A Mixed Reality Approach to 3D Interactive Prototyping for Participatory Design of Ambient Intelligence

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by

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ABSTRACT

Ambient Intelligence (AmI in short) is a multi-disciplinary approach aimed at enriching physical environments with a network of distributed devices in order to support humans in achieving their everyday goals. However, in current research and development, AmI is still largely considered within the engineering domain bearing undeveloped relationship with architecture. The fact that architecture design substantially aims to address the requirements of supporting people in carrying out their everyday life activities, tasks and practices with spatial strategies. These are common to the AmI's objectives and purposes, and we aim at considering the possibilities or even necessities of investigating the potential design approach accessible to an architectural context. For end users, AmI is a new type of service. Designing and evaluating the AmI experience before resources are spent on designing the processes and technology needed to eventually run the service can save large amounts of time and money. Therefore, it is essential to create an environment in which designers can involve real people in trying out the service design proposals as early as possible in the design process. Existing cases related to stakeholder engaged design of AmI have primarily focused on engineering implementation and generally only present final outcome to stakeholders for user evaluation.

Researchers have been able to build AmI prototypes for design communication. However, most of these prototypes are typically built without the involvement of stakeholders and architects in their conceptual design stage. Using concepts solely designed by engineers may not be user centric and even contain safety risks. The key research question of this thesis is: "How can Ambient Intelligence be designed through a participatory process that involves stakeholders and prospective users?" The thesis consists of the following five components:

1) Identification of a novel participatory design process for modelling AmI scenarios;
2) Identification of the requirements to support prototyping of AmI design, resulting in a conceptual framework that both "lowers the floor" (i.e. making it easier for designers to build the AmI prototypes) and "raises the ceiling" (i.e. increasing the ability of stakeholders and end users to participate in the design process deeply);

3) Prototyping an experimental Mixed Reality Modelling (MRM in short) platform to facilitate the participatory design of AmI that supports the requirements, design process, and scenarios prototyping;
4) Case study of applying MRM platform to participatory design of a Smart Laser Cutting Workshop(LCW in short) which used to evaluate the proposed MRM based AmI design approach. The result of the research shows that the MRM based participatory design approach is able to support the design of AmI effectively.

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ABBREVIATIONS

3D	Three Dimension(al)
AmI	Ambient Intelligence
MR	Mixed Reality
MRI	Mixed Reality Interface
VR	Virtual Reality
PD	Participatory Design
SE	Smart Environment
AR	Augmented Reality
MRM	Mixed Reality Modelling
LCW	Laser Cutter Workshop
MVC	Model-View-Control
MCRpd	Model-Control-Representation-Physical-Digital
WSN	Wireless Sensor Network

CHAPTER 1 INTRODUCTION AND MOTIVATION

Ambient Intelligence (AmI in short) is a multi-disciplinary approach aimed at enriching physical environments with a network of distributed devices, such as sensors, actuators, and computational resources, in order to support humans in achieving their everyday goals [1]. AmI can provide assistance in many circumstances to freeing people from regular routine tasks. Traditional memory aids can remind the user about activities on their daily schedule, but more sophisticated memory aids, on the other hand, can be context-sensitive: they could observe the user in their activities, guess their desired tasks and on that basis issue reminders and guidance [2]. AmI has potential applications in many areas of daily life, including in the home, office, transport, and industry; also in entertainments, tourism, recommender systems, safety systems, e-healthcare, and supported living of many different variations. AmI applications such as smart home, assistive living, health care, shopping recommendation systems, museums, and tourism are all based on specific architecture spaces that host them. This sensitive and responsive electronic environment could be seen as another layer of the building fabric. Architectural spaces consisting of a variety of environments are considered as places to live in, work, and have fun. As the most common physical environment for humans, architecture has been depicted as a machine for living [3], a space of memories, a container accommodating occupants and functional components, or a social interactive environment. In the first decade of 21st century, the emergence of internet of things, artificial intelligence and communication technology clearly changes our life as well as the living environment physically or virtually. The evolution of environment raised an important issue for architects, designers, planners, and inhabitants about the workplace of future, domestic space of the future, or public space of the future, etc.

However, in current research and development, AmI is still largely considered within the engineering domain bearing very limited relationships with architectural and urban design. The fact that architecture design substantially aims to address the requirements of supporting people in carrying out their everyday life activities, tasks and practices with spatial strategies. These are common to the AmI's objectives and purposes, and we should consider the possibilities or even necessities of investigating the potential design approach accessible to an architectural design team. The starting point of this research is to inquire how the design of AmI can be communicated from an architectural viewpoint that addresses domains of concern different from those of the electronic and computing engineers. Designing AmI systems and services for creating the future smart environments is an important design theme in future data-driven age. Therefore the research presented in this thesis aimed to explore and develop an experimental platform and process for participatory design of AmI applications in an architectural context: from conception to prototype implementation involving architects, planners, designers, inhabitants and any potential.

On realising and implementing smart environments, there is a large body of research dedicated to engineering a full scale architectural space into a smart environment. Obviously, this is a far-reaching and difficult goal to achieve and will take time. The research presented in this thesis did not aim to explore how to communicate AmI on a full scale prototype but attempted to improve human centric design of smart environments by providing a rapid participatory design approach to upgrade existing communication techniques in architecture design.

AmI brings together multiple areas such as networks, sensors, human-computer interfaces, pervasive computing and artificial intelligence. These areas are allrelevant but none of them conceptually fully covers AmI. The concept of AmI is closely related to the "service science and engineering" in the sense that its objective is to provide people with proper services. Users may not be of interests in what kind of computing or devices are embedded in the applications or environments or what type of middleware architecture is deployed to connect them. Only the services given to the user matter to them [4]. AmI service design is a form of conceptual design which involves the activity of planning and organizing people, infrastructure, communication and material components of an AmI system in order to improve its quality and the interaction between AmI services providers and users. Instead of developing of each elemental device separately, integrating existing technologies to form an accessible user experience has been a main requirement for the communication of AmI design. Thus, how to provide the design team and committed stakeholders with an intuitive user experience of the design in each phase of the design iteration has becomes an import issue.

When designing AmI services, gaining real insights from all stakeholders including project managers, users, and designers, and translating these insights into a clear service proposition, and experience prototyping, the process and quality of communication is essential. A fundamental characteristic of services is that they create values only when they are used by their users. For instance, a person can't use the bus from point A to point B unless she/he knows where to get on and off. Product-oriented design approaches often fail to see the potential of involving their end users to make a service more effective and valuable. If bus routes and schedules can be better informed to users, they are more likely to get more efficiently from A to B and more people will be inclined to use the bus [5].

When developing a service, design and test the experience before resources are spent on designing the processes and technology needed to eventually run the service can save large amounts of time and money. Therefore, it is essential to create an environment in which designers can involve real people in trying out the service design proposals as early as possible in the development process [6]. Because a new service may provide users with an experience that they have never had before; making it feel real and tangible is therefore important. When asked to imagine a new service, people tend to become analytical and problem-oriented. On the other hand, if people are provided with a simulated experience of using the service prototype—something tangible that contains the key elements of the design and information/data flow of the service—they may react to the performance rather than the abstract concept.

To successfully include stakeholders of a design project, the design process of either product or services needs to have appropriate facilitating features. Here we propose a set of conditions for effective and efficient participation of stakeholders:

- A direct and explicit communication between stakeholders and designers needs to be established, minimising the chance of misinterpretation on either side in the communication.
- Stakeholders should be enabled to have a realistic interaction with the design information. Exact functioning and experience of the design needs to be reliably assessed under a wide range of situations and circumstances.

- Stakeholders should be enabled to reliably become conscious of and assess the consequences of design decisions. Therefore, consequences of design decisions need to be communicated in a way that is explicit and comprehensible regardless of participants' theoretical knowledge and technical skills.

Mixed Reality (MR in short) which merges physical and virtual reality potentially provides solutions to meeting most of the conditions for effective stakeholder involvement. It transforms design information to realistic interactions: design information is presented in a comprehensible manner without prerequisite of technical know-how, whereas consequences of design decisions can be experienced rather than imagined [7]. The latter is especially beneficial when stakeholders (e.g. end-users) are unfamiliar with the service or product to be designed or with the technology that is suggested to be incorporated. With the actual experiences of design information and consequences made accessible to them, potential stakeholders will be able to engage with the design process more readily and productively. Furthermore, compared to static communication media such as natural language, sketches and models, MR interactive simulation could lead to less misunderstandings between human actors. In some situation where physical prototypes are difficult to be made, using MR simulation can play an alternative role. Mixed reality also allows stakeholders to evaluate candidate designs in more phases of the design process. Furthermore, mixed reality can offer user experience evaluation under risky or rare use circumstances without compromising safety or efficiency[8].

