interaction design professionals working as User Experience Designers predominantly designing websites and software

[11] The paper quoted here was published in 2008 and this thesis was published in 2012, therefore the time laps needs to be understood as 14 years, not 10.

interfaces, have recognized this. As a consequence, co-design approaches are more and more being utilized in these areas of design.

Cooperative Design in Industrial Design

Interactive device design (such as the SHB GAD OCU) falls into the field of Industrial Design where taking a co-design approach is not common practice yet. One reason for this is that designers find it difficult to access users or find the right users to participate in the design process. Another reason is that co-designing threatens existing power structures [such as designers controlling the processes] by requiring that control be relinquished and given to potential customers, consumers or end-users (Sanders & Stappers 2008). Many Industrial Designers may understand the relinquishing of this control to be a reduction of their creative input into a design project. On the other hand, many pieces of information form the basis for a design outcome and if one thinks of the input provided by co-designing users as pieces of information needed to achieve an outcome, the co-design component becomes simply part of the process. Even if end users make high-level design decisions during a co-design approach, it would not be possible for them to complete the project without an Industrial Designer. As stated earlier the designer takes on the role of a technical consultant (Czyzewski et al. 1990) or even the role of a mediator (Manzini & Rizzo 2011). In doing so the designer should try to manage the process in ways that keep important aspects of the product being designed in clear focus while filtering out less important aspects by relying on and valuing her/his technical training and experience (Iversen et al. 2012). Above all it is important to remember that thinking of co-design as the “new and only” way of conducting a design project is a misguided point of view. Co-design has to be understood as but another skill that in some cases will have an application and in others won’t.

After the literature had been reviewed there was, to the researchers knowledge, no evidence that co-design approaches are being utilized to design interactive devices for small, specialized user groups.

2.1.4 Robotic systems comparable to the SHB GAD

At the time of writing the SHB GAD was the first of its kind. That is, a robot that is capable of autonomously grit-blasting sections of a steel bridge structure such as the Harbour Bridge. There are other semi autonomous robotic systems that make use of grit-blasting to clean things such as the hulls of very large ships i.e. oil tankers (Faina et al. 2009; Iborra et al. 2010). However the mostly smooth surface of a ships hull is easier to clean than a complex steel structure such as the one on the Harbour Bridge. And although the work being carried out is similar, the environment in which it is done is very different. For instance the grit-blasting of a ships hull is done in a controlled environment such as a dry dock where is it possible to capture the used grit and paint particles after blasting. In contrast, the grit-blasting of the Harbour Bridge has to be done in-situ. This complicates the task considerably because the Harbour Bridge is in a metropolitan area where used grit and paint particles need to be captured after blasting to avoid them contaminating people and the natural environment. This makes it necessary to construct sealed blasting enclosures with elaborate dust extraction systems in which the grit-blasters work wearing Personal Protection Equipment (PPE) with a constant supply of fresh breathable air. This unique, hostile work environment presents a multitude of challenges to the people developing the hardware of the SHB GAD. Please refer to section 1.2 for detailed background information on the SHB GAD project.

2.1.5 Operator Control Units for robots such as the SHB GAD

The majority of industrial and professional service robots are designed to reduce the risk to human health by using the robots to perform dangerous tasks traditionally done by humans. Examples of such situations are the ship hull cleaning robots mentioned earlier, USAR (Urban Search And Rescue) robots in post earth quake and other natural disaster zones or EOD (Explosive Ordnance Disposal) robots. These types of robots are controlled remotely, where the operator is controlling the robot from a safe distance via a televised video link, also know as tele-operation. To make operation more efficient these types of robots are equipped with various degrees of autonomy. For instance an USAR robot may be instructed to go from location A to location B but rather than being guided by an operator every step of the way it is able to navigate its way to B autonomously. Once it arrives at its destination or is obstructed by an obstacle it can't get around it will prompt its operator via the OCU to give it further instructions.

It is desirable that OCUs are portable to allow a high degree of mobility for the operator while the robots are being used. Current OCUs are generally in the form of rugged PC laptops with auxiliary control units such as joysticks. Some (i.e. rugged laptops) require a flat surface such as a table for satisfactory operation and some are actually portable in that they can be strapped to the body (Foster-Miller 2011). However these OCUs can be cumbersome to use if the operator is in motion or walking and require almost permanent visual contact with the screen interface. Attempts to make OCUs less cumbersome has led to research being conducted into portable lightweight systems using touch screen PDA's (Portable Digital Assistant) such as Hande Keskinpala, Julie Adams and Kazuhiko Kawamura's PDA-based human-robotic interface (Keskinpala, Adams & Kawamura 2003). In this case the handheld PDA wirelessly communicated with the Master Control Unit and was attached to the forearm of the operator. Keskinpala et al.'s research findings are encouraging in that their system allows for a greater degree of mobility due to the reduction of weight of the system and a clear interface design. However it was designed for remote control tele-operation, which is unfortunately not possible to implement with the SHB GAD at this stage due to ricocheting grit flying around the enclosure during blasting which would obscure the televised image. There are commercial OCUs available for purchase by companies such as Siemens and Denso (see section 4.3) that produce robotic components. These devices are commonly referred to as teach pendants because they are used, by mechatronic engineers, as a tool with which to teach the robots what to do. They are very complex devices that can perform a multitude of functions but are only compatible with equipment from the same brand. The manipulator used on the SHB GAD is made by Schunk, however Schunk does not manufacture any OCUs or teach pendants.

In summary, considering there are no commercially available OCUs designed to function in the harsh work environment of the Harbour Bridge and considering that none are compatible with other components of the SHB GAD system it makes sense to design, develop and implement an OCU specifically for it.

2.1.6 Co-design to design the SHB GAD Operator Control Unit

Under section 2.1.3 it was established that taking a co-design approach to design and develop user interfaces in HRI for systems such as the SHB GAD is a currently not a common approach taken in HRI or Industrial Design. This is not to say that engineers and designers working in HRI are not aware of the advantages of such approaches. In 2005 Adams stated that many in the HRI field had only recently recognized the need for applying User Centered Design (UCD) and other standard human factors techniques (Adams 2005). So things were starting to change. Adams further states that an often cited issue is the inability to access real users. And that in fact, most HRI operators are the developers themselves (Adams 2005). However there are examples of projects where UCD was successfully implemented such as one conducted by Hank Jones and Pamela Hinds (2002) who studied SWAT (Special Weapons And Tactics) teams during training to develop HRI for USAR robots to be used by SWAT teams.

In terms of co-design, a study by Christian Bogdan et al. (2009) titled *Cooperative design of a robotic shopping trolley* did design together with users in the participatory design [co-design] tradition, by intensive use of video prototyping, enactment and video-aided reflection. Bogdan et al. go on to say that in the cooperative design tradition, the workshops also gave the users an opportunity to express concerns about such new technology. For example several users in different workshop groups emphasized that they would like the robotic trolley to be "on their side" (from user personal interests) and not the "on the shop side" (from shop commercial interests), when selecting the information to show on the screen or through speech (Bogdan et al. 2009).

The assumption can be made that the design and development of the OCU for the SHB GAD would benefit from a co-design approach since the UTS engineering team working on the SHB GAD project does not represent the user group, in this case grit-blasting professionals. Adams states that software engineers and programmers do not typically represent the appropriate user group. She goes on to say that their perception of the user interface design rarely matches the actual users and/or Human Factors results (Adams 2002).

2.1.7 User acceptance and degrees of autonomy

There is little point to the SHB GAD project if the grit-blasters are not comfortable using the SHB GAD. Taking a co-design approach that closely involves grit-blasters in the design process may help to build trust. Co-designing should also ensure that the resulting product is as useful as it can possibly be from the users perspective. As mentioned in the preceding section, in the case of Bogdan et al.'s (2009) robotic shopping trolley the [co-design] workshops gave the users an opportunity to express concerns about new technology. A study conducted by Leila Takayama et al. (2008) actually proved that people will feel more positively toward robots doing jobs with people rather than in place of people. This goes against the frequently cited opinion that robots should primarily be used for jobs that are dirty, dangerous and dull. Having said that, it is important to note that the main purpose of the SHB GAD is to reduce grit-blasters exposure to harmful substances such as read lead and asbestos and to reduce muscular skeletal strain on their bodies during manual blasting (for more detail regarding the health effects of grit-blasting of please refer to section 1.2).

Early in the project (Sep. 2010) it became apparent, during verbal discussion between RMS management and UTS engineering team, that the degree of autonomy that the SHB GAD should have could be a source of concern for grit-blasters operating it. The predominant concern was that grit-blasters might fear loss of employment once introduced to the concept of the SHB GAD. This could particularly be the case if the SHB GAD was functioning almost completely autonomously. In other words if the SHB GAD was capable of completing it's task without much operator influence other than pressing a start button. Reducing the level of autonomy so the grit-blasters are working with the SHB GAD rather than being replaced by it could help reduce the level of concern by grit-blasters in relation to job security. In addition to human operators feeling secure in their employment there are further considerations in relation to work process that need to be taken into account regarding the levels of autonomy of work robots as Clint Heyer states:

> *As robots are introduced, issues of trust and accountability come to the fore as well as how they fit into organizational structures. If robots have too little autonomy, human operators will waste time attending to robots instead of attending to their work tasks. If robots are highly autonomous, situational awareness of plant activity is diminished* (2010).

In view of this, the level of autonomy assigned to the SHB GAD needs to be balanced in a way that the human operator can trust that it will perform its tasks as planned but understands that he or she (human operator) is sharing the task with the SHB GAD and both parties are needed.

2.2 Small, Specialized User Groups

Within the framework of this thesis small, specialized user groups are defined by their size and their needs, where the size could be 1 to 20 users and the needs unique, in terms of professional or site specific requirements (for a more detailed description please refer to section 1.1.2). As a result of verbal discussions with fellow design practitioners and academics there is sufficient anecdotal evidence suggesting that there are many small user groups with specific needs. Under section 1.2 the researcher gave a brief account of his professional background and its relevance to this research. And in relation to small, specialized user groups his work as a part time academic and the supervision of 4th year Major Project students is of particular interest. While completing their Major Project work students are required to research new product opportunities and design solutions for them. In doing this most of the students go out of their way to find opportunities where no one else has looked which invariably leads them to areas where user groups are too small to warrant mass production and therefore have been overlooked by real-life manufacturers. The vast majority of students find their Major Projects by researching real-life problems and then designing high quality solutions for them. However due to the fact that these projects are hypothetical, in that they are not commissioned by paying clients, they rarely go on to be more than undergraduate university projects. In the process of researching their users needs the students almost always get in contact with real-life end users, who are encouraged by the enthusiasm and energy the students are putting into the projects. In many cases the process feels real to the end users and are therefore disappointed to learn that the project was a hypothetical exercise. So the researcher suspects that there are multitudes of small, specialized user groups that could offer potential design projects.

Yet during the course of this research it was challenging to find written evidence of this. One reason for this lack of evidence is likely to be manufacturing where, traditional methods of mass-producing products rely heavily on scales of economy so low volume production doesn't make sense. Consequently if a user group is too small to justify mass-production there is no point in researching and designing products for them, which, in turn, means there is no documentation available. Another reason for the lack of evidence of the existence of small, specialized user groups could be that they simply solve the problem themselves. In these cases user groups might have realized the need for a product solution and tried to purchase one but couldn't find a suitable solution. So they got together and produced the product themselves. Again it is unlikely that such projects are documented in any way.

Custom making products in low volumes or limited editions for select groups of people is not new. Such products are generally marketed as exclusive and are expensive to purchase, their need however, has not arisen from a user groups requirements but was more likely a marketing strategy. Other examples are products designed in a bespoke or tailor made fashion for one specific user only, such as clothing, musical instruments or tools such as surgical implements (Bongers 2007). For other examples in the personalized design service area please refer to section 1.1.2.

There are companies such as Custom Design Technologies Ltd[12], a manufacturer of custom-designed plastic enclosures capable of manufacturing quantities

[12] www.customdesigntechnologies.com

ranging from 1 to a maximum of 1000 units (Campbell et al. 2003). However they are not in the business of designing complete product solutions.
Even if the evidence of actual products designed for small, specialized user groups is not available yet there are indications that hint at the possibility (see section 1.1.2). Another such indication is the report mentioned earlier (see section 1.3) written by Paul Markillie for *The Economist*. And although this is repeating his earlier quote it is appropriate to do so at this point: *"As there are barely any economies of scale in additive manufacturing, the technology is ideally suited to low-volume production"* (Markillie 2012).

In summary, for any product, regardless of the size or special needs of its user group, to be available it needs to be manufactured. Once more designers and engineers recognize the possibilities that Additive Manufacturing and Open Source Hardware + Software offer they will consider designing products for unusually small, specialized user groups.

2.3 Additive Manufacturing, Open Source Hardware + Software

Additive Manufacturing

To make an interactive device available to a user it needs to be manufactured. Over the past few decades, manufacturing has evolved from a more labor-intensive set of mechanical processes to a sophisticated set of information-technology-based processes (Shipp et al. 2012) such as Additive Manufacturing. And to demonstrate how significant the impact of Additive Manufacturing will be the researcher will once more refer to the special report titled: *Manufacturing and innovation* in the April 2012 edition of *The Economist* (Markillie 2012). In this report Additive Manufacturing technology is referred to as *"A third industrial revolution"*, a claim that provides insight into the gravity that Additive Manufacturing technology will have on the way tangible products are manufactured. Terry Wohlers is president of Wohlers Associates, Inc., an independent consulting firm that provides technical and strategic consulting on the new developments and trends in rapid product development, Additive Manufacturing, and 3D printing. Although Additive Manufacturing was traditionally used as a method to make one-off prototypes, Wohlers estimates that currently around 28% of the money spent on [3D] printing things is for final products. He furthermore predicts that this will rise to just over 50% by 2016 and to more than 80% by 2020 (Wohlers in Markillie 2012). This growth in 3D printed parts used as final products can be linked to the rise in popularity of so called

"3D printing bureaus" such as Shapeways[13], Thingiverse[14] and Digital Forming mentioned in section 1.1.2. These companies manufacture parts only using Additive Manufacturing technology and are building a thriving industry that promotes Additive Manufacturing as a manufacturing method rather than just a prototyping method (Markillie 2012). CAD files can be uploaded via their websites and instant quotes are provided based on the material one selects. The choice of material ranges from polymers to metals and ceramics. Shapeways even hosts an online shop on their website through which people can sell their designs to 3rd parties.

Additive Manufacturing will also find its way into our homes as 3D desktop printing. Although the cost of such machines is currently prohibitively high and the part quality low it is only a matter of time before 3D printers are as common in our homes as high quality 2D colour inkjet printers. Historical parallels can be drawn here to the shift desktop publishing went through in the mid 1980's after the release of the first desktop laser printers. Used in combination with more user friendly desktop publishing software, desktop printers meant that small scale publishing no longer needed to rely on large scale printing technology. For people who don't want to wait until desktop 3D printers become more cost effective the Thingiverse website provides all the necessary information to build at least two types of 3D printers. Anyone can download the instructions, part lists, code and build their own.

Currently the predominant area of application for Additive Manufacturing as a part production method is for the production of low-tech products such as jewellery or lighting; products that have no intelligent electronic components. However as Open Source Hardware + Software components become more user friendly both as electronic building blocks and in terms of programming, Additive Manufacturing is set to be used increasingly to manufacture housings for interactive devices.

Open Source Hardware + Software

Massimo Banzi, a founding member of Arduino[15], argues that there is another industrial revolution going on, that of the Open Source Hardware + Software and makers movement (Banzi 2012) a movement that started in 2005 with the founding of Arduino. The Arduino website explains that Arduino is a tool for

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13 www.shapeways.com
14 www.thingiverse.com
15 www.arduino.cc

making computers that can sense and control more of the physical world than your desktop computer. It's an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. In the seven years since Arduino was launched and made available to anyone as an Open Source Hardware + Software tool, several thousand interactive devices of all kinds imaginable have been created (Torrone 2011). The vast majority of these projects, including all information needed to build them (i.e. part lists, building instructions and code for programming), are made available by their creators via websites such as Instructables[16] and Adafruit[17]. Due to the fact that most of the information/software is open source and therefore available to anyone, new projects building on the ones that went before are being created and published every day. In other words people are able to build complex devices using other peoples knowledge without having to worry about copy-right infringements.
Manufacturers of commercially available hardware components such as SparkFun Electronics[18] and Freetronics[19] soon realised the potential here and have their own versions of the various Arduino boards and peripheral components available on their websites. Again the fact that most of the elements are open source, and that manufacturers [of hardware] can see [via websites] what makers are building allows them to guide their production in directions that answer the demand of the makers. Often hardware manufacturers will work together with people in the open source community as was the case with the Lilypad Arduino. The LilyPad Arduino is a microcontroller board designed for wearables and e-textiles and was designed and developed by Leah Buechley and SparkFun Electronics (Buechley & Hill 2010).

In summary, Additive Manufacturing and Open Source Hardware + Software are changing the way interactive device are being manufactured. Apart from the actual cost of producing parts using Additive Manufacturing and buying Open Source Hardware + Software components the knowhow of assembly and programming is available to anyone willing to try. Currently this is a "makers movement" but it is only a matter of time before more designers and engineers realize the potential to create interactive devices targeted to small, specialised user groups.

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[16] www.instructables.com
[17] www.adafruit.com
[18] www.sparkfun.com
[19] www.freetronics.com

2.4 Working safely with robots

Of course people working alongside robots need to be confident that they will not come to any harm from the robots. This is especially the case with autonomous robots such as the SHB GAD because their movements can be at times unpredictable. In today's world working alongside of robots is nothing new and as a result there are many safety standards available. However different standards apply to different types of robots so to begin with it is necessary to define what type of robot the SHB GAD is.

What type of robot is the SHB GAD?

A 2002 survey by the United Nations (UN) and the International Foundation of Robotics Research (IFRR) groups robots into three main categories (U.N. and I.F.R.R. 2002). These three categories are defined by the area within which the robots are used and the type of tasks that they perform:

1. *Industrial robots* are used in industrial applications such as conveyor belt assembly lines and are designed to replace humans.
2. *Professional service robots* are designed to assist humans with their work. Applications include remote control operated search and rescue robots or surgical robot systems used for assisting physicians in surgical procedures.
3. *Personal service robots* are designed to assist or entertain people in domestic settings or recreational activities. Applications include robotic vacuum cleaners, robots that assist physically impaired people in their homes and robotic toys.