Mixed reality is not a solution on its own although it in principle can meet most of the communication needs. Integrating Mixed Reality with the Participatory Design requires supportsto 'embed' the digital technology in the design process. Thus we primarily make use of scenario design techniques to do so in this thesis project. In a virtual or real environment, a scenario can be expressed by displaying a prototype (either real or virtual)in it [9]. Scenario can be used to address problems, needs, constraints and possibilities. With Mixed Reality, scenario based design potentially facilitates explicit communication of design information among stakeholders involved.

I was therefore motivated by the feasibility of participatory design of AmIand smart environments by creating a synthesis of a mixed reality design platform and a scenario based design process. Naturally, tangible table-top based interaction can benefit a variety of users such as developers, builders, or end users; all stakeholders of a design process can contribute ideas to realisation. Participatory Design partaken by stakeholders can facilitate and enhance a design process in four aspects such as inclusive, negotiation, learning and flexibility [10]. In architectural design, aparticipatory approach offers to bridge between architects, builders, developers and everyone else who needs to play roles in the design process. This collaboration throughout the design process can benefit both each stakeholder as well as improve the overall outcome. End-users' involvement in the early stage of the design process can enrich architectural design solutions. Therefore, we consider it essential that our system research and development needs to integrate participatory design activities in order to open up new possibilities of AmI applications and smart environments.

Existing research project which tried to support participatory design of AmI with an interactive dollhouse has demonstrated the potential to carry out smart environment design with modified architectural communication techniques. The dollhouse used in Ambient Assisted Living (AAL) is an interactive scale model copy of the elderly participants' home. It is a physical model equipped with simple sensors that are able to track movement for simulating the actual monitoring environment. Simultaneously the scaled model communicates with a graphical user interface that displays simple feedback on what is being monitored in the dollhouse [11]. It demonstrates that older people asend users could be very much involved in this manner. This physical model based human-centred design approach which emphases the values and opinions of related stakeholders also upholds the ethical and democratic standards of the design process [12]. While this approach has been found effective in helping discussion and reaching more common understanding between the elderly, researchers and other parties involved. However, for more sophisticated and personalized smart environmental services, the level of sensing, interaction and simulation of this approach is far from meeting the demand of AmI design communication.

1.1 What Are Ambient Intelligence and Smart Environments?

There are two terms, 'ambient intelligence' and 'smart environments', which have now been adopted to refer to a digital environment that proactively, but sensibly, supports people in their daily lives. The term Ambient Intelligence (AmI) was coined by the European Commission (EC), when in 2001 one of EC's Programme Advisory Groups, the European Community's Information Society Technology (ISTAG) launched the AmI Challenge which was later updated in 2003 [13]. In spite of the fuzziness of defining 'Ambient Intelligence' it is possible to roughly define AmI as a computational paradigm aimed at designing, developing and realizing "augmented" environments (i.e., environments equipped with electronic devices, such as sensors and actuators) that are sensitive, responsive and aware of both humans and their activities. In order to support people in better carrying out their everyday activities, distributed devices in an AmI-augmented environment seamlessly cooperate with each other and with humans constantly. AmI is aligned with the concept of the "disappearing computer"[14].In particular, service provisioning and specific information should be conveyed through a hidden network connecting all these devices: as they grow smaller, more connected and more integrated into the real physical environment, the digital technologies disappear into the surroundings, leaving only elements of the user interface and the intended AmI effects visible, audible and/or touchable to the inhabitant.

As AmI's design vision, Smart Environments (SE) aim to satisfy the experience of individuals from every environment, by replacing the hazardous work, physical labour, and repetitive tasks with automated agents. Addressing the definition of smart environments is only the first step towards designing it effectively. Most researchers have a general idea about what a smart environment is and use that general idea to guide their design. However, a vague notion of smart environments is not sufficient; in order to design smart environment effectively, we must attain a better understanding of what smart environments are. A better understanding of smart environments will enable designers to choose what strategy of smart environments to use in their SE services and provide insights into the type of activities that could be supported and agents and mechanisms required to support smart environment design. Previous definitions and discussion of smart environments are found as follows.

1.1.1 Previous Definitions of Smart Environments

""Smart spaces" are work environments with embedded computers, information appliances, and multi sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers."[15]

National Institute of Standard Testing

(NIST), USA

"A "smart environment" is a small world where all kinds of smart devices are continuously working on make inhabitants' lives more comfortable. A definition of "smart" or "intelligent" is the ability to autonomously acquire and apply knowledge, while environment refers to our surroundings. Therefore, a "smart environment" is defined as one that is able to acquire and apply knowledge about an environment and also to adapt to its inhabitants in order to improve their experience in that environment. "[16]

D.J. Cook and S.K. Das (2005)

at University of Texas Arlington, USA

""Intelligent Space" is a denomination that encompasses several initiatives for creating an environment that is continuously tracking and sensing people and objects within a physical spcae while offering some type of feedback or help. "[17]

The Media House Project,

Barcelona, Spain

Poslad differentiates three different kinds of smart environments for systems, services and devices: virtual (or distributed) computing environments, physical environments and human environments, or a hybrid combination of these:

- *Virtual computing environments enable smart devices to access pertinent services anywhere and anytime*
- *Physical environments may be embedded with a variety of smart devices of different types and form factors ranging from nano- to micro- to macro-sized.*

- *Human environments: humans, either individually or collectively, inherently form a smart environment for devices. However, humans may themselves be accompanied by smart devices such as mobile phones, use surface-mounted devices (wearable computing) and contain embedded devices (e.g., pacemakers to maintain a healthy heart operation or AR contact lenses) [18].*

Poslad. Stefan (2009). Ubiquitous Computing

1.1.2 Defining Smart Environments

Following are our working definition of smart environment to get down to the practical work of deciding what is to be discussed:

- *Smart environments are the places designed for people where the inhabitants can be context-aware and therefore interactive with their surrounding created by applying AmI approach for receiving both information or mechanical support to enhance their working or living experience.*

1.2 Mixed Reality in Participatory Design

Mixed Reality refers to the merging of real and virtual worlds to produce mixed environments and visualizations to enable physical and digital objects coexist and interact in real-time. It takes place not only in the physical world or the virtual world, but is a mixture of reality and virtual reality, encompassing both augmented reality and augmented virtuality.

1.2.1 Previous Definitions of Mixed Reality

The first definition of mixed reality given by Paul Milgram and Fumio Kishino in 1994 was as " ...anywhere between the extrema of the virtuality continuum." , where the virtuality continuum extends from the completely real through to the completely virtual environment with augmented reality and augmented virtuality ranging between [19]. The result was the Reality-Virtuality continuum.

The conventionally held view of a Virtual Reality(VR) environment is one in which the participant-observer is totally immersed in, and able to interact with, a completely synthetic world. Such a world may mimic the properties of some real-world environments, either existing or fictional; however, it can also exceed the bounds of physical reality by creating a world in which the physical laws ordinarily governing space, time, mechanics, material properties, etc. no longer hold. This is a very essential characteristic for tasks of developing non-existent services. A particular subclass of VR related technologies that involve the merging of real and virtual worlds, which we refer to generically as Mixed Reality.

1.2.2 Mixed Reality with Tangible Means

Typical interaction tools used in virtual reality or mixed reality are 'space mice' with six degrees of freedom (horizontal, vertical, depth movements and yaw, pitch and rollrotations); and 'data gloves', where a glove is fitted with position sensors to track hand and fingers and also allows the grabbing and manipulation of objects in virtual reality. These tools support full three-dimensional user input [20]. As a practical application of haptics, tangible interaction has been used for thousands of years, such as abacus. In mixed reality ,tangible interaction has given rise to TUIs – tangible user interfaces, which have a structure and logic both similar to and different from graphic user interfaces. With the introduction of multi-touch displays, TUIs have been promised to be increasingly popular as they lead to direct interaction between virtual graphical content and physical objects through gesture recognition [21].There are amounts of reasons why we should explore the possibilities of tangible interaction. we potentially have the benefits of both the electronic and physical worlds if we can merge them together. Secondly We could have all the advantages of computation brought to us beyond the confines of the graphical display unit and have them, as it were, present-to-hand. Finally, there may be advantages in off-loading some of the burden of the computation by (a) accessing our spatial cognition and(b) adopting a more concrete style of interaction such as sketching. as compared to their virtual equivalents graspable physical objects could offer stronger affordances [22].