Based on this definition the SHB GAD belongs to category 1, "Industrial robots", because once installed and operational it can perform the actual task of blasting autonomously.

Australian Standards recommendations

All aspects of the SHB GAD including its OCU must therefore comply with the recommendations made in the Australian Standards, Safety of machinery, Part 3301: Robots for industrial environments-Safety requirements.

Upon review of the standards there are three recommendations the OCU should comply with:

1. *6.3.2 Protection from unintended operation* states:
   Actuation controls shall be constructed or located so as to prevent inadvertent operation.

2. *6.5.2 Emergency Stop* states:
   AS 4024.1604 sets out functional requirements and design principles for emergency stop.
   Each control station capable of initiating robot motion or other hazardous situation shall have a manually initiated emergency stop function that –
   a) complies with requirements of AS 60204.1;
   b) takes precedence over all other robot controls;
   c) causes all hazards to stop;
   d) removes drive power from the robot actuators;
   e) removes any other hazard controlled by the robot;
   f) remains active until it is reset; and
   g) shall only be reset by manual action that does not cause a restart after resetting, but shall only permit a restart to occur

3. *6.8.3 Enabling device* states:
   The pendant or teaching control device [OCU] shall have a three-point enabling device in accordance with AS 60204.1 that, when continuously held in a centre-enabled position, permits robot motion and any other hazards controlled by the robot.

Measures taken:

1. The screen that displays the GUI on the OCU is a resistive touch screen and will be equipped with a screen lock-out function. This is to ensure that functions cannot be activated by accident if, for example, something were to drop onto the screen. In addition confirmation pop-up dialog boxes will allow the operator to reconsider his or her selection.
2. The OCU will be equipped with a physical emergency stop button that is activated by pushing it down or hitting it.
3. The OCU will be equipped with an enabling device in line with the safety equipment used by RMS.

Chapter 3. Methodology

The research methodology is a combination of design research and action research and was applied to a case study. This case study describes the co-design approach that was utilized to design, develop and implement the OCU used to control the SHB GAD. A detailed stage-by-stage description of the study follows under section 3.3. Interviews and observational research were used to collect data during the study with the primary goal of assessing the co-design approach from the point of view of end users.

The secondary goal of the study was to establish how the OCU designed as a result of this study would compare with commercially available OCUs. For a detailed description of the research questions and the research problem please see sections 1.4 and 1.5 respectively.

3.1 Setting of the study

The bulk of the study took place at the RMS (Roads & Maritime Services) Sydney Harbour Bridge Southern Pylon Maintenance Site located inside the southern pylon of the Harbour Bridge (Figure 3.1). The maintenance site is an industrial facility that houses offices for RMS bridge maintenance management staff, change rooms, equipment storage and equipment decontamination facilities, lunch rooms and a meeting room. It also houses several trade workshops such as welding and carpentry workshop. The main function of the site is to provide a base for bridge maintenance workers and their equipment. The bulk of the work bridge maintenance workers do is conducted off the ground in blast enclosures, up in the structure of the Harbour Bridge (Figure 3.2).

Figure 3.1:
Sydney Harbour Bridge Southern Pylons.
(Image courtesy of RMS)

Figure 3.2:
Blast enclosure suspended beneath the
Harbour Bridge. (Image courtesy of RMS)

Most meetings, interviews and the co-design workshop were conducted in the meeting room which is a medium sized room with no windows containing a large meeting table capable of seating approximately 12 people.

On two occasions participants were required to come to UTS to the UTS SHB GAD lab for training sessions. The UTS SHB GAD lab is a room approximately 4m x 8m in size. This lab served as the SHB GAD testing facility and housed the SHB GAD and a 1:1 scale cardboard mock up of part of the section on the Harbour Bridge that the SHB GAD was designed to blast.

3.2 Participant selection

The design, development and implementation of the OCU formed part of a larger real-life project titled SHB GAD, which is a joint project between the UTS and RMS. The SHB GAD is a semi autonomous robotic system designed to remove rust and old paint from the steel structure of the Harbour Bridge (for more information see section 1.2). To use the SHB GAD it is set up in front of a section of bridge structure that requires grit-blasting. Once it is set up the operator uses the OCU to control the SHB GAD from a safe distance (Figure 3.3).

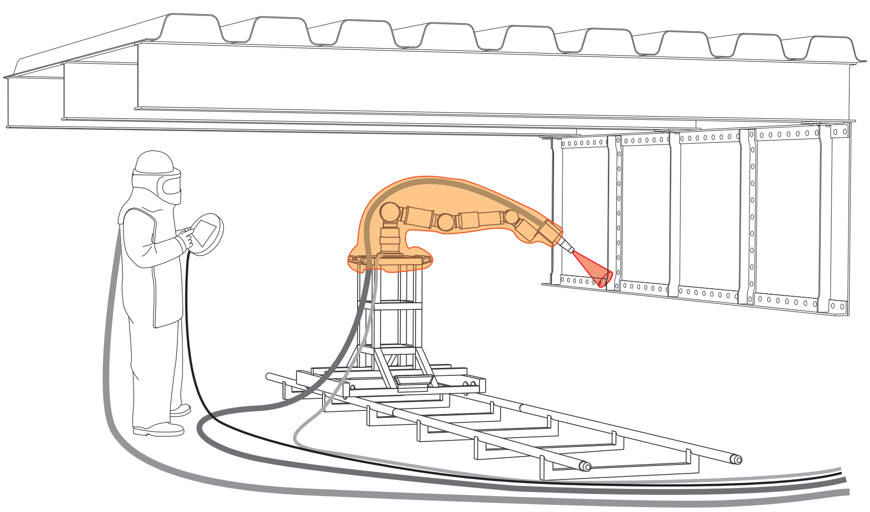

Figure 3.3:
Illustration of the SHB GAD system with operator, blasting a section of the Harbour Bridge.

Because the design and development of the OCU was part of that of the SHB GAD it was fundamental that some stakeholders in the SHB GAD project were also involved in the development of the OCU (Figure 3.4).

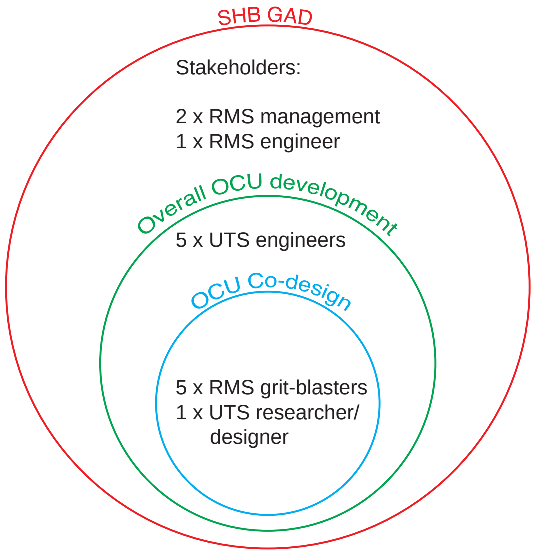

Figure 3.4:
Schematic representation of all stakeholders and their level of involvement in the project.

It is important to note that only the five grit-blasters were participants in the co-design component of the OCU design and development.

At the request of the researcher the selection of participants was conducted by RMS management. The reason for this request was that RMS management is very interested to see the SHB GAD project succeed and would therefore select participants that were likely to support the project. This would add to the study being as close to real-life as possible. The participants were from the grit-blasting team based at the RMS Sydney Harbour Bridge Southern Pylon Maintenance Site.

The participants were all male, Australian trained trades people and were fluent in English. They were physically strong and accustomed to physically hard and dangerous work. Participants varied in age and experience in the profession of grit-blasting. Of the five one was in his 20's, two were in their thirties and two were in their late 40's early 50's. The three younger ones were active grit-blasters. The two older ones each had approximately 20 years of blasting experience and were therefore very experienced grit-blasters, yet no longer active as grit-blasters. The two older ones occupied senior positions, one being foreman and the other pot-master[20]. None of the participants had any design experience or knowledge of design processes and none of them had ever operated a robot of any kind. To comply with UTS HREC requirements all participants were asked to sign a consent form (Appendix C). Participants were able to withdraw from the study at any point if they wished to do so.

3.3 Study

The study was conducted in the form of a design project, which was to design, develop and implement the OCU used to control the SHB GAD. The study ran for a period of 23 months commencing in September 2010 and concluding in July 2012. The project ran in five stages:

1. Knowledge building — Sep. 2010 – July 2011
2. OCU co-design — Aug. 2011 – Sep. 2011
3. OCU prototyping — Nov. 2011 – May 2012
4. OCU implementation — June 2012 – July 2012
5. Post-study impression — July 2012

Of these five stages Stage 2, *Co-design* is the most relevant to this research. However for the study to make sense as a whole all five stages need to be made explicit.

The diagram on the following page (Figure 3.5) provides an overview of the co-design approach, its Stages and the project timeline.

[20] Person controlling the supply of grit and compressed air to blast guns (the grit is supplied via large pots, hence the name).

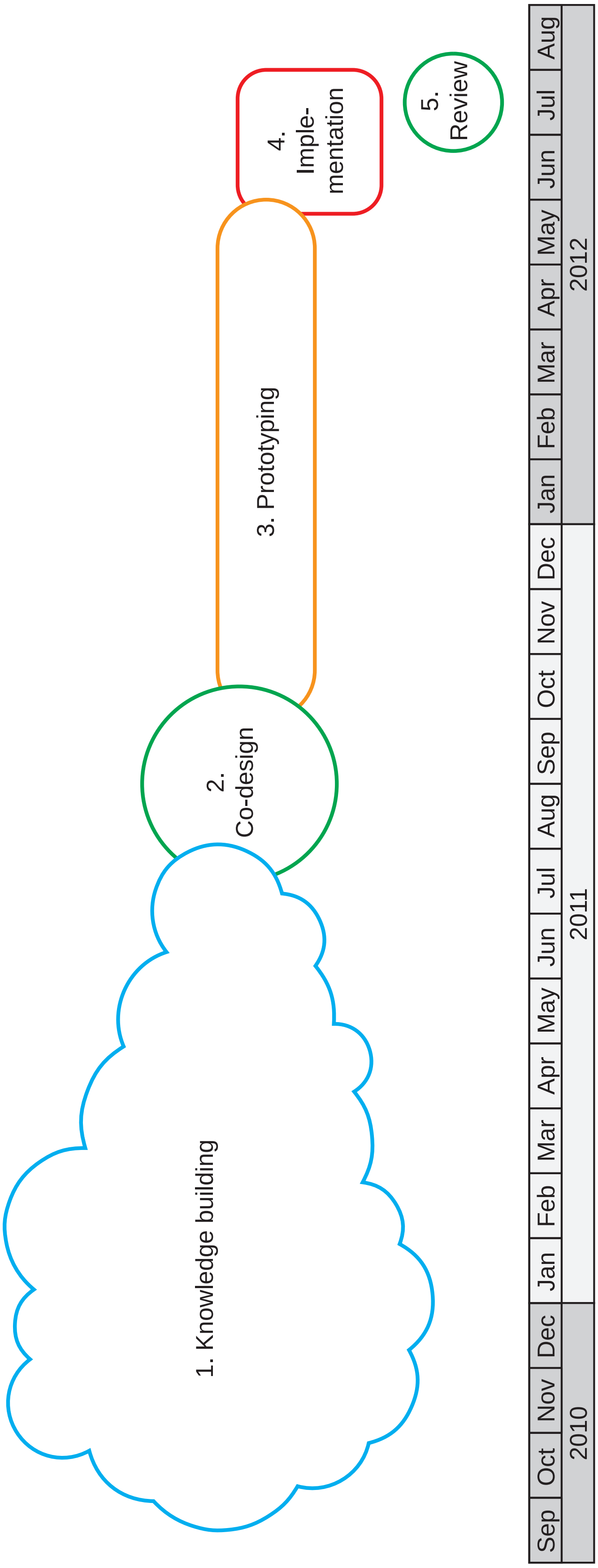

Figure 3.5:
Overview of the Co-design approach and project time line.

Stage 1. Knowledge building

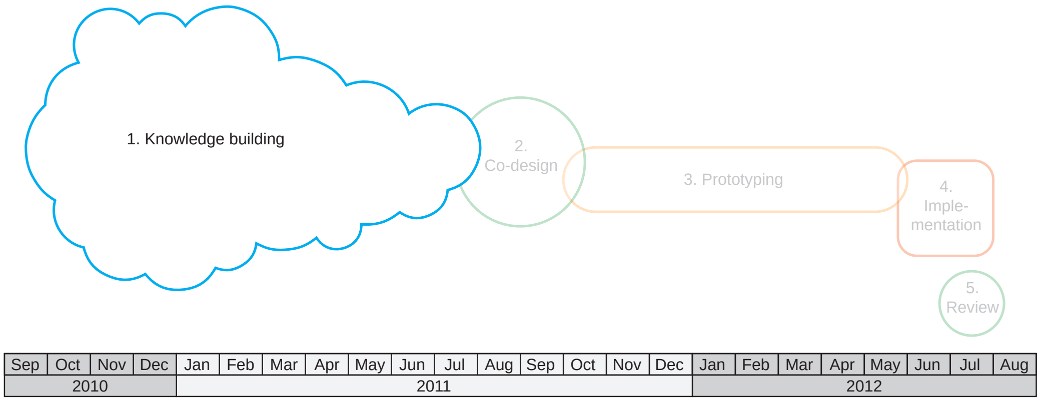

Figure 3.6:
Stage 1. Knowledge building.

At the time of the study the SHB GAD was the first of its kind in the world which, in the first eleven months of the study, made concept development of the OCU challenging because none of the stakeholders, including UTS engineers, had a concrete idea of how the SHB GAD would operate and how the OCU would best serve its purpose. To build a concrete mental model of the SHB GAD and enable all stakeholders to contribute to the project a knowledge building stage was devised. This knowledge building stage was conducted through monthly meetings with all stakeholders and involved the RMS team being updated by the UTS team on their research and development progress and seeking critical feedback from the RMS team. The knowledge building stage never focused on the OCU in particular but rather on the entire SHB GAD project and was fundamental in building trust and understanding between all stakeholders. It also provided the participants with an introduction to how designers work as well as sketch models, paper prototypes and scenario enactments. These were all elements that were to aid them in understanding the co-design stage (Stage 2).

By May 2011 there was sufficient data to commence developing preliminary concepts of the OCU in the form of physical models. These preliminary concepts were intended to give the OCU a touchable physicality and help participants visualize what a device may look like and how it may be interacted with. At this point in time the predominant requirement was for the OCU to have a resistive[21] touch screen interface. This requirement was based on participants not wanting

[21] Resistive touch screen, reads input signals if pressure is applied.

any physical push buttons that were likely to seize up due to the large amount of grit present in the work environment. The touch screen needed to be resistive as opposed to capacitive[22] due to the fact that grit-blasters are required to wear gloves. Using a touch screen to interact with the OCU was also a requirement of the UTS team as this allowed them to develop a screen based Graphic User Interface (GUI) that offered a higher degree of flexibility compared to physical push buttons that once installed could not be changed. An additional requirement came from the Australian Standards, Safety of machinery, Part 3301: Robots for industrial environments-Safety requirements that recommends that any device used to control an industrial robot must be equipped with an Emergency Stop (E-Stop) (see section 2.4).

Utilizing the two requirements as a framework the researcher designed OCU preliminary concept 1 and made a physical sketch model of it combined with a paper prototype representing the GUI functionalities (Figures 3.7 + 3.8).

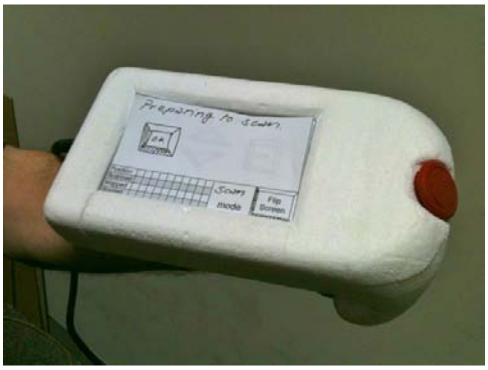

Figure 3.7:
OCU preliminary concept 1 with GUI paper prototype.

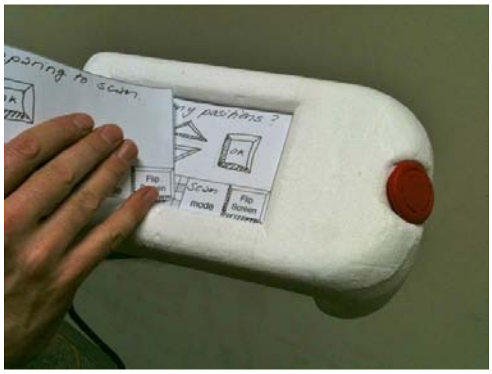

Figure 3.8:
Demonstration of GUI paper prototype function.

The sketch model of OCU preliminary concept 1 was true in weight and size to what it would have been if it existed as a real device. The model was reviewed by four of the participants in groups of two. This review, (Review 1) was conducted by running participants through an enacted scenario during which they had to imagine controlling the SHB GAD system via the OCU sketch model/paper prototype. To help them imagine the enacted scenario they were provided with images that represented how the SHB GAD would be set up and where the grit-blasters position would be in relation to this set up. In addition the furniture in the meeting room in which Review 1 took place was set up to approximately represent a blast enclosure. Figures 3.9 and 3.10 are snapshots of Review 1 where in figure 3.10 the blue chair in the foreground represents the robot.

[22] Capacitive touch screen, reads input signals if an electric conductor such as bare human skin touches the screens surface.

Figure 3.9:
Participant conducting Review 1.

Figure 3.10:
Participant conducting Review 1. The blue chair in the foreground represents the robot.

Figure 3.11:
OCU preliminary concept 2.

Figure 3.12:
All four OCU preliminary concept models.

Review 1 of OCU preliminary concept 1 revealed that several changes were required which led to preliminary concept 2 (Figure 3.11). In total four sketch models were made during Stage 1 (Figure 3.12).

OCU preliminary concept 2 was reviewed (Review 2) in one meeting with four of the five participants present (Figure 3.13). At this stage the UTS team had purchased the computer hardware component to be used inside the OCU (Figure 3.14). This component was an IP Code 65 (NEMA 2004) rated Algiz 7 (brand name) tablet computer with a resistive touch screen. It also had a simulation of GUI V1 of the user interface installed on it. This GUI Version 1 was based on the paper prototype used on OCU preliminary concept 1 and gave participants an opportunity to test the touch screen and provide feedback on GUI Version 1.

Figure 3.13:
Review 2 with four participants.

Figure 3.14:
Algiz 7 tablet computer with GUI Version 1.

During Review 2 it became evident to the researcher that participants had gained confidence in the project and understood that their contributions were considered valuable. Upon analysis of the data from Review 2 it was decided to commence the co-design stage.

Stage 2. OCU co-design

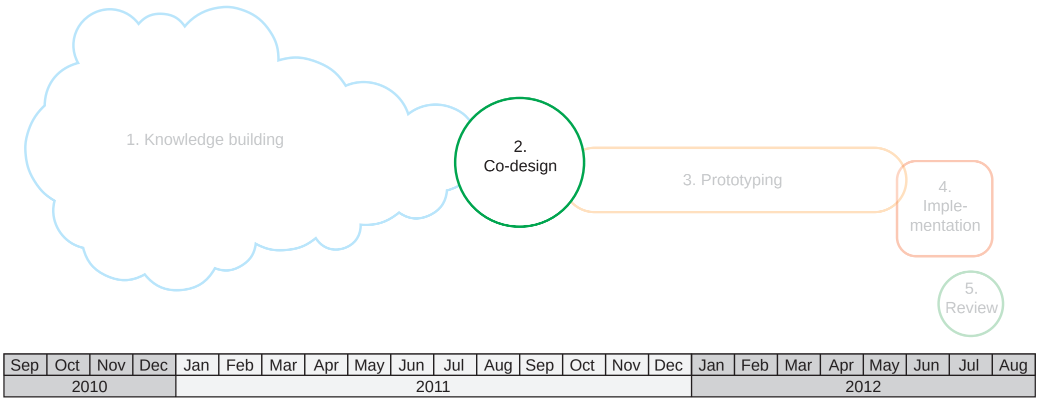

Figure 3.15:
Stage 2. Co-design.

The design approach that had been employed during *Stage 1, Knowledge building* was a UCD approach (see section 2.1.3) where the participants were asked to comment on design solutions that had been designed by someone other than themselves (in this case the researcher). The fundamental difference between UCD and co-design is that during co-design the participants are asked to take part in the design process as experts in the field. However asking people to participate in something they normally don't do can be a delicate matter. Many people feel self conscious about their abilities to draw or speak in front of a group which can result in them not actively participating, so the co-design stage needs to be planned carefully. The success of a co-design approach is also dependant on a good team dynamic and the responsibility of building such a team dynamic lies with the consulting designer. In this study the *Knowledge building Stage* was utilised to build a good team dynamic and resulted in all participants feeling comfortable working with one another. Due to this and the fact that all participants were manual labourers and therefore comfortable working with their hands it was decided to start the co-design stage with a co-design workshop.

The objective of the co-design workshop was to design the tangible element, the external housing, of the OCU. It was not possible at this stage to include the design of the interactive element, the GUI. This was due to UTS software engineers needing to retain flexibility regarding functionality of the entire SHB GAD system.

The co-design workshop was conducted as a model making exercise. To help participants, they were provided with an information sheet containing written information listing important points to remember while working on their models (Appendix D). They also had the following materials and tools available to them: Hot glue guns, masking tape, scalpels, Stanley knives, play dough, cardboard in various thicknesses, cardboard tubes, timber dowel (to represent the E-stop button) and electrical cords. In addition they were provided with five identical cardboard housings (Figure 3.16) that were able to house the Algiz 7 tablet. These housings were the absolute minimum in size the OCU could be and were intended to provide participants with a “starting point” around which they were able to construct their own designs. With the Algiz 7 tablet computer placed inside, the housing also gave participants an approximate indication of the weight of the OCU, which was important because it was to be a portable device. The physical set up of the workshop in the meeting room is show in figure 3.17.

Figure 3.16:
Cardboard housing to be used as a "starting point" around which to model the OCU.

Figure 3.17:
Co-design workshop set up.

The co-design workshop was planned and moderated by the researcher and scheduled as follows:

Introduction and run through of proceedings:	10 min
Round 1 model making session:	25 min
Short break:	5 min
Round 2 model making session:	25 min
Review and final design decisions:	15 min
Total duration:	**80 min**

Apart from the cardboard housing that participants were required to use the only other requirements were to find suitable locations for the E-Stop button and power cable. Other than that participants were encouraged to design/make whatever they deemed appropriate. Following are images of the models made by the participants (Figures 3.18 – 3.23).

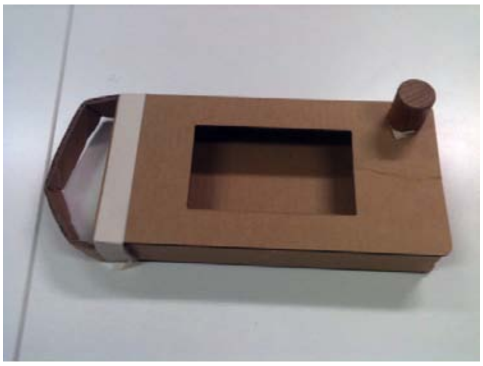

Figure 3.18:
OCU model made by a participant.

Figure 3.19:
OCU model made by a participant.

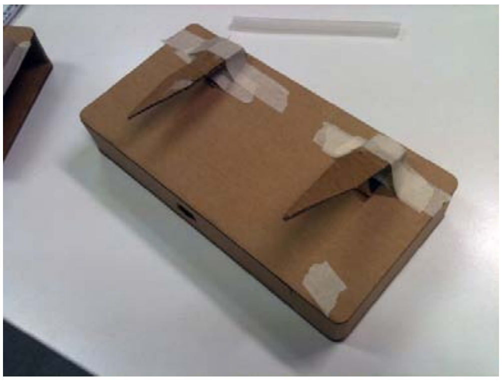

Figure 3.20:
OCU model made by a participant.

Figure 3.21:
OCU model made by a participant.

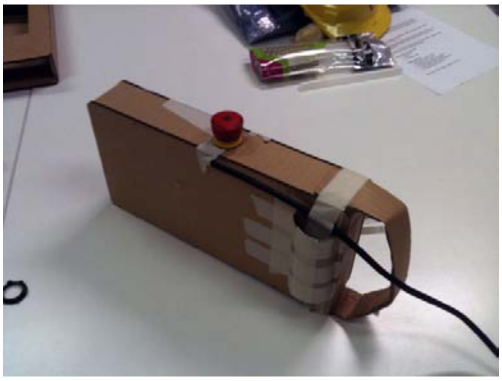

Figure 3.22:
OCU model made by a participant.

Figure 3.23:
OCU model made by a participant.

The design requirements of the OCU designed and cooperatively decided on through model making were:

1. The OCU to be used in landscape format
2. The E-Stop to be located on top centre of the OCU (Figure 3.21)
3. The OCU to have grip rails on the back to make holding on to it easier and safer (Figures 3.22 + 3.23)
4. The grip rails to have additional support straps (Figures 3.22 + 3.23)
5. The OCU to be accompanied by a dock that would hold it when not in use (Figure 3.21)

However not all design details were physically resolved using the models. Several were decided on through verbal discussion and noted on the white board. These include:

1. The OCU to be able to be used with both the left and the right hand.
2. The cable entry to be located in the bottom centre of the OCU
3. The enabling device (dead-man switch) to be located in the bottom centre (in front of the cable entry)

4. The OCU to be a bright colour so it can easily be located in the dark and dusty work environment
5. The dock could be magnetic so it would attach to the steel structure of the Harbour Bridge and be relocated at will of the operator

To avoid misinterpretations and ensure the OCU would be as intended by the participants, the researcher made one final sketch model of the OCU and its dock and got the participants to review (Review 3) them (Figures 3.24 – 3.27). The blue gloves are part of grit-blasting PPE (Personal Protection Equipment) used on the Harbour Bridge and are the gloves that will be worn while using the OCU.

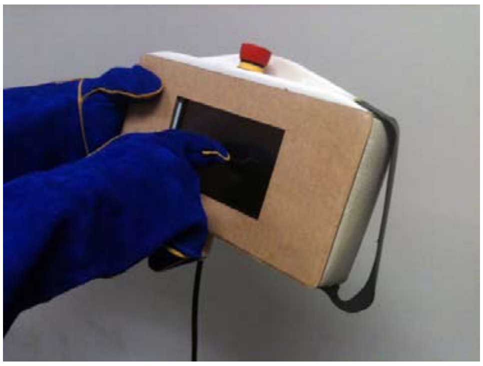

Figure 3.24:
Front view of final OCU sketch model made by the researcher.

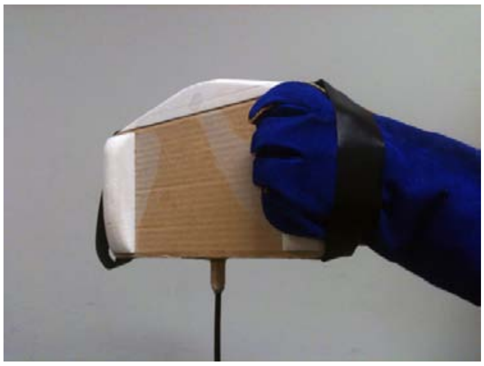

Figure 3.25:
Back view of final OCU sketch model.

Figure 3.26:
Sketch model of OCU Dock made by the researcher.

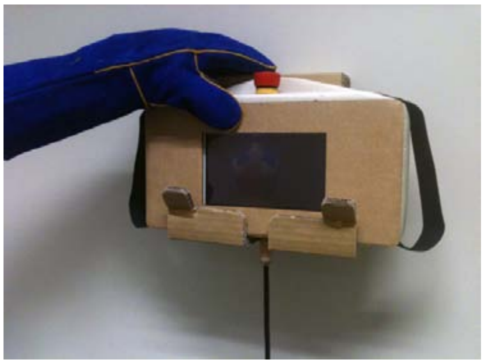

Figure 3.27:
Final OCU sketch model sitting in its dock.

The researcher endeavoured to make the final sketch model as close to the design of the participants as possible. However the researcher added one additional feature without consulting the participants. This was a guard behind the E-Stop (Figure 3.27) to avoid accidentally activating the E-Stop when placing the OCU in its dock or when putting it down somewhere. Upon review (Review 4) the participants were satisfied with the final sketch models including the E-Stop guard but asked for the shelf to be placed at an angle to facilitate viewing the screen when the OCU is sitting in its dock.

Stage 3. OCU prototyping

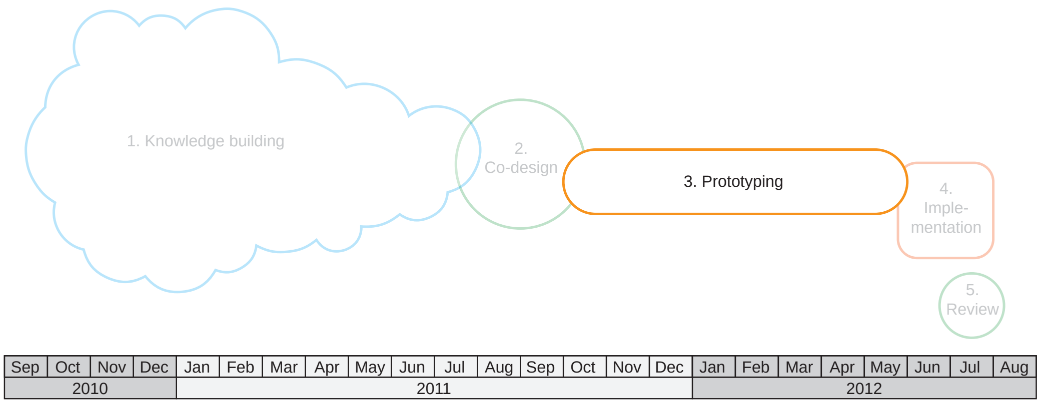

Figure 3.28:
Stage 3. OCU prototyping.

The researcher produced OCU prototype 1 by taking the data from the final sketch model and translating it into a virtual 3D computer model using CAD software. This virtual 3D model was then manufactured in ABS[23] plastic using an Additive Manufacturing method called Fused Deposition Modelling (FDM). Several open source hardware components were used to produce the prototype and included the Emergency Stop button, communication interface (internal component) and the power connection system. The prototype of the Dock was handmade from foamed PVC[24] sheet plastic (Figure 3.29 shell and Dock, figure 3.30 Dock only). OCU prototype 1 (including the Dock) was reviewed (Review 5) by the participants who were satisfied with the result. However tests revealed that the docks magnetic fixing wouldn't work because the Harbour Bridge steel structure is too uneven, a fact that prevented the magnet from adhering properly. So after re-evaluating the work environment the fixing was re-designed and changed by the researcher to a "spring clip push on fixing" (Figure 3.32). Fixing the dock in this way didn't offer as much flexibility as magnets but was more robust and allowed for single-handed operation.

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[23] Acrylonitrile Butadiene Styrene
[24] Polyvinyl chloride

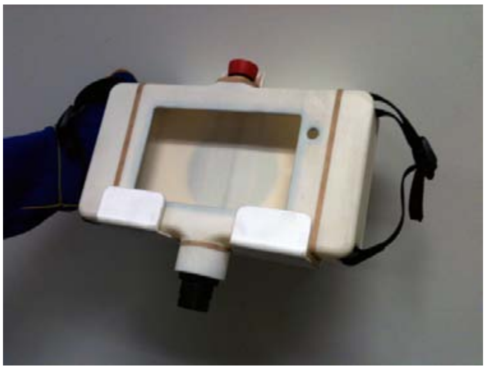

Figure 3.29:
Shell of OCU prototype 1 and Dock.

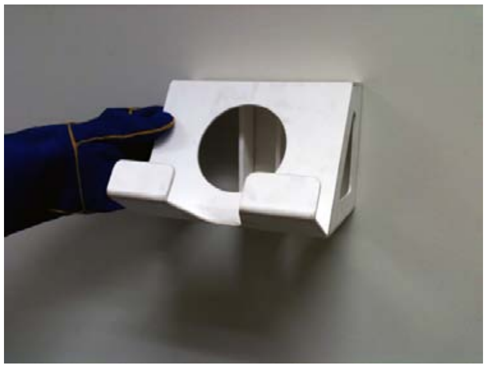

Figure 3.30:
Prototype of Dock made from PVC plastic.

Figure 3.31:
Fully assembled OCU prototype 1 and final version of the Dock made from alu.

Figure 3.32:
Final version of the Dock made from alu showing push on clip underneath.

At this stage the prototype of the entire SHB GAD system was ready for onsite testing and user trialling at the Harbour Bridge and in mid December 2011 the UTS team temporarily relocated the entire system to the Harbour Bridge and set it up in a blast enclosure. Figure 3.31 shows OCU prototype 1, fully assembled, sitting in its dock with the enabling device fixed to the centre bottom front. Figure 3.32 shows the final version of the dock manufactured from sheet aluminium, with the "push on spring clip fixing" (on the underside of the dock) made from galvanised sheet steel.

Figure 3.33 shows the complete prototype of the SHB GAD system set up, on site at the Harbour Bridge and ready for testing. The object covered in plastic is the SHB GAD, the OCU prototype 1 is visible in the front left area of the image. The GUI used for these tests was a fully functional version of GUI Version 1.

Figure 3.33:
The complete SHB GAD system set up in a blast enclosure on the Harbour Bridge.

The onsite tests revealed that two changes needed to be made to OCU prototype 1. The 1^{st} was to adjust the angle at which the cable exited the OCU at the centre bottom. The problem was that the heavy-duty strain relief gland used to protect the OCU cable was poking users in the lower abdomen while holding the OCU. The 2^{nd} change needed was the wall thickness of the OCU housing. Prototype 1 had a 2 mm wall thickness however tests revealed this to be inadequate so for prototype 2 it was increased to 4 mm. Additional features were also added such as a fixture for the enabling device and a yellow hi-visibility colour. After making these adjustments to the virtual 3D CAD model, OCU prototype 2 housing was manufactured in ABS using FDM, assembled (Figure 3.34) and made ready for the final round of user trials.

Figure 3.34:
Fully assembled OCU prototype 2.

The prototype version of the interactive element, the GUI (Graphic User Interface), was designed by the researcher and developed by the UTS software engineers with design input from the participants. So the participants did provide feedback on GUI concepts but weren't involved at a co-design level. It was designed and developed using Open Source Software. Not having participants directly involved was unfortunate but could not be avoided since the GUI functionality was closely linked to the progress made by UTS software engineers working on the entire system. During the time period of *Stage 2, Co-design* and *Stage 3, OCU prototyping* the UTS software engineers were progressing fast, particularly in relation to reduced processing times. Faster processing times meant that the scope of the GUI was ever changing. This changing environment made the design and development of the GUI challenging and so couldn't be completed until April 2012. By then the study had already progressed to *Stage 4, OCU prototyping* and there was not sufficient time left to involve the participants in the design of the GUI. However participants were able to critically analyse the GUI during the final user trials conducted at UTS. Following is a selection of screens of the interactive GUI representing various functions that were used in the final user trials (Figures 3.35 and 3.36, approximate scale 1:2).

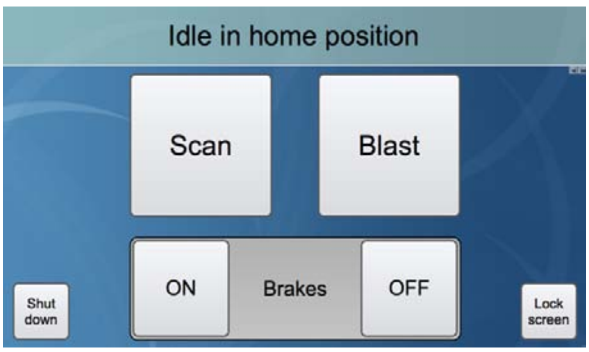

Figure 3.35:
OCU home screen, with main functions.