1.2.3 Participatory Design with Mixed Reality

Participatory design (PD) aims to involve the future users in all parts of the design process in order to produce design ideas based on use practices [23]. The design project could arrive at a functionally better and also a more 'creative' solution with a wider basis. hence, the space for design ideas should be expanded to human centred design but not only technology oriented possibilities. In a PD process mutual learning and iterative development could be achieved with concrete prototypes and traditionally involving committed users. In a typical interactive system design process, most parts of it was technology dominated, how to represent these work to stakeholders in a way they can understand and input their potential contribution is worth to explore.

The feasibility of applying mixed reality in support of new ways of experiencing and contributing to urban design had been demonstrated by a participatory project called Mixed Reality Tent [24]. In this project the mixed reality tool, is a foldable tent styled mobile urban design styled laboratory. This lab can be transported to a site of design and to illustrate, debate and experiment with different design concepts among various stakeholders real city scenes can be interactively augmented with digital visualisations in this lab. And the elements of this design space that affect the processes and outcome of the PD for co-developing ideas with Mixed reality tool are identified as: 1. the large of the project and the site, the role of the representations, and the participating stakeholders with different interests and commitments in the project and the workshop. Also with the comparison of the workshops using the mixed reality tent their research shows that PD can take very different forms. The way of coming together of different voices shapes the dynamics of participation in a project, and resulting in different outcomes.

AmI design could be breakdown to different levels such as device design, agent design and service design. The development of devices in AmI is in essence a sort of product development. The product development process(PDP) generally involves a sequence of gathering requirements, conceptual design, engineering, manufacturing and finally a market release. Successful product development depends on effective collaboration and communication between stakeholders (e.g. designers and engineers, but also end-users, markets or managers) throughout the phases in the development process. Various research projects have already demonstrated that Mixed reality can facilitate the involvement of external stakeholders in the PDP. Using mixed reality technologies to create realistic concept representations in the early stages of the design process can provide stakeholders with a clear presentation of a product concept and future use context. Mixed Reality creates an dual reality in which worlds, objects and characters coupled with physical corresponding objects and characters, therefore the design can be experienced not only through visual interaction but also coupled tangible interaction. As such it allows stakeholders to have a more realistic experience of a product and its use context.

1.2.2 Our definition of Mixed Reality

As we need a characterization of the field if we are to derive and develop applicable materials for it. Following is our working definition aims to permit us to get down to the practical work of deciding what is to be discussed in our work:

- *Mixed reality is a tangible table top based interactive system tries to bridge the gap between physical and digital spaces using intuitive and natural gestures, on which designers can communicate and share their ideas by manipulating the same references, simultaneously with their own input. It may also be augmented by pervasive physical computing and visible, audible media.*

The recent popularisation of 'Tangible Interfaces' and 'Tangible Interaction' driven by breakthroughs in the fields of human computer interaction, interaction design, and physical computation has opened up further opportunities for architectural researchers and designers to explore possible fusion between physical model making, data sensing & processing, and 3D virtual modelling, which is referred to as Mixed Reality in this research. We believe that mixed reality could provide an effective way to support communication of AmI design that is considered integral to architectural design. In our view, at present AmI has not been really fused into architecture design which aims to accommodate people's everyday life activities. We envisage that more and more architectural designers will be interested in knowing what AmI is and what it can offer, and thus in pursuing AmI design as integral part of architectural design in the foreseeable future. If an AmI vision is achieved, human inhabitants will be surrounded by intelligent interfaces supported by computing and networking technology which is everywhere, embedded in everyday objects in their architectural context. The potential connections between AmI and mixed reality in terms of theoretical principles and practical technologies offer a great opportunity of explore the possibility of communicating AmI with mixed reality. The proposed mixed reality for the communication of AmI design is built on a combination of architectural physical model-making, 3D virtual modelling, and elements of interactive physical computing that drives real-time tracking and multi-modal projection systems. This mixed reality configuration can be adapted and fine-tuned to adopt communication convention in an architectural project.

1.3 Why Is AmI Difficult to be Communicated?

As we will show in the literature review (Chapter 2), there is not much of a range in terms of the stakeholder engaged design process of AmI concept and correspondent communication approaches. Existing cases have primarily focused on engineering implementation and generally only present final outcome to subject for user evaluation. The main reason why cases have not covered the range of stakeholders participatory design is that AmI design is difficult to be communicated. AmI have the following properties that lead to the difficulty in design communication:

1. Current AmI design lacks of communication techniques to represent services design to intuitive experience to involve stakeholders in the design process.

2. AmI composes of non-standard equipments and new services, with which we have limited experience.

3. AmI acquire information from multiple distributed and heterogeneous sources.

4. AmI scenarios is dynamic and interactive.

Despite these difficulties, researchers have been able to build prototypes of AmI. But, the prototypes are typically built without stakeholders and architects evolved in the conceptual design stage. Using concepts purely designed by engineers may not humanistic and even be with safety risks.

1.4 Research Question and hypothesis

The Research question of this thesis is:

How can Ambient Intelligence be designed through a participatory process that involves stakeholders and prospective users?

And the hypothesis of this thesis is:

By identifying, implementing and supporting the prototyping and communications of AmI design, we can find an approach that makes it possible to participatory design, prototype and evaluate the design of AmI for an existing architectural space.

Through a detailed study of AmI and from our experience in prototyping AmI, we will identify a participatory design process for prototyping and communicating conceptual design of AmI. The design framework will comprise a Mixed Reality based design process that supports the user study, prototyping and communicating AmI design through iteration. On the prototyping and user experience side, designers will be able to easily build and experience new AmI scenarios that can be communicated between stakeholders with non-professional background using mixed reality models and objects.

The hypothesis of the thesis is three-fold:

1) A participatory design process partaken by stakeholders and prospective users can effectively bring in the architectural context;

2) Mixed reality modelling (MRM) is an appropriate approach to facilitating the participatory design process; and

3) The grounding of AmI strategies and features in designing smart environments can be better explored and managed through a MRM-facilitated participatory design process/platform.

Arduino as an open-source electronics prototyping platform provide the possibility for artists and architects to link physical environment to 3D design and simulation software such as Rhinoceros with grasshopper, Processing or even game engine like 3D.. Arduino based physical computing objects linked to virtual 3D agents in a game engine could be a shift the prototyping and representation of AmI from either conventional real space prototype or pure software simulation to user-friendly mixed reality game style scenarios. Mixed reality which is augmented with physical computing layers starts from the point of view that best way to design and to produce information is from the same source - mixed reality based architectural physical model. This physical computing enhanced mixed reality model allows people in an AmI team to create an "intelligent tangible model" where each element and space within the model can represent and simulate the corresponding component and behaviour in physical world with AmI system augmented. And any team member could experience the services prototyped and represented on this mixed reality model in a tangible interaction manner. Essentially, in using mixed reality the AmI team could build a scale-down AmI physical environment for design development and user experience. In this way, the committed stakeholders could identify and experience the invisible interaction of AmI and visible physical components as the built in the future.

AmI as a multiple services provider its design needs an interactive computational mapping system that allows variables to be seen, analyzed, simulated and manipulated from a 2D or 3D view. In other word AmI design needs support from a data representation and operating approach with the characters similar to GIS and graphic programming. At present maps in GIS often appear as static 2D layers that contain individual features. Each layer is linked to a specific feature. The researcher apply the aggregation of these layers to cross-analyze and consider a multitude of variables, and then makes informed decision. Similarly, in a AmI service design there are multiple invisible/hidden and overlapped patterns, relationships, and trends required to be pictorially demonstrated within a common spatial-graphic boundary for design collaboration. The 3d projection mapping technique in mixed reality has very potential to carry out this task.

1.5 Thesis Objectives and Contributions:

General objective: To identify a novel participatory design approach for communicating Ambient Intelligence Scenarios;

Specific objectives:

- To indentify the requirements to support communication and prototyping Ambient Intelligence
- To establish a framework of mixed reality modelling approach
- To develop an experimental mixed reality modelling platform to evaluate its feasibility to support the design communication of Ambient Intelligence
- To evaluate the effect of mixed reality modelling approach on supporting Ambient Intelligence design by participatory experiments for designing a laser cutter workshop with focus stakeholders
- 2.5 To analyse participatory experimental data and collect the stakeholders' feedback

The research contributions are as following:

Problems: With the popularization of smart environment technology, a lack of design and communication technology makes it difficult to consider smart environment as a design strategy in architecture project by architects. Current prototyping and evaluation methods of smart environments such as full-scale model, virtual reality simulation are expensive, time-consuming and difficult to include non-professions in the design process of smart environments.