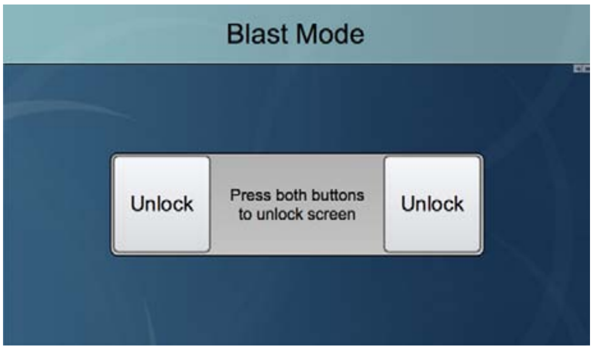

Figure 3.36:
OCU screen lock function.

The training sessions were conducted at the UTS SHB GAD lab. The UTS team had constructed a 1:1 scale cardboard mock up of a work environment identical to that of a typical blast enclosure on the Harbour Bridge. The focus of the training sessions was to allow participants to practice working with the whole SHB GAD system from beginning to end of an entire work cycle. The training sessions were conducted by four of the five participants in groups of two.

Stage 4. OCU implementation

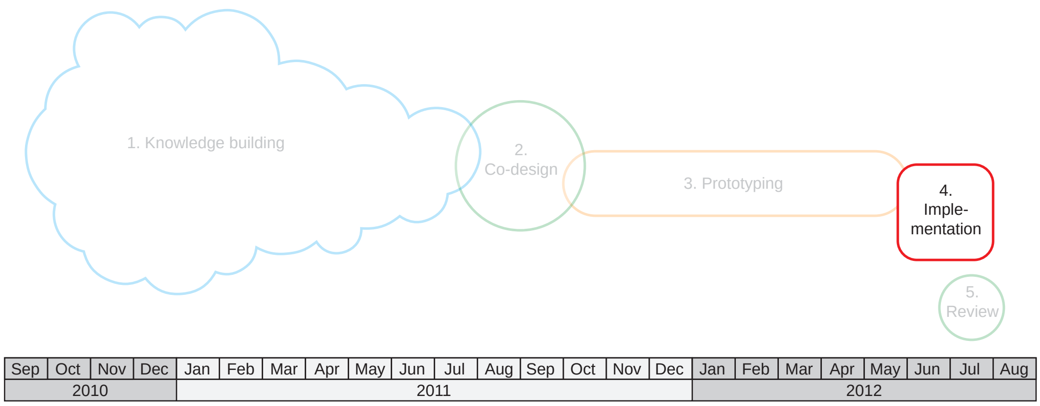

Figure 3.37:
Stage 4. OCU implementation.

The data obtained during the training sessions revealed that OCU prototype 2 required no further changes and was ready for implementation. Implementation of the OCU was the final stage of this study and was concerned with the manufacture the final real version of the OCU, the version that was actually going to be used by operators operating the SHB GAD on the Harbour Bridge. Implementing the tangible element (external housing and hardware) involved optimising the virtual 3D CAD model of the housing for manufacture and then manufacturing it utilising an Additive Manufacturing technology called SLS (Selective Laser Sintering). The material chosen was polyamide due to its high durability and impact resistance. The housing was then dyed yellow (dying the parts ensured they wouldn't show scratches), water proofed and assembled with all other components (Figure 3.38).

Figure 3.38:
Final version of the OCU, fully assembled and ready for implementation.

The interactive element (GUI) required no further changes so the version that had been used during the training session was implemented on the final OCU.

Stage 5. Post-study impression

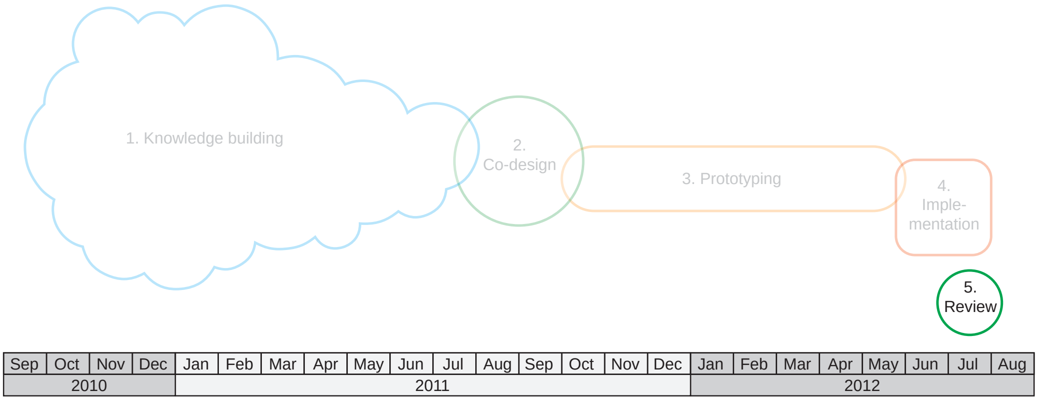

Figure 3.39:
Stage 5. Post-study impression.

On completion of *Stage 4, OCU implementation*, *Stage 5, Post-study impression* was conducted with four of the five participants. The objective the *Post-study impression* was to give participants the opportunity to reflect on the co-design approach and evaluate it from their perspective. Please refer to section 3.4.1 for a detailed explanation of how *Stage 5, Post-study impression* was conducted.

3.4 Measurement instruments

The measurement instruments were specifically devised to answer the two research questions. To review how the research problem arose and how it led to the research questions please refer to sections 1.4 and 1.5 respectively.

3.4.1 Measurement instrument for research question 1

Pre-study impression

To measure if participants thought the co-design approach was of value to them or not it was deemed useful to establish what they thought of the SHB GAD project prior to being aware that they would later be involved in a co-design approach. This would provide a pre-study impression of the project against which their impressions post-study could be measured (Bui 2009). Their pre-study impressions were evaluated through observation and exploratory questioning. Participants were observed and questioned in most project meetings during *Stage 1, Knowledge building* of the study. The meetings were held monthly and as much as possible all stakeholders, including RMS management and UTS engineers, were present in these meetings.

Post-study impression

Four of the five participants were interviewed one-on-one post-study and asked to reflect on the process. The interviews were conducted using a combination of direct and exploratory questioning supported by the non-linear interview map (Figure 3.40).

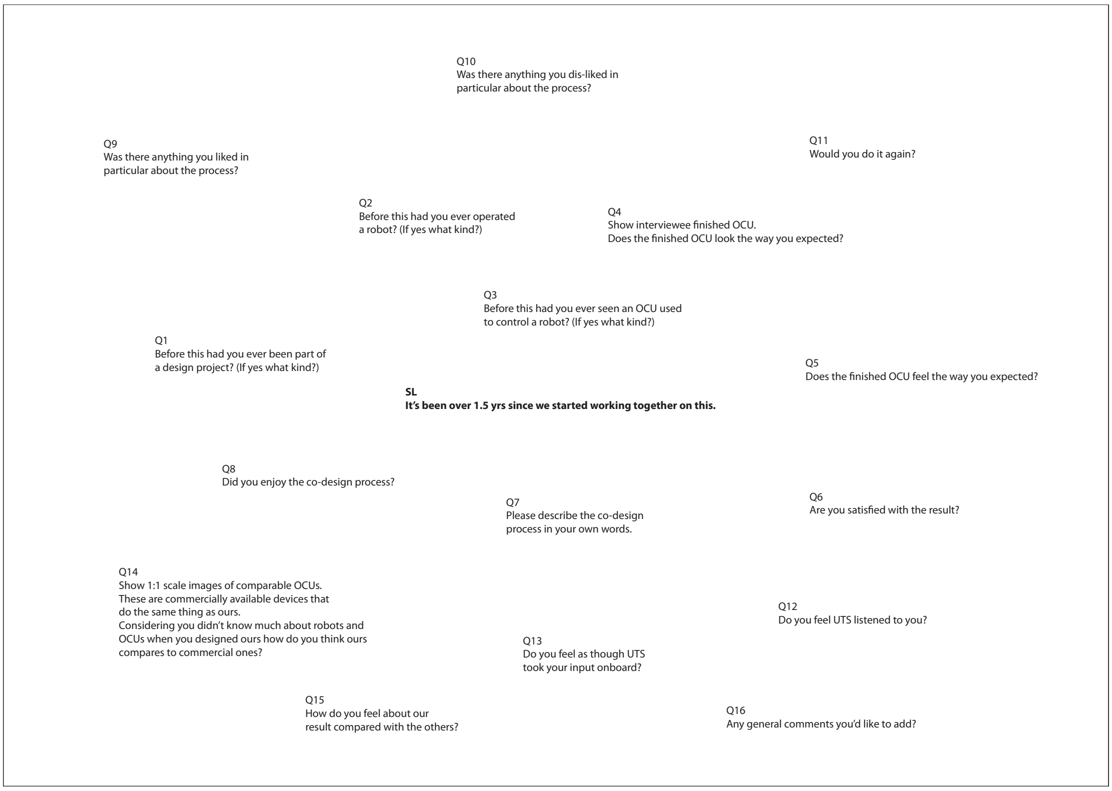

Figure 3.40:
Non-linear interview map.

The non-linear interview map contained all questions spread out on an A3 sized piece of paper. One map was used per interview. The purpose of the map is to allow the interviewer to use exploratory questioning and map the line of enquiry as the interview unfolds. Using the map ensures all questions are addressed while at the same time making the interview feel loose and flexible. In addition to this the maps proved particularly useful for post interview analysis in that they facilitated the reorganisation of transcribed interview data. The scaled down copies of the completed maps from all four interviews can be viewed in Appendix F.

Validation

Co-supervisor A. Prof. Bert Bongers reviewed and validated all interview questions and lines of enquiry prior to the interviews being conducted. The non-linear interview map was conceived during this review because there was concern that following a linear script would not allow participants to freely follow their train of thought. The non-linear interview map makes it possible to map the conversation as it unfolds. It also allows the interviewer to draw connections between questions that later can be used to analyse the train of thought the interviewee was following.

3.4.2 Measurement instrument for research question 2

Robotic OCUs are highly technical, specialized tools used in very specific work environments. This means that only people accustomed to working with them would recognise a robotic OCU if they saw one. Prior to this study none of the participating grit-blasters had any design experience nor had they ever seen or used an OCU able to control a robotic device. To measure if the OCU produced as a result of this study was relevant as a robotic control device, it was compared with two commercially available OCUs. The selection of the two comparison OCUs was based on the following criteria:

1. Must be IP Code 65 rated
2. Must be portable
3. Must be equipped with a resistive touch screen
4. Must be equipped with an E-Stop

Upon selection of the two comparison OCUs all three were compared by the following details:

1. Size
2. Location of handles
3. Likely ritual of use (manual handling)
4. E-Stop location

Validation

The measurement instrument for research question 2 was validated from two perspectives. The first being the selection criteria based upon which the comparison OCUs were selected:

1. Must be IP Code 65 rated
2. Must be portable
3. Must be equipped with a resistive touch screen (min 7" dia)
4. Must be equipped with an E-Stop

These criteria were selected because they were requirements that the SHB GAD OCU needed to comply with and were beyond the control the co-design team. They were also criteria related predominantly to the tangible element of the OCU, which was the element that was designed by the co-design team. Furthermore selecting comparable OCUs, utilizing these criteria ensured that there would be parallels between all three units.

The second perspective being the selection of details of each OCU that were compared, and in terms of validation these were more important:

1. Size
2. Location of handles
3. Likely ritual of use (manual handling)
4. E-Stop location

These details were selected because they were within the scope of the co-design team. By drawing direct comparisons between the details of all three units it was possible to identify the similarities and differences.

Other measurement instruments for research question 2 were considered and then dismissed due to budget or time restrictions:

1. Purchasing, hiring or borrowing the comparison OCU's and then conducting comparative user trials with all three OCU's.
2. Employing an independent expert in the field of mechatronic engineering or industrial design to author a product comparison report.

3.5 Data collection procedures

Data collection for research question 1

Handwritten notes taken during meetings (Appendix E) were used to collect the data for the pre-study impression.

The post-study impression interview data was recorded using a MacBook Pro (laptop) and iMovie (software). The file format for all video data was mov. The audio was extracted from the mov files using MPEG Streamclip, to aiff audio file format. All interview audio was transcribed (Appendix G) by Reporters Ink Transcription. Reporters Ink sent the transcripts via email in doc format. Each interview was mapped on a non-linear interview map (Appendix F).

Data collection for research question 2

The data to answer research question 2 was collected in discussion with UTS engineers working on the SHB GAD project and by researching comparable OCUs on the Internet. Images and dimensional data of the Siemens and Denso comparison OCUs were obtained from product specifications listed on the respective websites.

Chapter 4. Results

The results are presented in a manner that links them to the research questions. To begin with section 4.1 and 4.2 provide a detailed outline of the data analysis process. The results are then presented in section 4.3 and 4.4.

4.1 Data analysis of research question 1

A process of thematic analysis was utilized to analyse both the pre-study impression and post-study impression data.

The pre-study impression

The pre-study impression data (handwritten notes taken during meetings, see Appendix E) was analysed by identifying patterns in the comments made by participants. The patterns were then grouped into themes, which identified an overarching theme that allowed for a conclusive pre-study impression to be established (see section 4.3.1).

Post-study impression

All interview transcripts (Appendix G) were reviewed by the researcher and checked to ensure the transcription service had not made any errors.

Where applicable answers to direct questions were grouped and analysed in response to research question 1.

The sections of the interviews that existed as a result of exploratory questioning were subjected to a three stage process of thematic analysis (King & Horrocks 2010):

Stage 1	**Descriptive coding** Parts of the transcripts likely to aid in responding to research question 1 were identified by reading through printed copies of the transcripts and manually highlighting relevant material, supported by handwritten comments.
Stage 2	**Interpretive coding** Descriptive codes were interpreted and sorted into themes in relation to research question 1, using qualitative data analysis software (Nvivo 10).

Stage 3 **Overarching themes**

Interpretive themes were further analysed and sorted in Nvivo to allow for identification of overarching themes.

Each overarching theme was subsequently described and characterised using direct quotes made by participants (section 4.3.2).

4.2 Data analysis of research question 2

Based on the selection criteria (see section 3.4.2) the following commercially available OCUs were selected as comparisons:

1. Siemens Simatic Mobile Panel 277 (Figure 4.1)

2. Denso TP-RC7M-1 (Figure 4.2)

Figure 4.1:
Siemens Simatic Mobile Panel 277.

Figure 4.2:
Denso TP-RC7M-1.

The SHB GAD OCU was compared with the Siemens and Denso ones through a process of visual comparison. This process was conducted by comparing the details, listed below, by eye using 1:1 scale versions of figures 4.1 and 4.2 and by comparing overall dimensions.

The following details were compared:

1. Size
2. Location of handles
3. Likely ritual of use (manual handling)
4. E-Stop location

Both visual and dimensional attributes of each detail were collated in a table (see section 4.4, figure 4.3) and analysed based on how they compare to one another.

Interactive elements could not be compared because that would have required purchasing, programming and testing the comparison OCUs with the entire SHB GAD system, which was beyond the scope of this project.

4.3 Results for research question 1

The Pre-study impression and in particular the Post-study impression results necessary to answer research question 1 are extensive. So to help with a clear presentation they have both been given their own sub-section headings, which follow below.

4.3.1 Pre-study impression results

To establish what participants thought of the SHB GAD before the co-design stage, a pre-study impression analysis was conducted, by analysing comments made by participants during four project meetings held prior to the co-design stage commencing.

> Comment by a participant during the project meeting on 12.10.2010:
>
> > *"There is no advantage to blast an area that is flat with a robot, this is easy to do manually."*
>
> Comment by a participant during the project meeting on 20.01.2011:
>
> > *"It takes 5 min to blast the large flat area [of a panel], this is the easy work that we prefer doing. It takes 15 min to blast flanges and rivets this is harder. 'Pigeon holes' above the I-Beams [small cavities above head height] are very hard to do. The robot should do the hard areas so we can do the easier work."*
>
> Comment by a participant during the project meeting on 22.02.2011:

> *"The 'cream' of the job is the easy part, flat sections, we [blasters] want to do these. We don't want to do rivets, edges and hard to reach areas."*

Comment by a participant during the project meeting on 17.05.2011:

> *"The robot should hold the biggest nozzle possible, too big for a human to hold [due to too much force] then blast using a joy-stick [in other words: the machine should not be autonomous but remotely controlled]. It would be better if the robot did the difficult areas rather than the 'cream'."*

To enable analysis these comments need to be given a conversational context within which they were made. This context was that at that point in time, the UTS team was unable to guarantee that the SHB GAD would be able to scan and blast geometries more complex than flat vertical surfaces. Therefore more complex geometries such as rivets, flanges and "pigeon holes" could not be done by the SHB GAD. In all the meetings the complex geometry issue was raised and as a consequence participants repeatedly responded with what their expectations of the SHB GAD were.

This analysis identified an overarching theme, which was that participants wanted the robot to do the harder work. Considering that the comments were made repeatedly over a period of seven months it can be concluded that participants were not very interested in using the SHB GAD if they still had to do the harder work manually. At that point in the project setting up the SHB GAD system prior to blasting was a complicated and, at 2 hours, a time consuming process. Participants were arguing, that such a time consuming setup process was not worth doing, just to blast flat and easy to do sections that manual blasting could do in a very short time.

It is in no way implied here that the participating grit-blasters were not in favour of the SHB GAD project and did not want it implemented. However it can be concluded that, due to the type of work that the SHB GAD would be capable of doing, participants were at the time, not convinced that it would be a useful tool for them.

4.3.2 Post-study impression results

To establish what participants thought of the co-design approach, a post-study impression was conducted by interviewing four of the five participants and discussing the study with them. The fifth participant was unable to attend his interview due to last minute professional duties. To give the interviews and the resulting data context it is helpful to briefly reiterate the setting in which they took place and the working relationship that had developed between participants and the researcher. The interviews were conducted one-on-one in the "small" lunchroom at the RMS Sydney Harbour Bridge Southern Pylon Maintenance Site. This setting was chosen because it was a familiar setting in which the participants felt at ease. At that point of the study the researcher had been working with the participants for 18 months and had met with them more than 20 times for meetings, reviews and a workshop. So participants knew the researcher well and were comfortable talking about the study in his presence.

The thematic analysis of the data resulting from the interviews led to the identification of three overarching themes:

1. Did participants understand the co-design approach?
2. Did participants think the co-design approach was worth doing?
3. Were participants interested in using the SHB GAD?

In addition there were three direct questions asked during the interviews:

1. Did participants enjoy the co-design approach?
2. Would participants do a co-design project again?
3. Is the resulting OCU as participants expected?