Contributions: This work developed a Mixed Reality Modelling Platform to communicating, experiencing and evaluating smart environments scenarios through integrating physical model, mixed reality interface and wireless sensor network. And based on this platform a whole participatory design process including context investigation, Smart environments prototyping and stakeholders involved participatory workshop has been tested and evaluated. With the analysis of two rounds experiments, the MRM based participatory design approach has been proven it is able to support the context investigation, interactive prototyping and communication of smart environment with non-professional stakeholders. The limitation of current work is that participators are not able to prototype new AmI scenarios from their own idea on the MRM platform in the participatory design sessions.

1.6 Thesis Outline

Our definition of smart environments refers to not only ubiquitous computing controlled by multiple smart agents but also an everywhere projection system for human and computing interface. As a typical interactive system design, the design of smart environment still lacks a common communication approach to engage more stakeholder/users in the early stage of design. In this thesis, we will concentrate on the participatory design of AmI by our mixed reality approach.

Chapter 2 presents a critical review of Mixed Reality and its application in participatory design . The research literature review includes an in-depth discussion of existing mixed reality cases and demonstrates how MR can support participatory design.

Chapter 3 presents a critical review of related research. The research literature review includes an in-depth discussion of existing smart environments (Smart Environments = AmI + Architectural Context) cases and demonstrates why existing support for communicating smart environment design is not sufficient to involve stakeholders.

Chapter 4 introduces a conceptual framework that supports the communication of AmI design. It also presents Mixed Reality Modelling based participatory design method for designing and prototyping AmI.

Chapter 5 presents two pilot studies as implementation of the conceptual framework described in chapter 4. (a) A mixed reality modelling case for architectural enquiry, and (b) wireless sensor and actuator network for environmental monitoring.

Chapter 6 presents experiments of user study for designing a smart laser cutter workshop using the Mixed Reality Modelling Platform with multiple stakeholders.

Chapter 7 presents how to prototype AmI scenarios with MRM approach and a participatory workshop for evaluating and developing AmI scenarios on MRM platform. The workshop includes the evaluation of the Mixed Reality Platform as a participatory design common ground..

Finally, Chapter 8 presents a discussion and conclusion with suggestions for future research.

CHAPTER 2 MIXED REALITY AND ITS APPLICATIONS IN PARTICIPATORY DESIGN

Mixed Reality (MR) was defined as a continuum which combines real world and its synthetic worlds [25]. Within this continuum (Figure 2.1) the Augmented Reality (AR) region of scale aims to bring virtual information into a real environment and Augmented Virtuality (AV) describes a virtual environment augmented by real objects. Visual stimuli as the most common blending in AR uses a live video stream enhanced with computer-generated objects on top of the actual scene. Another emerging AR blending is 3d projection mapping which enhance physical objects with projected images from data projectors. By means of embedded sensor networks, AV adds real-time information to a computer-generated environment.

Figure 2.1 Mixed Reality Continuum

With the purpose of supporting the perception and interaction of humans, MR technology fuses information between the physical world and virtual spaces. As a symbiosis of spaces MR contains one space corresponds to the physical environments of humans and a synchronized space exists virtually. In MR, information is usually exchanged in the form of haptic physical objects representing with corresponding visual and auditory channels. Hence, MR interfaces which condition the communication with MR can influence the individual's perception directly. The term *mixing realities* is used to describe "Collaborative Mixed Reality" [26]. Sareika (2010) formulated a new definition building upon Mixed Realitywhich including collaboration:

Mixed Realities

"Mixing realities is an ongoing process of human communication, development and collaboration, where individuals engage to express their personal understanding of reality and engage to experience the understanding of others, mediated by the unified workspace provided by Mixed Reality." [27]

Markus Sareika (2010)

at Graz University of Technology, Austria

2.1 Mixed Reality Technology

Mixed Reality (MR) composes of three main elements, namely scene graphs, displays and tracking. MR technology represents virtual spaces with software and middleware for merging virtual spaces with the real world. Scene graphs are the software basis for this purpose. To output of the computation result various displays are developed to display visual information as information cues. Finally through synchronizing and register physical and virtual spaces of MR, the system could extract the spatial relationship of physical objects and user's gesture on them. The tracking system of MR is needed to extract spatial relationships of physical objects in order to synchronize and register dual spaces of MR[28].

3D Game Engines have become common tools for developing interactive virtual scene graph like which MR needs. By far, the game engine Unity3d is the most practical approach to create and address complexity for developing graphical applications. They offer a real-time rendering to create fluent multimodal visual effect and interaction. Typically, MR consists partly of the real world and partly of a virtual world. The MR scene is the virtual representation of MR based on a scene graph.

Egocentric displays such as head-mounted device (HMD) or cave automatic virtual environment (CAVE) are usually used as output interfaces to users to perceive the virtual space. These wearable displays obviously reduce eye-contact and introduce seams on the communication process in design communication processes which involve multiple participants. In face-to-face design communication processes, individual displays have limited natural information exchange and were seem unnatural. A common view with the same perspective for all viewers is essential to offer multiple actors a common view into the MR scene with communication processes. Large flat displays are suitable for such tasks and can be used together with tangible interactions. For application in participatory design an exocentric view could provide a shared, a summary, an overview which an egocentric viewing perspective could not allow. Directing the view on a common display requires user input to navigate in the 3d workspaces to generate a shared dynamic perspective in the communication process.

Tracking system of MR usually includes camera tracking and object tracking to extract spatial relations between objects. In this way, the digital objects and their dimensions can be registered and synchronized with their physical corresponding objects. By far, the most accessible indoor tracking solutions for MR is Infrared Optical Tracking approach which needs stable controlled lighting situation . There are two solutions based on Infrared Optical Tracking approaches: Fiducial Marker Tracking which tracks physically visible markers in a stable lighting situation and Natural Feature Tracking which allow the tracking of every-day objects on the tabletop of the MR installation[29].

2.2 Tangible Interaction for Mixed Reality

Adopting tangible interaction in MR removes the divide between the digital and physical worlds to offer us the benefits of both. With tangible interaction, virtual information and computation could be literally 'in our hands'. As graspable, physical objects can provide real affordances as compared to their virtual equivalents it allows the users to use their spatial cognition and more natural style of interaction [8]. Tangible interaction as a practical application of haptics has given rise to Tangible User Interfaces (TUIs). The logic and structure of TUIs are both similar to and different from Graphic User Interfaces (GUI). Many of advanced prototype systems have been constructed by the major research laboratories such as the Media Lab at MIT [30]. For instance Illuminating Clay illustrates the state-of-art in tangible interaction design for urban planning and landscape architecture among others. Using tangible interaction could take advantage of the richness of multimodal human senses and experiences of interaction with the physical world. Therefore TUIs have the potential to facilitate the live communication for collaboration and participation in a design process.

TUIs couple physical representations with digital representations. We could use a real pen which in some sense has been mapped onto the virtual equivalent pen on-screen. The virtual pen could be raised or operated through picking up and manipulating the real pen [31]. So an equivalent virtual drawing as a data object would be generated through drawing with the real pen. There are three important characteristics of TUIs:

- Rather than pictures displayed on monitors, TUIs use physical representations such as physical widget, modelling clay and so on. Without using a mouse, people can drag a 3d model on a screen by directly moving the corresponding physical object of this model.
- Only being linked to a digital representation, the tangible and graspable objects could perform computation.
- Representation and control are integrated in TUIs. Rather than using peripheral devices, TUIs provides a direct physical representation to control its digital representation [32].

The MCRpd structure (Figure 2.2), Mode-Control-Representation-Physical and Digital, can illustrate the main difference between TUIs and GUIs. Being different from GUIs' MVC structure (Model-View-Control), MCRpd splits the view component into Rep-p (physical representation) and Rep-d (digital representation) [33]. This modification brings a tight linkage between the control and physical representation. Based on physical objects that represent functions or other objects, different types of gesture such as picking, placing, sweeping movements, and rotation can be mapped onto specific functions. Many prototypes such as Illuminating Clay (Section 3.3.2), Reactable (Section 3.3.3) and Edddison (Section 3.4.1) have realized tangible interaction applications based on the MCRpd model.