Following is a discussion of all overarching themes and questions.

To allow for an informed discussion about what participants thought of the co-design approach it was deemed important to ascertain if participants had gained an understanding of it. To investigate this they were asked to describe the process in their own words as if they were talking with a friend or family member. The data resulting from these descriptions led to the first overarching theme:

1. Did participants understand the co-design approach?

   All participants were able to describe the approach succinctly as these direct quotes characterise:

   P1

   "We all got together, had a chat about it [the SHB GAD project] and then came up with a lot of different ideas and this is what came out of it [points at the OCU]. This is the baby."

   P2

   "Yeah, yeah, with everyone's input; everyone put in a bit - one guy said this, one guy said that, one guy said that and one of us said that [pointing at various details on the OCU]. It was a team effort."

   P3

   "… we [participants] designed something like that [points at the OCU] and you guys [UTS team] refined it. And, yeah, it's mainly all of us."

   P4

   "So using everybody's individual ideas, pretty much, was the lead-up to the design [points at the OCU]."

Although these comments are short in length they demonstrate an understanding of the fundamental aspects of the co-design approach as it was used in this study, since all make reference to the fact that it was about doing something together and using everybody's input. Therefore it can be concluded that participants had understood the co-design approach in principle.

Overarching theme 2 emerged through an indirect line of enquiry as a result of several questions posed. In relation to research question 1 this overarching theme is the most relevant because it gives one insight into how participants had experienced the co-design approach.

2. Did participants think the co-design approach was worth doing?

   Following is a selection of indirect quotes in relation to this:

   P1

   "Well, I think it's important that this process was carried out because you [participant referring to himself] obviously have a better idea/understanding [better than the UTS team] what the environment is going to be like and the product [points at the OCU] shows how that's reflected in being able to put these together [manufacture of the OCU]."

   P2

   "At least everyone listened to everyone and it wasn't just one way dictating. So everyone had something to say and they were listened to; not discriminated against, it looks like a piece of everyone went in there [points at the OCU]."

   P3

   "Well, yeah, I mean, you know, the process that we [participants and researcher] did, designing it and building it and everything, I mean you guys [UTS team] have taken everything into [account] what we have actually said. The end product is - you know, you couldn't really ask for anything else. You look at the end result here. I mean, in the group of four/five, however many of us were involved in the whole process, I mean you guys [UTS team] definitely listened because all the little things - you know, how strong this has to be and the environment it's going to be in and you guys really took that all in …"

   P4

   "We [participants] told you [UTS team] what we want and everything just went there; on paper and design. It was bloody fantastic."

All responses clearly demonstrate that participants thought the co-design approach had been worthwhile. The response from P1 is particularly interesting because it demonstrates confidence in his knowhow of the work environment, knowhow that he knows the UTS team didn't have. He then points out that after working together participants' knowhow of the work environment combined with UTS teams' technical knowledge led to a successful outcome.

Overarching theme 3 emerged from random comments made by two participants in relation to using the SHB GAD.

3. Were participants interested in using the SHB GAD?

P3

"… can't wait to see it [SHB GAD] out there in the environment and give it a go."

P4

"I just can't wait to get started."

Both comments indicate that these two participants are interested to see the SHB GAD operational and would like to use it themselves.

Answers to direct question 1:

1. Did participants enjoy the co-design approach?

   All participants said that they had enjoyed it but their reasons were not all the same as the first two quotes indicate:

P2

"Ah, I suppose it's better than being on the job, yes (laughs). Better than going out there and sucking lead and better [being] in a clean environment, yeah."

P4

"For sure, yeah. Got me out of work (laughs). No, it was good. I liked designing things like that [points at the OCU]. It was good. I was happy with it."

P2

"Yeah, I did, actually. I thought it was really good. You know, having UTS sort of approach us - I mean, this [grit-blasting] is our [participants] job. This is what we do every day. To have you guys [UTS team] sort of include us in on that, you know, come up with a design and all the rest of it, I thought that was great, yeah. I enjoyed it. I really liked the modelling process [co-design workshop]. You know, with the cardboard and with the

plasticine and all the rest of it and where the E-stop is going to go and - I don't know, it felt like we were really involved. I thought that was really good. Some people might take [your] ideas and run off with them and it's like, 'Hang on, where did that come from?', but we were really involved in the whole process and we still are, which is good."

P4

"Oh, for sure, yeah. To see someone design and to see something like this [points at the OCU], and it's all real/physical [exists as a real device] and things like that, it's fantastic. You can see some of the ideas [from participants] in here, too. Yeah, I loved it."

It is necessary to reiterate here that participants do very hard, dirty and dangerous work, therefore it is not surprising that two of them were happy to participate because it "got them out of work". To give this a temporal context: the sum total of time that their participation allowed them to be away from work amounted to approximately 26 hours over a period of 80 weeks, so approximately 20 min per week for the duration of the study. This does not constitute much time away from work considering participants work around 35 hours plus overtime per week.

In contrast to this the responses from other participants are a clear indication that they enjoyed the process as a whole. In addition they appreciated being involved, in that their contributions and ideas were noted during the process and applied to the end result. The fact that ones contributions have been considered and included in the final outcome may be pertinent to a participant enjoying a co-design approach. This will be further discussed in Chapter 5, Discussion.

Answers to direct question 2:

2. Would participants do a co-design project again?

   All participants answered this question with a clear yes:

P1

"Yeah, of course."

P2

"I would say I would, yes."

P3
"Oh, 100 per cent. Yeah, definitely do it again."

P4
"Oh, for sure, yeah."

However considering some of the answers to question 2, being away from work may be the motivation for some. Nevertheless, the clear yes answers viewed in conjunction with responses to overarching theme 2 (Did participants think the co-design approach was worth doing?) indicate that participants saw value in being involved and that being part of a project in this way had been a positive experience.

Answers to direct question 3:

3. Is the resulting OCU as participants expected?
   This question was to identify if participants thought we had achieved what we set out to achieve. During the one-on-one interviews participants were shown the final version of the OCU they had helped design for the first time. Until that point there had been no concrete evidence that their design would actually be implemented. In broad terms all participants agreed that it was the way they had intended. This is likely to be due to the participants being bias towards something they helped design and, due to their sense of pride and achievement were commenting favourably on it. However during the course of being able to touch and feel the OCU some interesting comments were made:

P1
"It actually feels, and looks, a lot more bullet-proof. It is a lot more rigid [than expected]."
(this comment was made in an upbeat and positive manner)

P3
"It looks very tough. It looks like it can withstand the lifestyle environment, which it's going to be in. Yeah, it is comfortable [holding the OCU in is hands]. I think that will go well. I think that will work really well in that environment."

P2

"Considering the job that we are dealing with and that, how else would we - with all the input from the boys, I think this [pointing at the OCU] is what you end up with. If there was an easier way, we would have thought about it. You would think so. But it seems alright. I think so. It looks pretty robust. Yeah."

In retrospect these responses are not surprising considering participants did not know how and from what material the OCU was to be made. Not having this information prompted them to elaborate on the final OCU in more detail and the resulting comments show, to a degree, that the result exceeded their expectations. On the other hand most designers would deem it important to know exactly what material the device they were designing was to be made from and how this material would feel.

The post-study impression results demonstrate that participants saw the co-design approach as worthwhile and would do it again if the opportunity presented itself. They appreciated having been involved in the study and being able to contribute at a high level in the design process. They were satisfied with the end result and two of them were looking forward to using the SHB GAD themselves.

4.4 Results for research question 2

The following table (Figure 4.3) lists the attributes of the four details in relation the each OCU and how they compare.

	Siemens 	Denso 	SHB GAD OCU 	How they compare:
Size	290 mm (Dia) 103 mm (D)	290 mm (W) 198 mm (H) 80 mm (D)	300 mm (W) 164 mm (H) 73mm (D)	Comparable
Location of grip area (handles)	Left + Right	Left + Right	Left + Right	Identical
Likely ritual of use (manual handling)	Pick up with left or right hand by left or right grip and use other hand to interact with screen.	Pick up with left or right hand by left or right grip and use other hand to interact with screen.	Pick up with left or right hand by left or right grip and use other hand to interact with screen.	Identical
E-stop location	Front facing, top left	Front facing, top right	Up facing, top centre	Non comparable

Figure 4.3:
OCU comparison table.

Code: Identical = the same size, area or ritual of use
Comparable = within a similar range of size, area or ritual of use
Non comparable = not within a similar range of size, area or ritual of use

The data presented in figure 4.3 shows that out of the four details compared details 2 + 3 are identical, detail 1 is comparable and detail 4 is not comparable.

Chapter 5. Discussion

Additive Manufacturing combined with Open Source Hardware + Software offer new possibilities for the manufacture of interactive devices. These new possibilities may mean that such devices no longer need to rely on high volume mass production for manufacture but rather could be made in numbers as low as one unit. If products could be produced in small numbers designers could turn their attention to user groups that are small in size due to unique professional or site specific requirements. If user groups were small, ranging from 1 to 20 users, it may be feasible to cooperatively design the device with the users.

Co-design approaches are not yet widely used in Industrial Design or HRI (Human Robot Interaction) practice so to gain a better understanding a real-world project was selected and a qualitative study conducted. The study attempted to investigate how well a co-design approach would work when designing an interactive device for small, specialized user groups. The study was to design and develop the OCU to be used to control the SHB GAD.

Primarily the study sought to investigate how the co-design approach is viewed from the perspective of the participants involved in the study, this is research question 1. Secondarily it investigated how the resulting OCU would compare with commercially available OCUs and this was research question 2.

The following discussion focuses first on the results to answer research question 1 (section 5.1) and then on the results for research question 2 (section 5.2).

5.1 Discussion of research question 1 results

Research question 1 (see section 1.5) was a complex question that required several lines of enquiry for it to be answered. In an attempt to make this coherent each following paragraph seeks to address research question 1 from a different line of enquiry.

Did the co-design approach affect participants' opinion of the SHB GAD?

To begin with it was deemed necessary to establish a pre-study impression to ascertain if a co-design approach would have an effect on participants opinion on the SHB GAD project. The results that emerged from the pre-study impression (see section 4.3.1) showed that participants were unlikely to use the SHB GAD if the setup time was around 2 hours, when it would only be capable of grit-blasting flat vertical sections, sections that are easily and quickly done manually.

Participants were quite clear about the fact that they wanted the SHB GAD to do the hard work for them, such as rivets, flanges and pigeonholes. The pre-study impression was based on participants' view of the entire SHB GAD project whereas the post-study results are in relation to the co-design of the OCU and the resulting OCU, not the entire SHB GAD project. In comparison the pre-study impression results were not as positive as the post-study impression results, which are decidedly enthusiastic (see section 4.3.2). And the post-study impression revealed that two participants were looking forward to seeing the SHB GAD in action and using it themselves. This increase in enthusiasm from participants is likely to be as a result of having taken a co-design approach. This is probably due to the fact, which it is inherent to the nature of co-design, that just being asked to contribute to something will increase ones enthusiasm for it. Of course there were other factors that may have increased participants enthusiasm for the project. It could have been due to the passing of time because being involved in something over a long period of time may provide more context and understanding, which may change ones point of view. Or it could have been due technological advances made by the UTS engineering team working on the SHB GAD. However it can be concluded that the co-design approach and its resulting outcome had an overall positive effect on participants' opinion of the SHB GAD project.

Did participants understand the co-design approach?

The results here suggest that participants had understood the approach and were able to articulate it quite succinctly. However these results are not surprising considering that the researcher explained the approach to them in detail before commencing. Nevertheless it was thought necessary to ascertain if it had made sense to them before further investigation into their views of the co-design approach were possible.

Did participants think the co-design approach was worth doing?

These results demonstrate that participants thought the co-design approach was of considerable value to the project, but they also suggest that participants may have a sense of fondness for the approach. They realized that they had knowledge to contribute and appreciated that they were taken seriously as experts in their field and that all were treated as equals. It has to be said here that this fondness towards the process is likely to be linked to the outcome. In other words if participants cannot see any evidence of their contribution in the end result they may no longer care about the approach. So for a co-design approach to be worthwhile from a participant's point of view their contributions need to be visible in the end result. This may seem obvious but it is intrinsic to the success of a co-design approach.

Did participants enjoy the co-design approach?

Would participants do a co-design project again?

The responses to both of these questions are clearly in favour of the co-design approach. In some cases this was due to being able to "get out of work" and this may be understandable considering the type of work they are required to do. Or this could be simply due to the fact that they had attention paid to them. However based on all that has been discussed up to this point participants are likely to have enjoyed the co-design approach for more noble reasons than just "getting out of work".

Is the resulting OCU as expected?

The responses to this question are interesting because they reveal that participants did not know what the material of the OCU housing would look and feel like. This is no surprise considering they had little to do with the manufacturing of it. Yet it is an important detail, considering that the OCU is a device that is used with ones hands, therefore it may have been an advantage to discuss material and manufacturing in more detail earlier in the project. This could be done by showing participants material samples and giving them the opportunity to critically analyse the samples in relation to the device in question.

5.2 Discussion of research question 2 results

Please refer to the comparison table (Figure 4.3 under section 4.4) to review which details of the three OCUs were compared.

How did the details compare?

Of all four details compared only one, the location of the E-Stop button, was different. Of the other three, two were identical, such as the location of the handles and the likely ritual of use, and one, the dimensions, was comparable. This data demonstrates that, when viewed in context, there are obvious visual connections between all three OCUs that allow the SHB GAD OCU to be indentified as a robotic OCU. This may be an interesting finding considering that none of the participants had any prior knowledge of industrial design nor had any of them ever operated a robotic OCU. They made their design decisions based on what they thought would serve the purpose best.

How to decide which details to design cooperatively?

What this finding may be revealing is that for a co-design approach in a specialized setting such as this one to be successful the design problems that are to be addressed during the design process need to be as clear and specific as possible with concrete boundaries that should not be crossed. In this study participants were asked to make high-level design decisions relating to ritual of use, manual handling and safety. Low-level design decisions such as wall thickness of the housing, radii on corners, what type of straps to be used on the handles and ergonomic data considerations were all made by the researcher. High-level design decisions are generally more important and interesting problems to solve and being asked to make high-level design decisions indicates to participants that their contributions are valuable due to their professional knowhow. And participants are likely not to have the knowledge and skill to solve the low-level design decisions. The location of the E-stop button on the SHB GAD OCU illustrates this well. During the co-design workshop participants discussed at great length, where the E-stop should go. Figures 3.18 and 3.19 in section 3.3 show models made by participants where a piece of timber dowel represents the E-stop button. In both those figures the E-stop is in a different location to where it is on the final version. Participants made this decision because they wanted to ensure their OCU could be used in the same way with the right hand as with the left. In this instance participants were not concerned with low-level considerations in relation to how this would technically and physically be achieved. Not needing to deal with such low-level considerations allows for a certain freedom in decision-making.

5.3 Discussion of additional findings

This section discusses important additional findings uncovered by this research, however they are not directly related to the research questions.

Small, specialized user groups exist

The SHB GAD is a machine that is designed for a site-specific location and only two of these machines will be built for deployment on the Harbour Bridge. The group of users that will receive training enabling them to use the SHB GAD consists of ten people. This is a small user group with a special need and is proof that small, specialized user groups exist.

Manufacturing in low numbers is feasible

The results furthermore prove that it is feasible to manufacture a robust and fully functioning interactive device, using Additive Manufacturing and Open Source Hardware + Software, in numbers as low as two units.

Know your participants

One has to appreciate how awkward it could be to encourage five construction workers to sit down together in a room and make cardboard and play dough models for 1.5 hours, as was done in the co-design workshop during this study. So getting to know each other during *Stage 1, Knowledge building,* of this study was of utmost importance. Depending on the type of participants the planning has to be done well in advance and with a clear understanding of participants capabilities and personalities. If the workshops are not planned well and participants not well understood the results may be of little use and everybody's time wasted. This could be particularly detrimental if the project is real-life and participants' time is paid for by an employer expecting a useful outcome.

50% user representation

For this project the entire user groups only consisted of ten users and five of them were directly involved in the study. This means that 50% of the entire user group was represented which constitutes a very large sample. This is of course possible due to the fact that small user groups are low in numbers. Nevertheless it is important to note that compared with larger user groups where the sample size may be around 5%, a 50% sample size is very good coverage of a user group.

5.4 Limitations

What follows is a discussion of limitations to the study and to some degree to the validation of the results.

Improvements to the pre-study impression

The pre-study impression was constructed by retrospectively reviewing notes taken during meetings, which was not optimal. But at the point at which the pre-study impression was needed, retrospectively reviewing the notes was the only way to do it. The early stages of real-life projects can be confusing for all involved as was the case here. Because they are set in real-life, where large amounts of money may be involved, they move forward at a pace that is different to an academic study. It is therefore recommended that early in the project as much early data and insights as possible be gathered, even if the project has yet to gain a clear focus and gather momentum. The more early data one has to choose from allows for a better understanding of the problem space and for a richer pre-study impression to be constructed.

Improvements to validating the results

The validation of the results could be reinforced by bringing in an independent observer, who analyses the data and compiles his or her own set of results against which the researchers set of data could be compared with.

Independent user evaluation

It would have been useful to have the SHB GAD including its OCU independently evaluated by users who were not involved in the co-design approach. Such an evaluation was originally planned for but this research concluded before the entire system was ready for testing.

Process of self-reflection

During the study the researchers role was also that of a consulting industrial designer. Due to this it would have been useful for the researcher to reflect on the co-design approach from his perspective as the consulting industrial designer. This may have provided other designers interested in experimenting with a co-design approach in real-life with additional information to what is presented here.

5.5 Future research

The researcher is of the opinion that more research needs to be conducted in the area of interactive device design for small, specialized user groups. This is both in relation to user groups and their needs and what design approaches to take. There are many indicators that prove this area will expand rapidly and that such user groups exist as the research presented here demonstrates. However there is not yet enough literature available to verify this. If there were a contextual definition and demonstrated existence of such groups it will be easier to conduct more research in this area.

The above could then be connected to the finding that participants of this study designed an OCU that is comparable with commercially available OCUs. They did this even though they had no previous design or robotics experience, which is interesting in that it will prove useful for the design of specialized interactive devices for other professions. The thinking here is not that professionals would repeatedly design similar products that are already in existence but rather that participants may develop new solutions that, using conventional design approaches could be missed. This could help generate new ways of structuring design processes and could therefore be useful to investigate.