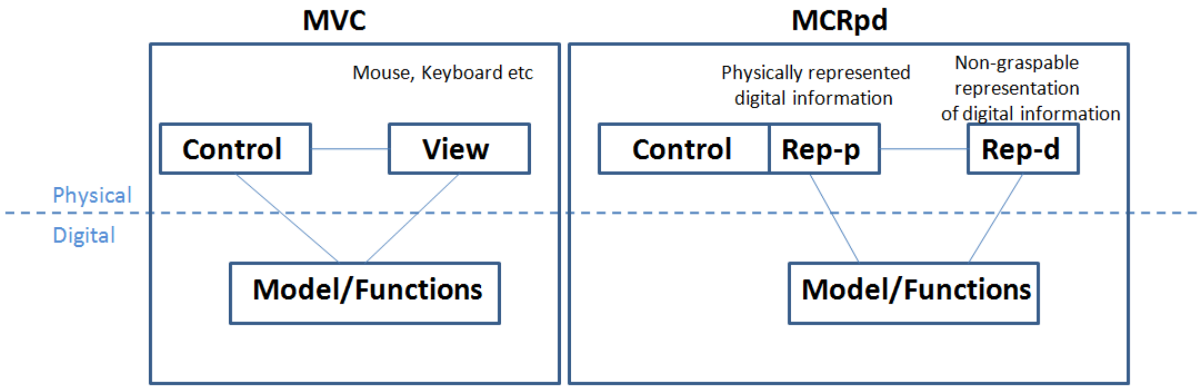


Figure 2.2 MVC and MCRpd Structure

2.3 Case Studies of Tangible Computing

To illustrate the basic concepts of TUIs inaction, the case studies presented in this section provide a number of exemplar systems developed from various research projects.

2.3.1 Bricks

The Bricks system developed by Fitzmaurice, Ishii and Buxton in 1995 is a pioneer example of a graspable user interface [34].This design realized the TUIs idea with physical 'bricks' which were used to manipulate digital objects. This system composes of a large, horizontal computer display surface called the Active Desk and a set of bricks which are placed and operated on the Active Desk. As the size of the bricks are approximately the size of Lego they are very agile to be manipulated by users. The bricks as graspable, tangible objects is designed as an object composed of both a physical and virtual objects by Fitzmaurice, Ishii and Buxton. Physical bricks play the parts of the handle of the corresponding virtual objects. In a graphic package like CorelDraw or Photoshop,a rectangle can be drawn by its handles which can 'get hold of' the rectangle in order to drag it, rotate it and even rescale it. With the Bricks, the user can manipulate the physical bricks to control the coupled digital object

(Figure 2.3). Rotation or motion of the physical brick are mirrored by the virtual object. Tracking the transformation of the physical representations and reflecting those changes in the virtual representation can be implemented from the range of 2D to 3D with different technological solutions. For instance 2D tracking could be realized by the camera tracked marker system, and the 6D tracking could be implemented by compass and acceleration sensors.

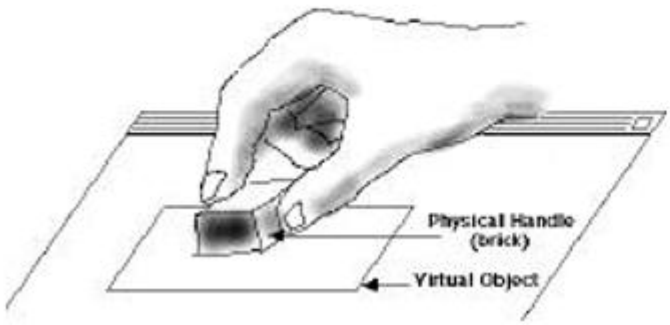


Figure 2.3 A graspable brick(Source: ACM/SIGCHI Conference Proceedings 1995, Figure 15.5 'An image from Bricks: laying the foundations for graspable user interfaces', © 1995.)

2.3.2 Actuated Workbench

Conventional tabletop tangible interfaces are primarily input devices with visual feedback. Actuated Workbench (AW) built by Pangaro, Maynes-Aminzade and Ishii (2002) from the MIT Media Lab can physically moves the tangible objects on the table top in two dimensions by manipulating an array of magnets hidden below [35]. In this way AW provides a physically dynamic feedback loop for interaction output. Rather than other interactive tables which only provide audio or visual output, AW is intended for helping to resolve inconsistencies that tangible objects can move their corresponding digital objects but not vice-verse. The AW's ability to physically move objects on the table has successfully established a two-way feedback between virtual and physical objects. In this case, tangible objects is not only an input interface they have already been transformed as a tangible display augmented by video projection. The possibility of a rounded coupling system between physical and digital objects has been demonstrated by AW. Figure 2.4 shows a schematic of how the AW works.

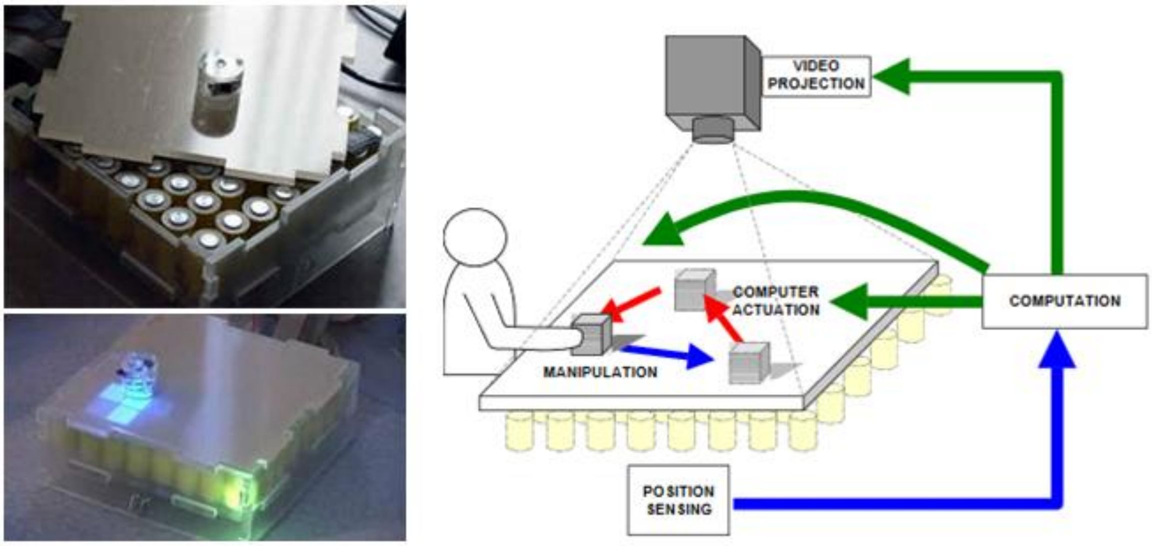


Figure 2.4 A modular tile of the Actuated Workbench and a schematic representation of the Actuated Workbench (Source: Dan Maynes Aminzade)

2.3.3 Reactable Music Table

The Reactable is a revolutionary new electronic musical instrument designed to create and perform the music of today and tomorrow. It combines state of the art technologies with a simple and intuitive design, which enables musicians to experiment with sound, change its structure, control its parameters and be creative in a direct and refreshing way, unlike anything you have ever known before.

Figure 2.5 Reactable Multi-touch Platform.

The Reactable uses a so called tangible interface, where the musician controls the system by manipulating tangible objects. The instrument is based on a translucent and luminous round table, and by putting these pucks on the Reactable surface, by turning them and connecting them to each other, performers can combine different elements like synthesizers, effects, sample loops or control elements in order to create a unique and flexible composition. As soon as any puck is placed on the surface (see Figure 2.5), it is illuminated and starts to interact with the other neighbouring pucks, according to their positions and proximity. These interactions are visible on the table surface which acts as a screen, giving instant feedback about what is currently going on in the Reactable turning music into something visible and tangible [36]. Additionally, performers can also change the behaviour of the objects by touching and interacting with the table surface, and because the Reactable technology is “multi-touch”, there is no limit to the number of fingers that can be used simultaneously. As a matter of fact, the Reactable was specially designed so that it could also be used by several performers at the same time, thus opening up a whole new universe of pedagogical, entertaining and creative possibilities with its collaborative and multi-user capabilities.

2.3.4 Illuminating Clay

Based on the similar underlying principles, Illuminating Clay was developed to investigate the possibilities of tangible computing in urban or landscape design. This specialist example is a much more sophisticated implementation than the aforementioned Bricks. Its creators introduced it with the following scenario [37]:

" A group of road builders, environment engineers and landscape designers stand at an ordinary table on which is placed a clay model of a particular site in the landscape. Their task is to design the course of a new roadway, housing complex and parking area that will satisfy engineering, environmental and aesthetic requirements. Using her finger the engineer flattens out the side of a hill in the model to provide a flat plane for an area for car parking as she does so an area of yellow illumination appears in another part of the model. The environmental engineer points out that this indicates a region of possible landslide caused by the change in the terrain and resulting flow of water. The landscape designer suggests that this landslide could be avoided by adding a raised earth mound around the car park. The

group tests the hypothesis by adding material to the model and all three observe the resulting effect on the stability of the slope."

Piper, Ratti and Ishii (2002)

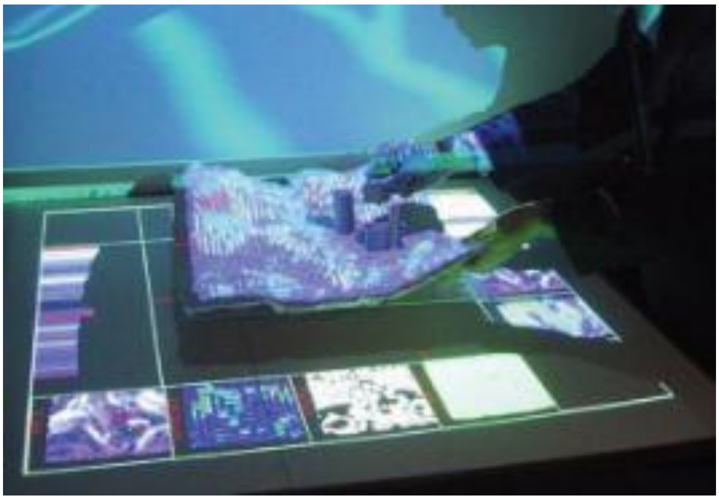


Figure 2.6 Illuminating Clay

Being different from Bricks which used a computer display surface to display the virtual objects, Illuminating Clay proved that the digital elements could also be projected on a thin layer of plasticine supported by a metal mesh core. With Illuminating Clay, ordinary design tasks in landscapes such as examining the effects of wind flow, drainage and the position of powerlines and roads could be carried on the clay model itself. By means of a ceiling-mounted laser scanner and digital projector, Illuminating Clay system coupled clay model and its digital representation not only by their position but also by their geometry form. The scanner and projector are aligned at the same optical origin using an angled mirror for reflecting images and lasers. Through calibrating the two devices to scan and project over an equal area, any changes of clay model could be sensed and represented by the laser scanner and digital projector [38]. When users are allowed to manipulate the spatial relationships of the physical clay model by hands those highly complex topographies could be explored more intuitively and quickly (see Figure 2.6). Thus this project demonstrates that complex design work such as landscape analysis could be facilitated by combining physical and digital representations.

2.3.5 Illuminated Talking Touch Models

This touch model shown in Figure 2.7 was initially created as a kind of way-finding system which was expected to be a great value to the students in the Carroll Centre for the Blind in New York. In the beginning, its designers defined it as an interactive touchable talking campus map which featured a scale model of the campus of the Carroll Centre. This directory system was produced from organic materials using a 3D printer. Those learning to navigate the environment are encourage to touch the model; as they do, a computer senses their touches and offer audio helpful descriptions and way-finding information for each building and the landscape feature on the physical model. Touches are detected by embedded electrodes connected to a multichannel sensor.

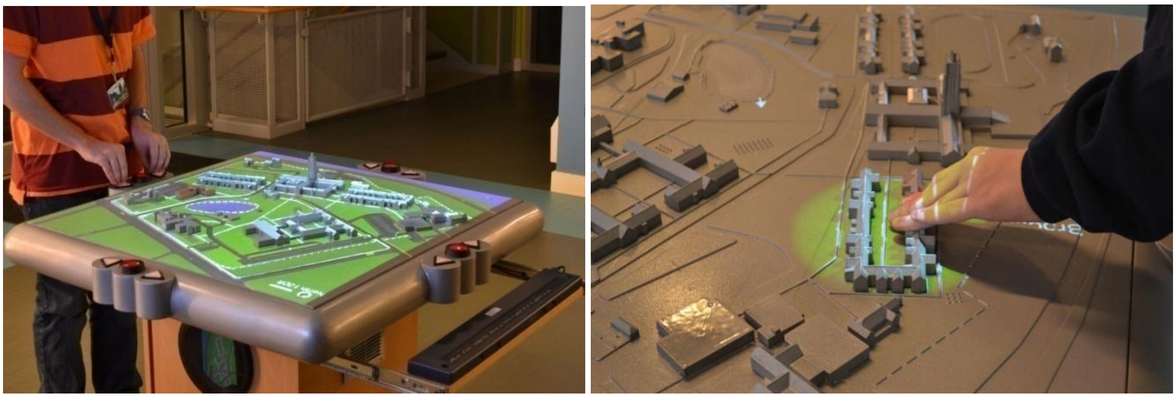


Figure 2.7 Illuminated Talking Touch Models.

Oddly, as a system produced for the vision-impaired, the talking touch model has been added a rendering system in its recent development. Its designers painted the model entirely white and projected on to the white surface with a rendered image of the campus map. As various buildings are touched, the model illumination dims, except for a spotlight to highlight the thing that was touched. In the meantime, the specific photo of the building which is touched will be displayed on the computer screen. They hope this approach to information display may improve comprehension of a complicated three-dimensional representation for a very wide audience not only for blind students [39].

2.4 Mixed Reality in Participatory Design

Participatory Design (PD) originated as a strategy for increasing workers' understanding and mastery of the tools they use in their work (Nygaard 1996). Traditionally, this approach emphasises mutual learning and interactive development involving concrete prototypes with committed users. In order to generate design ideas based on use practice, PD aims to involve the future users throughout the phases in the design process [40]. Successful PD depends on effective collaboration and communication between designers, engineers, end-users and other stakeholders. Hence providing stakeholders a clear presentation of a design concept and future use context is essential to engage stakeholders to help the design project to arrive at a functionally better and even a more 'creative' solution [41]. Hence the tools and space of PD should be able to support both internal and external communications (i.e. communication between internal professional developers and external stakeholders such as end-users or customers). As external stakeholders are usually not trained in being involved in a participatory design process, how to facilitate their involvement poses particular challenges.

The design process of architecture, product or service generally involves a sequence of gathering requirements/briefs, conceptual design, modelling/prototyping, engineering, construction/manufacturing and finally a market release [42]. In this process, traditional communication techniques such as sketches and drawing are used to facilitate communication between designers; CAD models can facilitate communication between engineers and presentations or reports are used for communication between departments. External stakeholders' involvement usually aims at facilitating concept generation and usability evaluation. Only when stakeholders are provided with more realistic representations to illustrate, debate and experiment with different design possibilities, they can be deeply engaged in PD. Stakeholders with multiple backgrounds and expertise bring different perspectives, attentions, interests and competencies into the PD process[43]. How to express and apprehend these in the design process is the main challenge in the PD process. More recently, there is a trend that urban and architecture designers have attempted to use interactive tabletop tangible interfaces to support non-experts' understanding of the design and engaging them in a dialogue.

The term 'Stakeholders' in the domain of interactive system design refers to those groups who will affect or be affected by the actions or results from an interactive system design as a whole. It includes end-users who will finish up using the new system derived from the design and many other people whose jobs might be changed by the new system [44].

Stakeholders can be people from the same organization and also be people outside an organisation. In order to decide the number and type of stakeholders who will be involved in the PD design, we have to consider all the different stakeholders and how they might be affected.

For including stakeholders in a PD process, a set of characteristics of the process for facilitating the communication is proposed: Firstly, a direct and explicit communication between designer and stakeholders. Secondly, the exact functioning and experience of the design should be able to be assessed through a realistic interaction by end-users. Finally, consequences of design decisions need to be presented in a comprehensible way regardless participant's training or background. MR potentially provides solutions meeting these characteristics for facilitating the involvement of stakeholders in a PD process [45]. MR technologies could potentially create realistic interactive concept representations for the communication and collaboration in the PD process. It creates an alternative dual reality in which worlds allows stakeholders to not only see the design (which could also be achieved with other traditional communication techniques), but also experience and interactions with its use context. As MR is rarely a solution on its own it needs supporting principles to integrate the MR technology with the PD. In the case studies in the following section *scenarios* are used to achieve it. With design processes a scenario is usually expressed by displaying a prototype (either real or virtual) in an environment (either real or virtual). Designers can make use of scenarios to address problems, needs, constraints and possibilities. Scenarios as a simulation of real use context it can also facilitates explicit communication of design data among stakeholders.

The case studies presented in this section focus on research projects in which MR with tangible interfaces are adopted for facilitating PD. The application domains range from architecture design and urban design to healthcare. Rather than involving stakeholders only in the user-evaluation stages these cases have demonstrated that with the support of MR none-expert stakeholders can be triggered to explore new opportunities. To explain how these applications are able to facilitate PD we develop a framework with two dimensions, as shown in Figure 2.8, to position these case studies. Also each case study is explained from the aspects of the application context, technical implementation and the specific contribution to user involvement.