Another avenue for future research could investigate what factors enable or work against a co-design approach in work situations comparable to the case study presented here.

For future projects of a similar nature to this one it would be helpful to draw a cost comparison between the cost to design and make a device (the way we did in the project) and the cost of purchasing an off the shelf device.

Both for the mapping of the interviews and the post interview data reorganisation, the non-linear interview maps proved to be effective. However this a new tool and technique and as such requires further refinement.

5.6 Contributions

Following are the contributions that the researcher is able to make to further the knowledge is this area of research.

1. **Employer driven participant selection**

   The researcher consciously chose to leave participant selection up to RMS management (see section 3.2). In a real-life study this is important because the management structures have an interest in the project succeeding, which in turn, will influence the selection process. It also forces management to see their employees as active collaborators in the process and makes the connection between employees and the project explicit.

2. **Non-linear interview map**

   The non-linear interview map (see section 3.4.1 and Appendix F) was conceived with co-supervisor A. Prof. Bert Bongers. It consists of a large piece of paper, in this case A3, which has all interview questions spread out on it in a non-linear way. It allows the interviewer to conduct the interview in an unstructured fashion while still keeping track of all relevant lines of enquiry. It was utilized during the post-study impression interviews and was very successful in its application. Furthermore it facilitates reorganisation of transcribed interview data during the post interview analysis.

3. User group specific co-design

This research demonstrates that for a co-design approach to be effective all participants need to be comfortable working with each other. Therefore, regardless of the type of participants, one of the most important tasks of the consulting designer is to work actively at building a good team dynamic. This will contribute considerably to a successful project outcome.

5.7 Conclusions

The results from this study lead to five conclusions.

Conclusion 1

When one is working on a real-life project that involves designing an interactive device for a small, specialized user group, taking a co-design approach is likely to increase participants/users understanding of and support for the project. With some projects that involve designing an interactive device for such a user group users could be in support of the project right from the start and there may be no need to attempt to increase user support. However if it is probable that users are anxious or unsure of how the project will affect their profession and or employment situation, planning a co-design approach and involving users as participants in the process may assist in reducing such anxieties. As a strategy this is particularly likely to succeed if participants are involved in high-level design decisions that will affect the outcome in meaningful ways. However some, not necessarily all, of these high-level design decisions need to be visible on the final outcome. If they are not visible participants may be of the opinion that their contributions were valued. Having said this if some design decisions are deemed inappropriate by the designer, based on his or her expertise, this needs to be discussed with the co-design team. In other words at the end of the process all participants need to be happy with the outcome.

Conclusion 2

If users/participants of a small, specialized user group are involved in a co-design approach for the design of an interactive device they are likely to enjoy the process, and the results from the study suggest that this may occur at different levels. At an individual level, participants seemed to value that their own professional knowhow was seen as important and enjoyed being able to contribute to high-level design decisions. At an interpersonal level, participants appreciated that they had been involved in the co-design approach together and that they had managed to solve high-level design details cooperatively. And at the project level participants were proud that much of the work they did while co-designing was implemented on the final outcome and that their contributions were visible.

Conclusion 3

This conclusion is in relation to the OCU resulting from this study being visually comparable to commercially available OCUs if viewed in context, even though none of the participants had any previous design or robotics experience. It appears that two elements enable good design solutions to eventuate as a result of taking a co-design approach. The first is that the technical and contextual constraints of a project need to be concrete and clearly stated. The second is that the professional knowledge that is being applied to the design decisions by participants needs to be directly focused on the design problems. Of course this is easily achievable because the user groups are small and the function of the device very specific. This in turn simplifies the design because it reduces the amount of functions the device needs to have.

Conclusion 4

To successfully apply a co-design approach under real-life circumstances the preliminary stage should be used, amongst other things, to build relationships between all participants including other stakeholders and the researcher. While conducting a co-design approach it is important that participants feel comfortable to speak their mind during meetings and reviews. Especially if they may be contradicting the opinion of another participant or stakeholder that is higher ranked in the company than them. It seems worthwhile for the person who is in charge of managing the co-design approach to keep this in the front of their mind and apply effort to build and strengthen interpersonal relationships.

Conclusion 5

The fifth and final conclusion is that there is a need for interactive devices catering to the needs of small, specialized user groups. Once designers are able to identify such user groups this area in design is likely to gain traction. The user groups themselves also need to realize that there are ways to manufacture interactive devices for them, no matter how low the production numbers. As soon as they realize this they will seek out designers to do the design work for them. Once there are more channels to identify the need for interactive devices catering to small, specialized user groups this area is set to become a new direction for design consultancy services to specialize in.

In closing the researcher would like to clarify that this was not a comparison of design approaches but rather a professional experiment, a unique real-life project opportunity to work on an interactive device cooperatively with a small, specialized user group. The project and all stakeholders were real and if this study had been conducted in a theoretical framework to investigate if participants would enjoy a co-design approach without actual implementation of the final outcome, the results would most likely not have been a true representation of participants' views. This study is unlikely to have yielded the same results if it had not been a real-life project and had not been seen through to implementation. This has to be understood as the most significant aspect of this study and was also the aspect that made this a highly enjoyable research and design project.

Appendices

Appendix A

UTS HREC approval of ethics clearance for this research.

UNIVERSITY OF TECHNOLOGY SYDNEY

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UTS CRICOS PROVIDER CODE 00099F

10 February 2011

Associate Professor Dikai Liu
School of Elec, Mech and Mechatronic Systems
CB02.06.07
UNIVERSITY OF TECHNOLOGY, SYDNEY

Dear Dikai,

UTS HREC 2010-422 – LIU, Associate Professor Dikai, BONGERS, Associate Professor Bert (for LIE, Ms Stefan, Masters student) – "The development and design of the interaction interface for a Grit-blasting Assistive Device"

Thank you for your response to my email dated 15/11/10. Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics clearance is now granted.

Your clearance number is UTS HREC REF NO. 2010-422A

Please note that the ethical conduct of research is an on-going process. The *National Statement on Ethical Conduct in Research Involving Humans* requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

If you have any queries about your ethics clearance, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,
Production Note:
Signature removed prior to publication.
Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee

THINK.CHANGE.DO

Appendix B

Letter submitted by RMS (formerly RTA) management granting consent for RMS grit-blasters to participate in this research.

RTA

Date: 24 February 2011

Susanna Gorman
Research Ethics Manager
University of Technology Sydney
PO Box 123
Ultimo
NSW 2007

Re: RTA Letter of Consent for masters student research

Dear Susanna,

I am the Alliance Manager - SHB who has overall responsibility for the RTA Sydney Harbour Bridge maintenance site.

This letter is in regard to UTS Engineering Masters student Mr Stefan Lie who is on the Project Team and undertaking research into "The development and design of the interaction interface for a Grit-blasting Assistive Device for the SHB".

Mr Lie's research forms part of the UTS RTA GAD (Grit-blasting Assistive Device) project which is a joint project between UTS and the RTA. The GAD is a device that will assist RTA grit-blasting professionals in their bridge maintenance work on the Sydney Harbour Bridge.

To ensure that the UTS RTA GAD project results in a successful device that suits the needs of the SHB blasting team it is essential that Mr Lie works closely with my RTA grit-blasting professionals. The RTA grit-blasting professionals will be able to provide crucial insight into the way they conduct their work as grit blasters and how the GAD will best assist them in their work.

I understand that the Human Research Ethics Committee (HREC) has granted approval (UTS HREC REF NO. 2010-422A) for Mr Lie to interview my personnel. I am hereby granting consent for our RTA grit-blasting professionals operating on our Sydney Harbour Bridge maintenance site to be interviewed by Mr Lie for his critical research work.

Yours sincerely,

Production Note:
Signature removed prior to publication.

Signature 24/02/2011

Mohammad Qaium
Alliance Manager
Sydney Harbour Bridge

Name:- M Qaium

Appendix C

Blank copy of consent form and accompanying information sheet that participants willing to participate in the study were required to sign.

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UNIVERSITY OF TECHNOLOGY, SYDNEY

CONSENT FORM

I ______________________________________ *(participant's name)* agree to participate in the research project "The development and design of the Interaction Interface for a Grit-blasting Assistive Device" (UTS HREC 2010-422) being conducted by Stefan Lie (UTS: PO Box 123, Ultimo, NSW 2007, Ph: 0412 406 697) of the University of Technology, Sydney for his degree Master of Engineering by research under the supervision of A. Professor Dikai Liu (Ph: 02 9514 2587). Funding for this research has been provided by the Road Traffic Authority (RTA) of NSW and UTS.

I understand that this research is about designing an electronic device that will allow RTA personnel, such as myself, to control a new Grit-blasting machine.

I understand that my participation in this research will involve:

- Me granting to be interviewed by the researcher Stefan Lie about my work process as a Sydney Harbour Bridge (SHB) grit-blasting professional. I acknowledge that the interview will be audio recorded.
- Me providing critical verbal feedback about several prototypes of the device. I acknowledge that these critical feedback sessions will be video recorded.
- Me providing a total of approx. 4 hours of time during working hours at the SHB maintenance site.

I am aware that RTA management has given full consent for me to participate in this research and that I am free to do so during working hours.

I am aware that my participation in this research will in no way affect my employment situation with the RTA and that RTA management will not have access to any information I give out.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

I am aware that I can contact Stefan Lie or his supervisor A. Professor Dikai Liu if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that Stefan Lie has answered all my questions fully and clearly.

____ ____/____/____

Signature (participant)

____ ____/____/____

Signature (Stefan Lie: Researcher)

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in

Consent Form, October 2010 *Page 1 of 2*

Information Sheet to accompany the **Consent Form** for the research project:

"The development and design of the Interaction Interface for a Grit-blasting Assistive Device"
UTS HREC 2010-422

WHO IS DOING THE RESEARCH?
My name is Stefan Lie and I am a student at UTS. (My supervisor is Dikai Liu)

WHAT IS THIS RESEARCH ABOUT?
This research will help to make an electronic device that will allow RTA personnel, such as yourself, to interact with a Grit-blasting Assistive Device.

IF I SAY YES, WHAT WILL IT INVOLVE?
I will ask you do one interview about your work as a grit-blaster working on the SHB.
I will ask you to give me your opinion on approximately four prototypes of the electronic device.

ARE THERE ANY RISKS?
There are very few if any risks because the research has been carefully designed. However, it is possible that

WHY HAVE I BEEN ASKED?
You are able to give me the information I need to make the electronic device because you are a grit-blasting professional on the SHB and may be using the device in the future.

DO I HAVE TO SAY YES?
You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?
Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?
You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?
If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me (us) on 02 9514 2587.

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this number: UTS HREC 2010-422.

Thank you for your time.

Appendix D

Information/worksheet handed out to participants at the beginning of the co-design workshop.

SHB GAD
Operator Control Unit Co-design workshop

Date: 31.08.11

Participants: Ivo Brdjanovic
Justin Bush
Stefan Lasek
Jim Manos
Anthony Violi
Stefan Lie (moderator)

Why?
The main purpose of this workshop is to design the outside shell of the OCU together with professionals like you that will end up using the OCU. This will fast track the design process and get the OCU as close as possible to your requirements.

How?
We will do this by making 1:1 scale sketch models using cardboard, masking tape, hot glue, modelling clay etc.

I have made boxes of the minimum size we think the shell will need to be. You can slide the tablet computer into these boxes to get a feel for weight, size and proportion.

Any things you then want to add just cut out of cardboard to roughly the shap you want and stick them onto one of the boxes.

Things the OCU must have

1. External shell
2. E-Stop
3. Hardwired cable

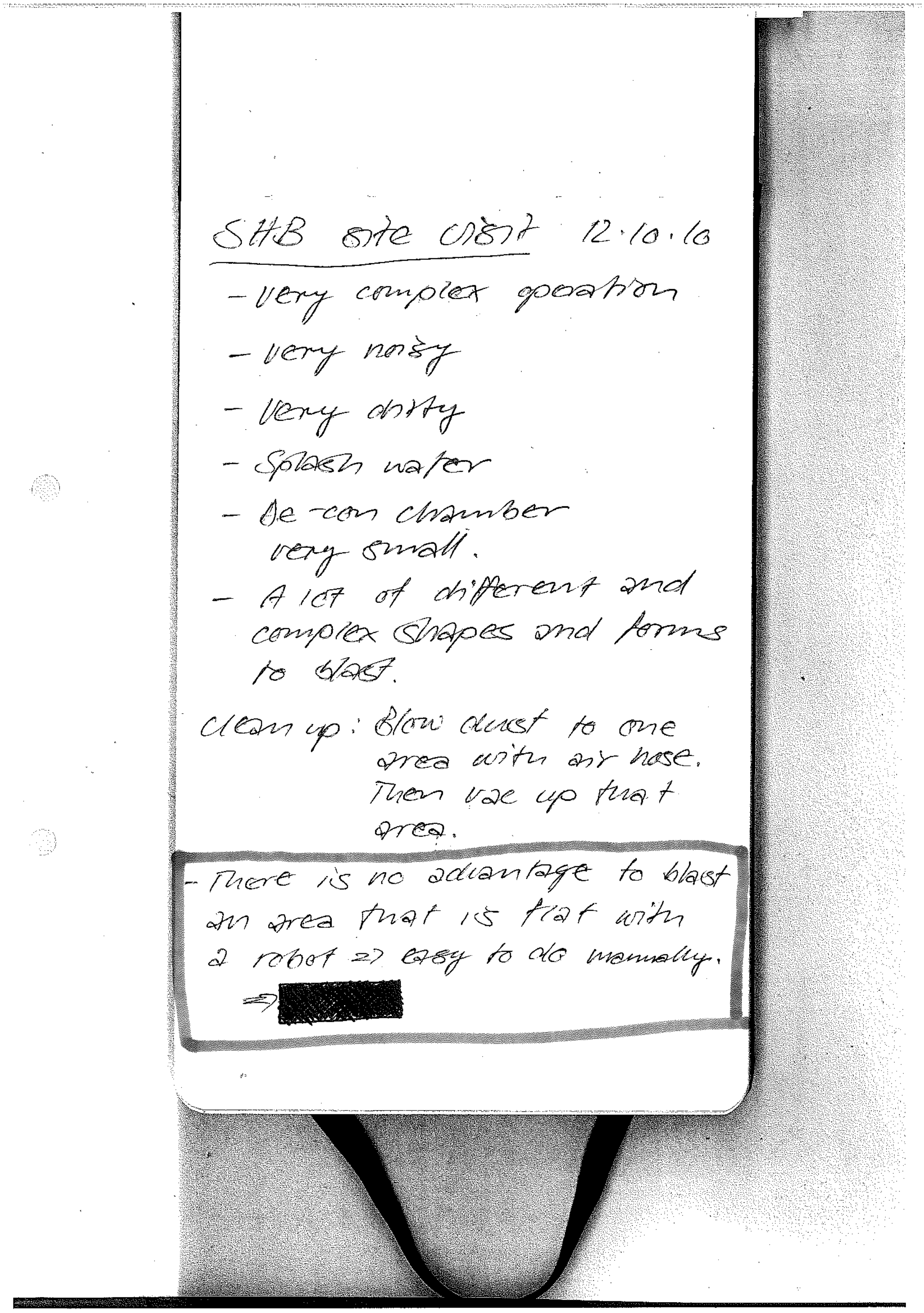
Things to consider

1. Working with the OCU on site
2. Design with gloves in mind
3. Orientation (as in vertical or horizontal)
4. Viewing angles at different heights
5. Hook or shelf that will fix to the robot frame
6. Anything else you can think of

Please note I'll be recording the session on video.

Appendix E

Copies of handwritten notes relevant to the pre-study impression data analysis. Notes were taken by the researcher during project meetings.



SHB site visit 12.10.16

- very complex operation
- very noisy
- very dirty
- Splash water
- De-con chamber very small.
- A lot of different and complex shapes and forms to blast.

Clean up: Blow dust to one area with air hose. Then vac up that area.

- There is no advantage to blast an area that is flat with a robot => easy to do manually.

=> [redacted]

SHB meet 20.01.11

- What is best blast angle?
  blasters => depends on what's being blasted
  => UTS to do tests

- blast durations for spec. areas?
  Responce by blasters:
  => 5 min for middle (of panel) large flat sec.
  => 15 min for flanges + rivets
  robot should do these not these.
  Also "pideon" holes on top of I-6's are very hard

- Tear off's?
  => use about 20 p/day

- 1 pot lasts how long?
  => on average 90 min

Next meet 22.2.11

CLAD SAB meet p.1 22 · 02 · 11

3 - distance from surface test w. blast nozzle
=> get results from RTA.

4 - Long side 6 panels 8 m track max.
short side 3-4 panels 3 m track length

14 * Access hatch size ? (800 × 800)

5 - No winch, just push to next pos.

6 - To keep an eye on robot? } see pt. 8
=> fully PPE GBP

7 - No hydraulic lock, manual lock.

8 - Observer is outside but fully suited.
=> holding dead mans switch.
* => deactivates to move robot
=> deactivates to get pot refill.

9 - End of March next blast cycle.
=> for Andrews test
=> to observe work in progress

10 - Fixture for tear offs ?

11 - 90 min p. pot.

12 - Calibrating blast stream

p.2

22.02.11

Blast size nozzle 6.5 min. 6.
=> turbo nozzle.
=> measure pressure
15 – Safe weight lifting 28 kgs. => Blue.

16 – The "cream" of the job the easy part, flat sec's, blasters want to do these
(don't want to do rivets, cut's, edges + hard to reach areas)
=> comment by [redacted]

next meeting March / April

SHB meet 17.05.11

- after lunch blasting in container 31st.

- RTA will find a plate to do blast testing on (=> paint first).

- Gav presenting + chairing
  " update on path planning + coverage

- Greg updating on structure + protection

- current SMS behind screen. ✓

- Flip out legs on screen.