2.4.1 Edddison

Context - Edddison is a framework solution for interacting with 3D software in real-time. It can integrate a wide range of hardware devices including the edddison hardware interface, tablets, and touch screens. It allows users to create a walk through in a 3d file without any scripting skills[46]. It successfully bridges the gap between 'old technologies', like models and drawings, and the new digital technologies such as virtual reality. Edddison is developed to handle and navigate through 3D presentations with tangible interface. It enables everybody to prepare, navigate and view 3D files and applications. Edddison allows non-technical users to easily develop and present real-time 3d applications without programming skills. Edddison is a platform of different programs, plug-ins and interface technologies. It allows users to control 3d software like Unity, SketchUp and Autodesk Navisworks with hardware such as mixed reality tools (tangible objects & webcams), touch devices and tablets.

Technical Implementation - The platform consists of Plug-in, editor and hardware. The plug-in supports standalone 3d software such as Unity3d, Sketchup to create 3d scenes. The editor of Edddison provides non-technical users an easy way to develop interactive 3D applications efficiently (Figure 2.9). The hardware working as a user tangible interface could be an interactive projection table, a desktop lamp or mobile devices such as tablets. A floor plan is needed on the control device to ensure perfect orientation in the 3D view. With Edddison it is possible to maintain constant orientation in spatial environments. This solution provides better recognition between 3D(plan) and 3D (VR view) information. To avoid getting lost in 3d file, Edddison adopts the split screen mode. Through adding Edddison markers (unique bar-codes) to any tangible object generates control objects. Printed markers are tracked seamlessly by a camera and send the coordinates (position, rotation) to the 3d software. Control objects are the first visible items for users. These objects are the real representatives of designers' ideas inside the virtual world - they help users navigate through the 3d data. The tangible control objects as virtual representations could be designed in a creative and customized way and produced using 3d printing, laser cutting or hand-making.

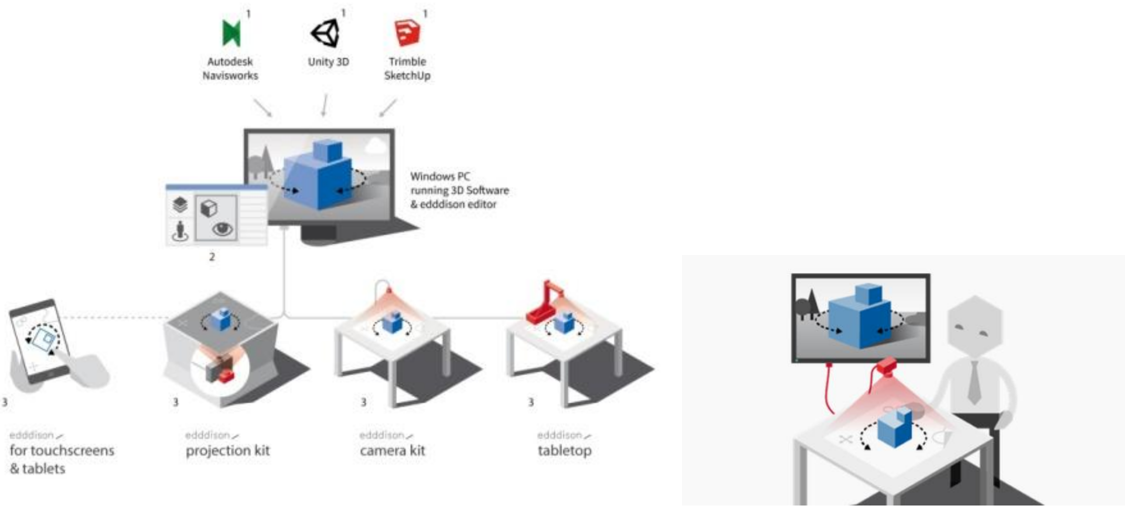


Figure 2.9 A schematic representation and a user scenario of Edddison

Stakeholder Involvement - Edddison also enables multi-user and multi-hand control, making 3d data navigation a collective experience. In future, edddison will come with a collaboration feature, which will enable several people to work together on the same 3d file, via the internet too. It offers architects, real estate developers, builders, designers, the automobile industry and others a simple and attractive alternative to static product presentations. Edddison provides a presentation and sales tool to involve customers, managers and stakeholders directly in the design and decision-making process and also get them excited about their product in a new and fascinating way [47]. Viewers can walk through a planned house or take a seat in a futuristic car model. The smart technology even allows non-technical users to work with the displayed objects almost as if they were playing a game.

2.4.2 Room Layout Configurator

Context - In ambient experience design domain, designers usually make use of physical replica rooms to prototype and evaluate different ambient concepts (e.g. lighting and sound) with various contexts [48]. To solve the flexibility and cost issue of these mock rooms in this case study, a special room has been built according to the theme under investigation(e.g. patient rooms, living rooms or hotel rooms). In this special room designers can able to reconfigure room layouts and evaluate the ambient experience rapidly with the support of a MR application.

Technical Implementation - Based on the similar underlying principle and mechanism this MR application employs a Microsoft Surface Table which is synchronize with a large projection wall (see Figure 2.10). The projection is in charge of displaying a 'first-person' navigating view of a virtual room. Designers can arrange the furniture in the virtual room through manipulating tangible objects located on the surface table. Also the perspective of the navigation camera could be controlled by a corresponding object/widget with a visual tags underneath.

Figure 2.10 The Room Layout Configurator consists of a Surface Table with tangible objects which are connected to the virtual objects on the wall display.

Stakeholder Involvement - The Surface Table with a common view display (a wall projection) enables a PD group with experts and non-experts to collaboratively discuss, compose and evaluate the layout of the hospital room. With tangible objects coupled with virtual perspectives each participant is able to create and reconfigure the layout of the room. By this means each group participant has provided an equal share in determining the room layout regardless of the background and expertise. And everyone is able to explain his/her perspective on the design case. This setup allows every participant has a chance to explain her/his idea with hands-on modelling. With this MR application in multidisciplinary group meetings every participant's design concepts can be rapidly prototyped, demonstrated and 'experienced' in a mixed reality way.

2.4.3 Mixed Reality Tent

Context - This case study comprises the development of a participatory mixed-reality tool in support of new ways of experiencing and contributing to urban design [49]. The mixed-reality tool is a mobile laboratory which can be transported to a site of design. With this mixed-reality lab real city scenes can be interactively augmented with computational visualisations to illustrate, debate and experiment with different design possibilities among various stakeholders of the design project.

Technical Implementation - The MR-Tent provides a very specific collaborative setting. It is a mobile urban design laboratory, which can be transported to an urban planning site, and where real city scenes can be interactively augmented with audiovisual scenes to illustrate, debate and experiment, with different design possibilities among various stakeholders of design. It provides users with the possibility to arrange and position tokens on physical maps of different scales, representing interventions in urban space. A vertical projection renders the scene against different representations of the physical site. Object of the mixed-reality world can be modified and adapted in scale, transparency, colour and offset to the ground. Users can work with different types of visual objects (3D and 2D objects), visualising buildings, bridges, activities, ambience and sound.

Figure 2.11 The framework of the Mixed Reality Tent for urban planning

Stakeholder Involvement - The participants can place different types of paths animated by flows of pedestrians, cyclists, cars, a train, and so forth, to a scene. They can also define areas, marking them with textures. In addition, the participants can create and explore the soundscape connected with the visual scene. These mixed reality scenes are viewed against different representations of the site: different photographic panoramas that have been edited so as to provide views and spaces for interventions; an aerial view of the whole site; a real-time video stream produced by a fixed as well as a mobile camera; and a see-through installation, in which the mixed-reality scene is directly projected onto the site as seen through a window. Figure 2.11 shows the framework of the Mixed Reality Tent.

2.4.4 Operating Theatre Design

Context - To include stakeholders in the design of a dedicated endoscopic operating this case study employs a MR design tool for concept composition and evaluation [50]. A Ceiling Mounted Arm (CMA) system has been designed and evaluated in a tangible interactive virtual environment provided by the MR tool among stakeholders such as anaesthetist, surgeons and nurses. With this approach the consequences of any design decisions is able to be understood and discussed immediately.

Technical Implementation - As shown in Figure 2.12 a large curve projection wall and a Microsoft Surface Table connected miniature tangible models of the CMA systems compose this MR application. The position and movement of the physical models on top of the surface Table can be tracked by the table for controlling the components in the virtual theatre displayed on the projection wall. For supporting the participants create new CMA concepts the Surface Table also displays a top down view of an operating theatre. By manipulating the miniature CMA models on the top view of the theatre the coupled digital CMA systems in the virtual environment can be modified simultaneously. A real-time walk-through on the wall display is also allowed while the operating theatre being still modified for supporting usability evaluation.