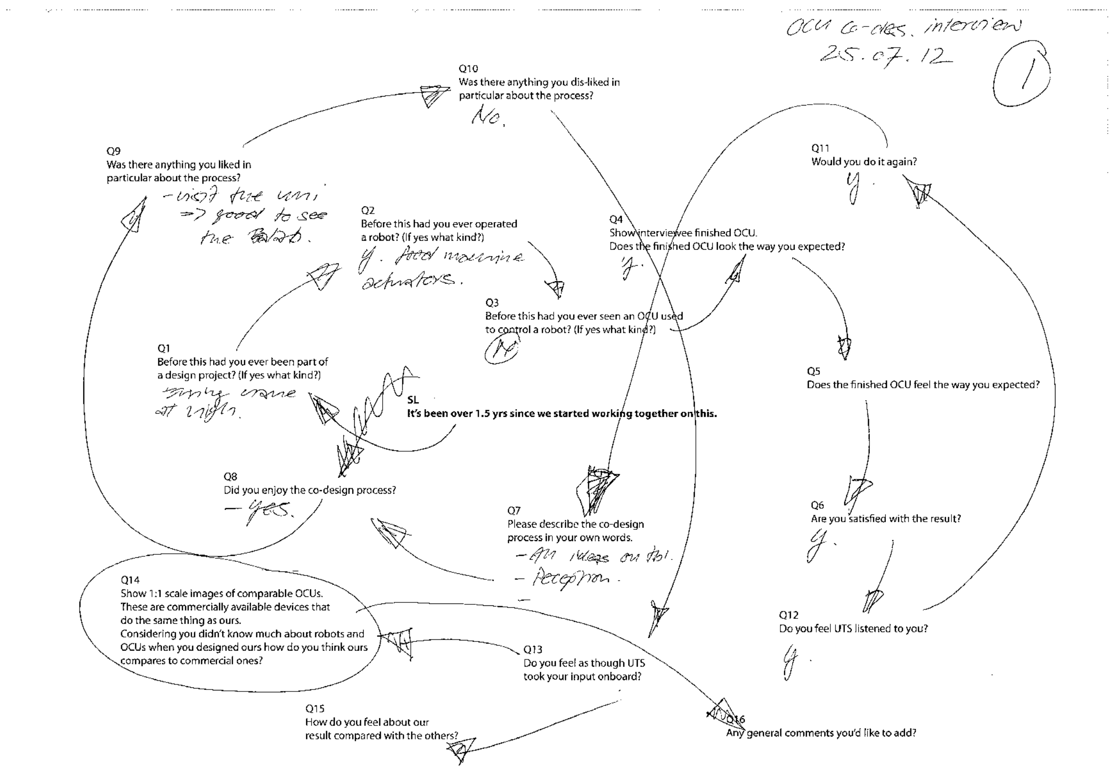
- Not attached to the body
  => trip hazard
  => Escape obstructions etc.

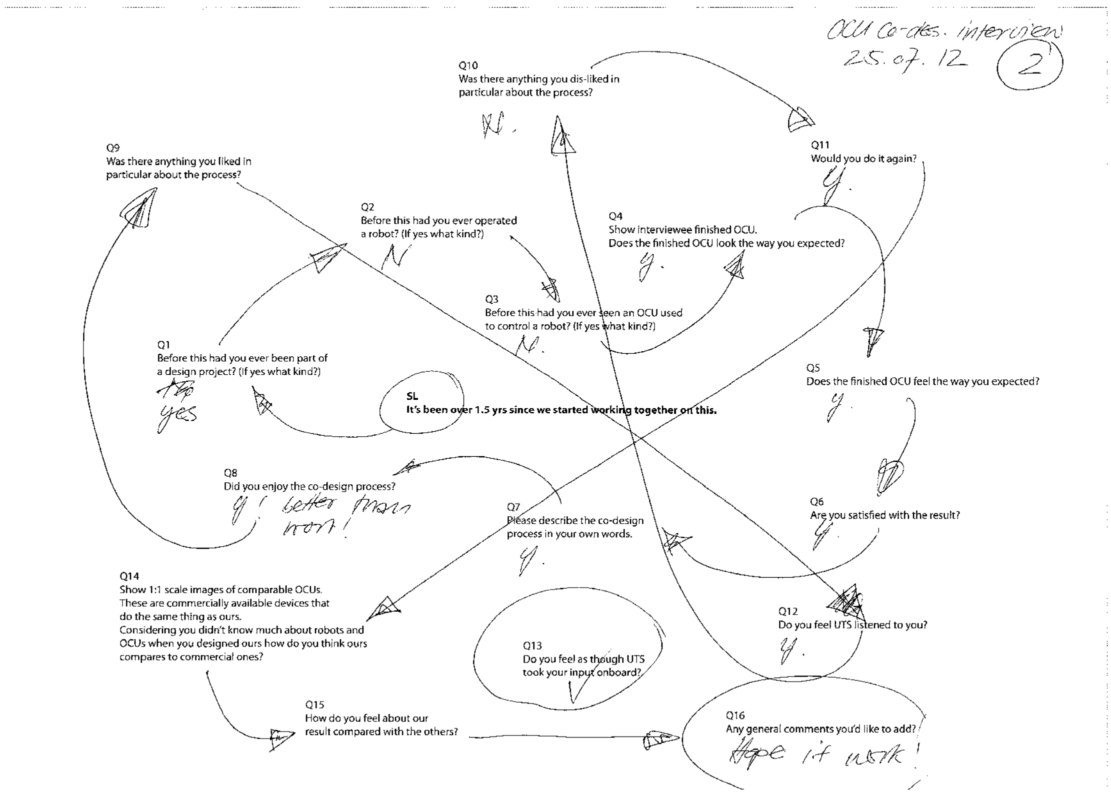
- Robot should hold biggest nozzle possible, too big for human to hold
  => then blast using a joy stick
  => better if robot do difficult rather than cream

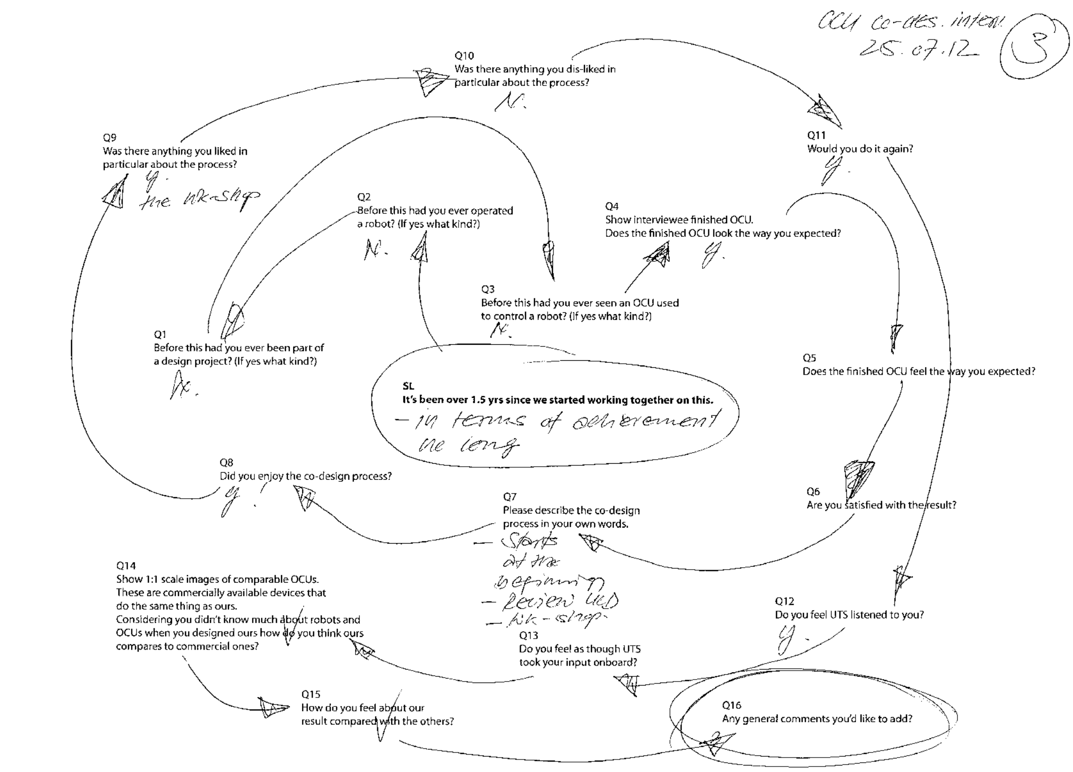
Next meet mid June

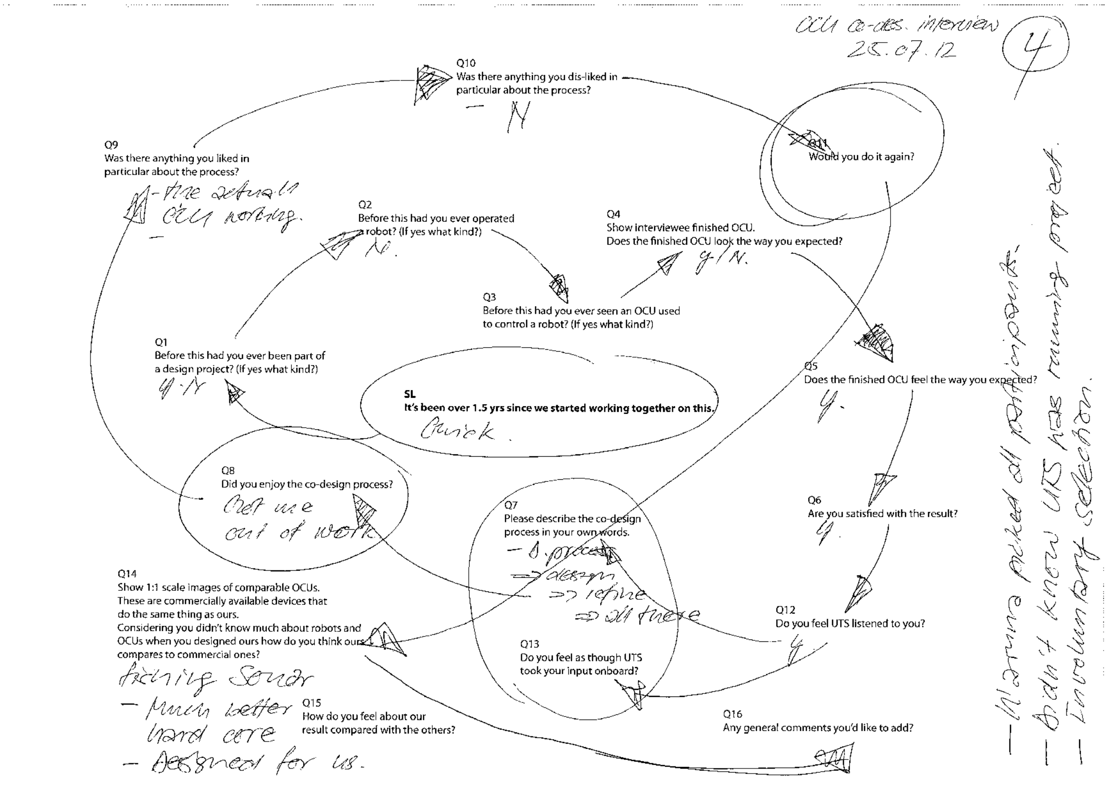
Appendix F

Non-linear interview maps of all four post-study impression interviews.






OCU co-des. interv.
25.07.12
3
Q10
Was there anything you dis-liked in particular about the process?
N.
Q11
Would you do it again?
Y.
Q9
Was there anything you liked in particular about the process?
Y.
the wkshp
Q2
Before this had you ever operated a robot? (If yes what kind?)
N.
Q4
Show interviewee finished OCU.
Does the finished OCU look the way you expected?
Y.
Q3
Before this had you ever seen an OCU used to control a robot? (If yes what kind?)
N.
Q1
Before this had you ever been part of a design project? (If yes what kind?)
N.
Q5
Does the finished OCU feel the way you expected?
SL
It's been over 1.5 yrs since we started working together on this.
– in terms of achievement
Q8
Did you enjoy the co-design process?
Y!
Q6
Are you satisfied with the result?
Q7
Please describe the co-design process in your own words.
Q14
Show 1:1 scale images of comparable OCUs.
These are commercially available devices that do the same thing as ours.
Considering you didn't know much about robots and OCUs when you designed ours how do you think ours compares to commercial ones?
Q12
Do you feel UTS listened to you?
Y.
Q13
Do you feel as though UTS took your input onboard?
Q15
How do you feel about our result compared with the others?
Q16
Any general comments you'd like to add?


OCU co-des. interview
25.07.12
4
Q10
Was there anything you dis-liked in particular about the process?
– N
Q11
Would you do it again?
Q9
Was there anything you liked in particular about the process?
– the actual OCU working.
Q2
Before this had you ever operated a robot? (If yes what kind?)
N.
Q4
Show interviewee finished OCU.
Does the finished OCU look the way you expected?
Y/N.
Q3
Before this had you ever seen an OCU used to control a robot? (If yes what kind?)
Q1
Before this had you ever been part of a design project? (If yes what kind?)
Y/N
Q5
Does the finished OCU feel the way you expected?
Y.
SL
It's been over 1.5 yrs since we started working together on this.
Quick.
Q8
Did you enjoy the co-design process?
Got me out of work
Q6
Are you satisfied with the result?
Y
Q7
Please describe the co-design process in your own words.
=> design
=> refine
Q14
Show 1:1 scale images of comparable OCUs.
These are commercially available devices that do the same thing as ours.
Considering you didn't know much about robots and OCUs when you designed ours how do you think ours compares to commercial ones?
– Much better
– Designed for us.
Q12
Do you feel UTS listened to you?
Y
Q13
Do you feel as though UTS took your input onboard?
Q15
How do you feel about our result compared with the others?
Q16
Any general comments you'd like to add?
– Didn't know UTS was running project
– Involuntary selection.

Appendix G

Post-study impression interview transcripts as supplied by Reporters Ink.

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MATTER: Co-des Rev Interview 1

It's been a year and a half since we started up this project, 18 months, quite a long time. So been working on it consistently and the relationship in terms of the working relationship has been quite a long one. The project in itself is 23 months now. But it's been quite good from my point of view.

Before this, had you ever been part of a design project? Have you ever designed anything?

I have but only small things. For instance, for my Year 10 major work at school, I designed and drew an engine crane, which is a hoist to lift an engine out of a car.

Have you still got it?

Yeah, still works.

It's like a hoist in the garage or something like that?

It's on wheels and it's got a hydraulic rev. It extends, the actual boom part of it, the mechanism.

So you roll it under the car-----

Under the car, under the bonnet, and you have got the tray hanging down and once you have undone the mounts, et cetera, everything else attached (01:34)....

In terms of design, you were yourself the client in a way; you were designing for yourself?

Yes.

Have you ever operated any kind of robot?

I have worked with kind of a few bits, such as actuators and things like that, which is food machines. Been involved, yeah, because my father is an engineer and used to work with him on weekends and things like that. Yeah, I have pretty much learnt how to use all those designs and seen how they work, as pneumatics, electronic actuators and things like that.

So you have a little bit of an idea what a manipulator would be able to do?

Yes.

In general, have you ever used an operator control unit?

No, apart from PlayStation, which - yeah.

This is virtual...so this is the final version, in all its glory. Can't turn it on because it is not hooked up to the robot. The-----

What material is that?

This is polyamide, like a nylon plastic.

Is this what they use in rollercoasters and things like that?

You mean the wheels?

Yes.

No, that is urethane.

Oh, right, okay.

This is a thermoplast urethane. You can't melt urethane again. But the process with which this is made is additive manufacturing. So that is a digital file that was sent to a place and they build it out of a powder and a laser.

Oh, interesting.

And then it's dyed yellow - I dyed it yellow, and water-proofed it and put the whole thing together.

Cool.

Is this what you expected?

From the prototypes?

Yes, from the process that we went through?

Yes.

So it definitely looks the way you thought it would look. Does it feel the way that you expected?

It actually feels, and looks, a lot more bullet-proof. It is a lot more rigid.

Oh, yes, the material-----

Yes, it looks very tough. It looks like it can withstand the lifestyle environment, which it's going to be in. Yeah, it is comfortable. I think that will go well. I think that will work really well in that environment.

Just from looking at it now and knowing what you will be able to do with it, are you satisfied with the result?

Yes.

So are you satisfied with the end result in terms of sense of accomplishment, like that you were part of the process sort of thing? I mean, that was a leading question, sorry. Do you feel that UTS have listened to you?

Yes.

And is that in itself a good enough reason to do it again?

Yeah, of course.

Would you-----

Well, I think it's important that this process was carried out because you obviously have a better idea/understanding what the environment is going to be like and the product shows how that's reflected in being able to put these together.

So knowing that I have called it "a cooperative design process", how would you describe it in your own words? Like, if you had to explain it to somebody, friends/family, what we did, how would you describe it?

I would say that the engineering group, and yourself, came in; just sat down, discussed with the people that were using this specific item here. I would say that all the ideas were put on the table and basically you worked out a perception, basically overlooking what these parts were, which enabled you to put together this.

So using everybody's individual ideas, pretty much, was the lead-up to the design.

Did you enjoy the process?

Yes.

Was there anything in particular you liked about it?

Well, I did like how we went to the university and we got a good feel of how the machine/the robot was designed, which was extra to where we were; so all the other divisions, all the other people involved, and how you guys come up with the conclusions in many of the circumstances.

So that was good. It was also really interesting, listening to all of the different information that you guys sourced as well. Hence, the difference materials used and different things like that.

Like, from the research and development side of things?

Yes, yes.

Is there anything that you didn't really like about the process?

No, I enjoyed it.

Anything that annoyed you?

No, not really. It's all positives for me.

In terms of the overall theme, you would definitely say - no, do you feel that UTS took your input on board?

Yes.

Just something...these are commercially available. These are one-to-one scale photographs of commercially available operator control units. So they are designed to do the same thing as ours. These two are more universal and you can see there's lots of buttons around the outside...considering you didn't know much about robots, operator control units, what do you think in comparison to the one that we designed compared to the others?

For starters, that design and this design, the E-stop design is completely different; which I think the centre one is better. Because if it drops, it can drop forward. It's more secure as well; more support with that bar around it.

I mean, there are different things here. The cable is slightly different. But most of all, this one looks a lot simpler to use.

Because of the buttons?

Yeah, because of the display.

Because these are designed to teach robot things as well as operate robots.

Right, okay.

So you could probably imagine these without buttons on either side.

Mmm.

It is just a visual comparison in terms of shape, really. We can't compare functionality because this thing, the one that we have designed, is purely for a specific function, so we can't go into all the buttons and stuff.

Anything else, in terms of the comparisons?

Well, the shapes?

Yeah, shapes, the way it picks them up, that sort of thing, signs.

This one here looks a lot more economical as well, based on what we do. I am sure they both do the job but I would still - I think that would be a little bit too small and the shape of it looks a bit - it could be a little bit, how can I put it, hard to read at times. If your gloves/hands are covering half of it and things like that.

So you mean the finger coming into the screen?

Yeah, things like that. It's probably obstructed, a little bit. I'm not saying it's bad. I am just comparing-----

No, at the beginning of the project we looked at buying a standard and just designing the interface. But you can't - this is from Siemens and this is from Denzil. They both make robots. And you can't use other kinds of operating systems on different robots, like the (?) Schuck. So we had to make our own system, which is great for us because that's how come we ended up doing a cooperative design exercise, which was good for everybody; you know, the project in general and, of course, the operator control unit.

Have you got any other general - anything that you want to comment about, in general?

Not really, no.

Thank you.

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MATTER: Co-des Rev Interview 2

So it's been a year and a half since we started...do you feel like it's been a long time?

Yeah. It's been going on a bit. It's a government department, isn't it?

Government departments and I think the type of work that we were trying to get to do and stuff that it then could do for a while. It's all getting better now but I think that - you know, only flat surfaces which isn't really worth it because the-----

Because they are a start. You have to start somewhere. You have to take the easy part and I suppose it's harder for me.

Have you ever been part of a design project before?

Oh, not really, no.

Not really? What would you-----

Nothing mechanical. Nothing like that, no.

Any kind of design process?

Oh, just once recently I had a go at the bearings. It's a bit hard to explain. A double nozzle blaster for the bearings; sort of helped design that. But otherwise, no, that was about it.

Was that a design consultant who came here and you gave-----

No, just in-house. All the boys here with the fitters. Not so much anyone else, but mainly just the fitters and the boys.

Did (?) Guy know?

Actually, well, we blasted the bearings with him, yeah.

So it was just like a jig-----

It was a tunnel, and two nozzles blasting; one blasting down, one blasting up; two hoses and - yeah, on a stick (?). Basically it done the job. Saved the bloke going in there. Yeah, it worked. It is unique to the bridge. You wouldn't use it anywhere else, except the bridge.

Sounds like another project for my category (laughs).

Have you ever operated a robot before?

Ah, no.

Not really? Have you ever used an operator control unit?

Ah, no.

So looking at the finished product now, is this what you expect?

Uhm, yeah. Well, there's nothing else.

I mean, from the prototype, the only new bit is-----

Yeah, that might be a bit bulky, but otherwise, yeah. Considering the job that we are dealing with and that, how else would we - with all the input from the boys, I think this is what you end up with. If there was an easier way, we would have thought about it. You would think so. But it seems alright. I think so. It is pretty robust. Yeah.

Yeah, it shouldn't-----

It looks pretty strong. It looks like it's not going to go anywhere in a hurry.

4 millimetre walls thickness. I double it, after you what guys said last.

Yeah, it looks alright.

I have increased the number of screws as well because somebody said, "Oh, if it drops, it will just bust open".

Yeah, it looks alright.

In terms of touches/feels, is it what you expected?

It's alright, considering - you know, where we are going to go and what we are going to do with it, it should be right; it feels alright. Instead of it hanging on that frame there and not having to pick it up at all.

Yes, I don't think there will be much-----

Man-handling. Probably just sit there, punch it in and let it go. Otherwise, yeah, good.

So it look the way expected, it feels-----

Yeah, that's what we sort of - well, I sort of expected.

Overall, you are satisfied with the result?

Yeah. Yeah, good.

In your own words, if you could describe the process that we went through to get to that?

We all got together, had a chat about it and then came up with all different ideas and this is what came out of it. This is the baby.

It is a bit like that, isn't it? Are you talking about the workshop we did?

Yeah, yeah, with everyone's input; everyone put in their own - one said this, one said that, one said that and one said that. It was a team effort. I think it's alright.

Did you enjoy the whole process?

Ah, I suppose it's better than being on the job, yes (laughs). Better than sucking lead and cleaning the environment, yeah.

What in particular did you like? Like, when we went through-----

Oh, look, everyone's input. At least everyone listened to everyone and it wasn't just one way dictating. So everyone had something to say and they were listened to; not discriminated (06:05)...it looks like a piece of everyone went in there.

So you definitely think we listened to you?

I think so, yeah.

And was there anything that we did in the process that you didn't like?

Well, no. All good.

Would you do it again?

I would say I would, yes.

If you had the choice to be on the team again-----

Yeah.

So you would definitely say "yes" to input-----

Yeah.

In terms of the fact that you didn't know anything about what robotic...use was then compared to the result that you came up with, what do you think; just in terms of visual comparison?

There is a lot of buttons, by the way. It looks a bit complex, you know. Plus, with gloves and - it's too - it looks confusing, just looking at that. Yeah, the other one - after I have seen the other one working, it tells you what to do. Simpler system, even thinking how long will it last; too much buttons, too much stuff going on.

Both of these are IP 65.

You drop one of these and - it's not robust.

Just in terms of the form and the way that you would handle it? I mean, it's difficult, without being able-----

Yeah, no, no, using that one, I wouldn't want to - well, F3, F2, F plus/minus, in a simple - it is not simple enough. Just by looking at it, it looks difficult. That's comparing it to this one. Because I have used this one and anyone I think can do this.

Yes, operate the robot. You reckon that-----

The way that I have interpreted it, it is simple. It tells you step by step and off you go, rather than trying to think about "what the hell is all this?"

All the buttons.

Yes.

Any general comments about the whole thing?

(08:53)....(laughs).

Don't we all. Thank you.

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MATTER: Co-des Rev Interview 3

One and a half years since it started. Do you think that is a long time?

Oh, when you say "a long time", like it feels like a long time but you have got to look at what we are designing and trying to achieve, you know. We are not trying to, I don't know, design something a lot more simpler. It is a robot, especially in an environment where we are and what we are trying to achieve and what we are blasting.

So a year and a half, it does feel a little bit long, but really it's not, with what we are trying to achieve. Something like that is going to take time, for sure.

Looking back, it feels long but-----

Yeah.

-----when I actually think about the project itself, it's like yesterday when it started.

Exactly, yeah.

Have you ever operated a robot before?

No. Never.

Have you ever done a design project before?

No, I can't say I have.

Have you ever seen an operator's control unit before?

No, no, I can't - definitely not.

In terms of what we have here, does the finished thing look the way that you expected?

Well, yeah, I mean, you know, the process that we did, designing it and building it and everything, I mean you guys have taken everything into what we have actually said. The end product is - you know, you couldn't really ask for everything else. Everything that you talked about, with the handles on the side and the E-stop and nice and strong, I mean that really is what it has to be. At the end of the day, we wanted something that was going to be - that can take the hit out there, basically, from the environment. So no, all in all, at the end I think it's definitely come up the way we have expected it, yeah.

Are you satisfied with the result?

Yeah. I reckon. I would like to - can't wait to see it out there in the environment and give it a go; because I reckon it will handle it. It's nice and solid and - yeah, it would be interesting. Yeah, for sure.

Yeah, I can't wait to see it in action.

Yeah.

Can you please describe the co-design process in your own words?

From the beginning? Or how we all - okay.

When you talked to somebody-----

And what it was all about, yeah. Basically, UTS wanted to bring up a design in blasting the Harbour Bridge. So a few of us got down and had a few meetings and talked up a few designs. Anyway, UTS would come back with a few more designs and we all chatted about it and changed things. Then we come up with a modeling stage where we design the control panel and all the rest of it and pretty much we are sort of where we are at now.

I think it's definitely stepped forward compared to the very first time when you guys come in; work on the transfer study. Remember that time? It was the old robot.

Oh, yes. I have seen the pictures.

Well, that's the big difference from there to now.

What the big difference?

Well, the whole design in the robot itself. One being a lot lighter, being able to move it a lot easier, and I think you are getting better results.

In terms of blasting-----

Blasting, yeah, yeah. You are getting (04:10)...results, so we are definitely on the right track, that's for sure.

Can you enjoy the cooperative design process?

Yeah, I did, actually. I thought it was really good. You know, having UTS sort of approach us - I mean, this is our job. This is what we do every day. To have you guys sort of include us in on that, you know, come up with a design and all the rest of it, I thought that was great, yeah. I enjoyed it.

Was there any particular thing that you liked about it; anything that stands out?

I really like the modeling process. You know, with the cardboard and with the plasticine and all the rest of it and where the E-stop is going to go and - I don't know, it felt like we were really involved. I thought that was really good. Some people might take ideas and run off with them and it's like, "Hang on, where did that come from?" But we were really involved in the whole process and we still are, which is good.

Is there anything that you didn't like about it?

No, I can't say - no, definitely not.

Would you do it again, if there was another-----

Oh, 100 per cent.

-----a different type of project?

Yeah, for sure. It is interesting. It is very interesting. Yeah, I enjoyed it. Yeah, definitely do it again.

So do you feel that UTS listened?

Oh, yeah, for sure. You look at the end result here. I mean, in the group of four/five, however many of us were involved in the whole process, I mean you guys definitely listened because all the little things - you know, how strong this has to be and the environment it's going to be in and you guys really took that all in, on-board and definitely listened, yeah, that's for sure.

These are our commercially available OCUs, that you could purchase to do the same sort of thing. Considering that you knew nothing about designing operator control units and this being the result, how do you think ours compares to these?

Well, see, for instance, if you brought one of these in and say, "Oh, look, how do you think these would go in the environment that we are using?", straight away you would look at it and say, "No way. No chance." You have got a lot of buttons on here. A lot is going on in this control panel here; whereas ours is a lot more simple and really that's what you want. One being the environment that we are in, you have got all these buttons here. This wouldn't last long, I tell you now. Whereas this here, it is pretty straightforward. You don't want to get too complicated because more things, I reckon, can go wrong. Everything from connecting the robot up to running through the scan process, you can't go wrong. You have put it down to so simple, even different colours to plug in leads and stuff like that. Yeah, that's spot-on. Whereas this here, you look at it and you give this to someone - you give this to someone and have a ten-minute run-down, I reckon they will pick it up a lot easier than this. You look at this and go, "Oh, gees, what was that again? What does this button do? Minus/plus?" I reckon you would get pretty confused. So, no, I like our design, actually.

In general, for the whole thing, the whole experience, is there anything that you would like to add/say?

Not really. If there was, it would have been said along the way. No, other than that, I think it's been really good. I can't wait to get the robot out there and give it a go. See how we go, you know.

I think they are bringing it out tomorrow.

Yeah. Greg was down last week and we were going up there. There was a little bit of a drama. Like, we wanted an open bay for you guys to use but this move has got floor laterals coming through. So basically you are getting half a bay.

What are they called, (?)wind bays-----

Wind bays, yeah, they come through, but anyway that doesn't matter. We are going to block off two bays for you guys to sort of - as Greg said he wants to run them into the ground. He wants to put them to a big test. See how they hit/miss and that. He goes, "I want to use it. I want to use it." So, yeah, we have got two bays ready there, so we can put it to a test.

Thank you.

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MATTER: Co-des Rev Interview 4

So a year and a half since we started. How does that feel; a long time, it's been ages or-----

No, it's been quick. Very good. I thought it was longer than a year and a half, isn't it?

Yeah, I mean, all-up from September 2010 to now.

Oh, since we have been involved with the robot, yeah.

Since you guys started...but it felt quick, the process?

Yeah, it did.

Have you ever been part of a design project before?

No, first one - oh, I did design a house-----

Any kind of process where it takes some requirements to turn it into something?

Oh, you can't classify renovating a house, can you?

No, that would be interior design, instead of product design.

Yeah, I have been doing that with my brother-in-law. He buys houses and renovates them, old Queenslanders, so I have been involved with that a fair bit. But as in industrial robot things, no.

Have you ever been operated a robot before?

No, definitely not.

Have you ever seen an operator control unit before you were on this project?

No, this is the first one, actually, the one we designed - oh, no, I went to university's one, high tech ones there.

Oh, at UTS, when they have training sessions?

Yes, that's right.

The one with the joystick on the side?

Yeah.

After being through the process and now seeing the end result pretty much for the first time, does it look like what you expected?

I would say fifty-fifty. I knew it was going to be a screen of some sort but didn't know you can have it dead-on there, no.

You have to be flexible, so you can take it off.

I think it's a good one, actually. It's got everything in one compact.

I think that was the right decision in terms of - I think it was one of your guys' suggestion. Because when we did last year's trial, I had it masking-taped to the bottom...apparently those are the new detonators that you will be using?

...

It's got a little pivot.

Oh, you have to really push it in there.

....

It's going to be hard with gloves on.

Yes, that's what I thought.

That's a stupid idea. You have to take your gloves off, put that on, and try to angle it. I know on a steel platform - a lot of these guys work with steel and you have got a cherry-picker, so you have to do it yourself. So you have the squatter and the blaster (03:55).... so you have to handle this and blast at the same time. Really, with the old ones you can do it with one hand. You take that out, put that in there, push it in like that, the blaster is held like that and start blasting. With this one here, it would be pretty tricky.

It took us a while to work out that you had to push that far and we just kept lodging it and it would pop out all the time. Does the result feel the way you expected?

Feel?

Feel, in terms of picking it up. Knowing what you know about the process, looking back, does it feel like the way you-----

Yeah, it does, actually. I like these back bits here, that's good.

Yes, they are bigger now. Made them bigger. First prototype they were too small.

....

So looking at it now, are you satisfied with the result?

Yeah, it's good. It's spot-on, yeah.

Would you say UTS listened to-----

They have, yeah.

-----to the process?

They have, actually, yeah. Like, you tell the engineers up here and they don't listen to you. When we talk to you guys, it is just amazing. Yeah, it's good.

That's good to hear.

You tell these guys upstairs, it goes through one ear out the other. With you guys, you put it all down.

Very engaged. In terms of the process, the cooperative design process that we did, could you please describe to me in your own words how it works or what happens during the process? Like if you had to tell somebody over a drink, give them a brief run-down of the project, how would you describe it?

We have got a robot and a blast.

(Laughs). You were involved in it?

In the process?

Yes-----

I will be operating the robot, myself, so the extra two people - because you need - the robot is the on tracks, so you need another person to be there on the tracks.

You are talking about using it now?

Yeah.

I mean the design process, like-----

Oh, involvement?

Yes, how we reached this result.

Because of you guys, really, to tell you the truth. We, uhm - I don't know, we designed something like that and you guys refined it. And, yeah, it's mainly all of us - the ideas with the E stopper and the straps. No problems with that. No, it's good. What are these called again?

Grip rails.

Grip rails. That's a good idea.

That was your idea, wasn't it?

Yeah, I cut (07:10)...in half.

And the straps.

Mmm. I like the colour.

Yeah, Dave, he didn't want to do it yellow... "The boys have said they want it yellow or green".

Yes, that was the last question that we were just talking about. We told you what we want and everything just went there; on paper and design. It was bloody fantastic. It had to be a bright colour anyhow because up there, it's just too dark.

Oh, no, it makes complete sense to me. It's going to mark very quickly and all that but it will still be easier to see.

When you blast up there, everything is marked. (07:55)...a thousand dollars just for a light.

What, a thousand bucks?

A thousand dollars for one light.

Those lights?

Yeah, a thousand bucks. And the lens that goes over the top, $300. $300 just for a lens and they don't last long, especially with us guys blasting up there.

They are big and pretty robust.

Mmm.

Put a cage around them when they blast.

It was more than that when they first started. Then they started buying in bulk and it got cheaper and cheaper and cheaper. But, yeah, the prices are a thousand bucks.

Do you know where they are made?

No, there's one just outside. The sparky do it.

Did you enjoy the co-design process?

For sure, yeah. Got me out of work. No, it was good. I liked designing things like that. It was good.

Was there anything in particular you liked about the process?

Designing this.

The actual OCU?

Mmm.

Is there anything you disliked?

Well, there's no coffee in the coffee. That's what I didn't like. No, it was good.

No gripes. Would you do it again?

Oh, for sure, yeah. To see someone design and to see something like this, and it's all real/physical and things like that, it's fantastic.

Yeah, it's a good feeling, being part of something and then in the end "there it is. That is what we wanted. That's what we suggested and here it is".

You can see some of the ideas in here, too. Yeah, I liked it.

So you definitely feel you got your input-----

Mmm. I like how you have done these. Start from the centre and went around in circles. Yeah, it's good.

Yeah, we like to try and remain flexible. I have got rough questions that I want to follow but everybody go in different directions...this gets sent to a transcription centre...

Lastly, these are commercially available operator control units. They are one-to-one scale. Of course, they have got-----

Oh, yeah, it looks like (11:43)...boat. Look at it.

Oh, yeah, the fishing... Considering you don't have any robot experience or anything like this, what do you think, how it's compared to those two?

It's better because we designed. No, it's much, much better. That's hard core. See, that's not designed for us. This is designed for us. Actually, I thought the thing was going to look like this, to tell you the truth, when you guys were first talking about it. I thought it was going to be buttons and stuff like that.

Yeah, well, at first-up I was - Dick said, "We should buy an existing system, big existing device and put the interface on it..." and we couldn't find comparable devices to run with the robot. So then it was decided it would be easier if we are using tablet

computer and design in-house. The fact that our operating systems wouldn't work with our robot, it was a blessing.

Just looking at this design here, it looks like it should be up on an art wall something like that, the way it's shaped - yeah. It is just a circle, isn't it? A little lip up here. What are they for? It looks like (?)hockeys.

I don't know. Ah, yeah-----

It looks like a blast (?)box, these ones here. That's the main (14:03)...that goes into the blast box.

Or there could be a mix in devices, so you need some of this and some of this and it gets mixed up and then comes out at the bottom.

Mmm.

So percentages...this costs 8 grand....

And you design it yourself, the program?

Well, if you are using it with the robot, it will come with a user interface. And they just give you the whole system - actually, I don't know the answer to that, truthfully, if you design that. But in our case, we would have then just done the interface. Wouldn't have the done anything else... Any general comments?

It was good. I was happy with it. As I said, it pulled me out of work. So any time, any week, yeah, come over. I just can't wait to get started.

Can't wait to see what happens....

It is like waiting for a baby to be born.

It is. Thank you.

RECORDING CONCLUDED

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