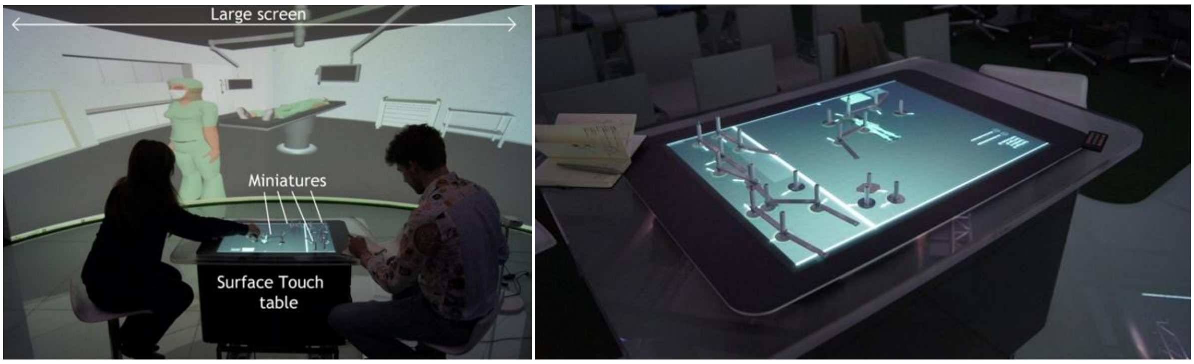


Figure 2.12 As shown in the right image, the Surface Table displays the floor plan of the Operating theatre and there are a set of miniature tangible CMAsystems on top of it for supporting PD among stakeholders. The left image illustrates the user scenario of this MR application in which the platform in the right image is used an interface for the virtual theatre (shown in the background).

Stakeholder Involvement - This MR application provides session participants a semi-immerse environment with movable virtual avatars. With the support of this setup the consequences of the design decisions they have made can experienced. The dynamic 3D perspective effect of repetitively configuring a CMA system can be immediately visible and walked through for every participant on the wall display. Not only CMA design concepts can be created and evaluated using this MR application future use scenarios with CMA systems also can be re-enacted on it.

2.5 Summary

This chapter reviewed existing applications of mixed reality technology on participatory design. Benefiting from the intuitive characteristics of mixed reality technology the cases reviewed demonstrate its capability and effectiveness to support participatory design. However, all these cases only use an two-dimensional floor plan to bound tangible objects as a spatial reference to correspond to the three dimensional space in the virtual reality. From the perspective of architecture, physical architecture model is an effective representation to facilitate the design communications between designers and clients. Obviously, this capability has been ignored in current mixed reality applications. It makes that physical architecture model which could provide its surfaces as tangible interfaces cannot have a chance to play a role. How to integrate scaled architectural model into tabletop mixed reality interface needs to be investigated to see if it could help users to immerge and understand the design more effectively.

A logic flaw of existing tabletop mixed reality is that besides visual feedback its physical side lacks of capability to represent other types of reaction to virtual side. This results most of the users' attentions focus on the virtual side on the monitor, and the role of tangible objects degenerate to input tools as mouse and keyboard. It has violated mixed reality's original intention. Therefore, developing diverse reaction mechanism on the physical side to balance users' intention on both sides of mixed reality should be investigated.

CHAPTER 3 AMBIENT INTELLIGENCE AND SMART ENVIRONMENTS

3.1 WHAT AREAMBIMENT INTELLIGENCE AND SMART ENVIRONMENTS

The term Ambient Intelligence (AmI in short) was coined by the European Commission, when in 2001 one of its Programme Advisory Groups, the European Community's Information Society Technology(ISTAG), launched the AmI challenge, later updated in 2003 [51]. Ambient Intelligence (AmI) stems from the convergence of three key technologies: Ubiquitous Computing, Ubiquitous Communication, and Intelligent User Friendly Interfaces. In AmI scenarios, on convergence humans will be surrounded by intelligent interfaces supported by computing and networking technology which is everywhere, embedded in everyday objects such as furniture, clothes, vehicles, roads and smart materials even particles of decorative substances like paint. AmI implies a seamless environment of computing, advanced networking technology and specific interfaces. It is aware of the specific characteristics of human presence and personalities [52], taking care of needs and is capable of responding intelligently to spoken or gestured indications of human desires, and even can engage in intelligent dialogues.

More and more people make decisions based on the effects their actions will have on their own inner, mental world. This experience of rational way of acting is a change from the past when people were primarily concerned about the use value of products and services and is the basis for the experience economy. Ambient intelligence addresses this shift in an existential view by emphasizing people and user experience. AmI addresses in particular the need to design digital things/systems from a user's point of view.

The interest in researching user experience has also grown because of the overload of products and services in the information society that became difficult to understand and hard to use in the past. Ambient intelligence is influenced by user-centric design where the user is placed in the centre of the design activity, and askinguser feedback through specific user evaluations and tests is now considered essential to improve the design or even co-create designs together with other system designers and users.

In the past decade, location sensing and tracking technologies have been developed to track people and objects over an existing wireless network in order to make the Ambient

Intelligence dream a reality. Some of the existing solutions for determining people/object location are summarised as follows . [53]:

- **RFID Radio-Frequency Identification(RFID).**RFID has been used widely across many different applications. The vast majority of these applications, however, only use the data contained in RFID tags within the RFID reader's zone, rather than the location of the tag at any given time.
- **Ultra-Wide Band (UWB)**. UWB is precisely timed short bursts of RF energy to provide accurate triangulation of the position of the transmitting tag. Since the short time UWB signal is very broad in frequency spread (typically 1 to 2 GHz wider) the system can operate on a very low power output and is robust against interference. Typically battery-operated radio tags and a cellular locating system to detect location of tags. Locating systemsare usually deployed as a matrix of locating devices (or sensors). These sensors determine the locations of the radio tags.
- **ZigBee Sensor Modules**. The ZigBit device is a low-power, high-sensitivity 802.15.4/ZigBee module..
- **802.11 WiFi**. This generally consists of 3 elements: 1. Radio beacons in the environment. 2. Databases holding beacon location information and 3. Clients which estimate their location from data.

How can we implement an AmI system? In order for AmI to become a reality a number of key technologies are required:

- Unobtrusive hardware (Miniaturisation, Nanotechnology, smart devices, sensors etc.)
- Seamless mobile/fixed communication and computing infrastructure (interoperability, wired and wireless networks, service-oriented architecture, semantic web etc.)
- Dynamic and massively distributed device networks, which are easy to control and program (e.g. service discovery, auto-configuration, end-user programmable devices and systems etc.).
- Human-centric computer interfaces (intelligent agents, multimodal interaction, context awareness etc.)

In an AmI world, devices work in concert to support users' everyday activities and tasks that are hidden in the network connecting these in a natural way using information and intelligence devices. AmI emphasizes user experiences and ensuring invisible characteristic of the AmI until only the end user interface remains visible to users.

AmI specifically focuses on the convergence of several computing areas. The first is ubiquitous computing which focuses on self-testing and self-repairing software, privacy ensuring technology and the development of various ad hoc networking capabilities that exploit numerous low-cost computing devices. The second key area is intelligent system research, which provides learning algorithms and pattern matchers, speech recognition and language translators, and gesture classification and situation assessment. Another area is context awareness which attempts to track and position objects of all types and represent objects' interactions with their environments. Finally, an appreciation of human-centric computer interfaces, intelligent agents, multimodal interaction and the social interactions of objects in environments is essential.

There are two terms, 'ambient intelligence' and 'smart environments', which have now been widely adopted to refer to a digital environment that proactively, but sensibly, supports people in their daily lives. In spite of the fuzziness of defining 'Ambient Intelligence' it is possible to roughly define AmI as a computational paradigm aimed at designing, developing and realizing "augmented" environments (i.e., physical environments built with electronic devices, such as sensors and actuators) that prove to be sensitive, responsive and aware of both humans and their activities. In order to support people in better carrying out their everyday activities, distributed devices in an AmI environment seamlessly cooperate with each other and with humans constantly. AmI is aligned with the concept of the "disappearing computer". In particular, service provisioning and specific information should be conveyed through a hidden network connecting all these devices [54]: as they grow smaller, more connected and more integrated into the real physical environment, the digital technologies disappear into the surroundings, leaving only elements of the user interface and the intended AmI effects visible, audible and/or touchable to the inhabitant.

On the other hand, as a design vision of AmI, Smart Environments (SE) aim to satisfy the experience of individuals in a various of situations, by replacing the hazardous work, physical labour, and repetitive tasks with automated agents. Addressing the definition of smart environments is only the first step towards designing it effectively. Most researchers have a general idea about what a smart environment is and use that general idea to guide their design. However, a vague notion of smart environments is not sufficient; in order to design a successful smart environment effectively, we must attain a better understanding of what smart environments are supposed to be. A better understanding of smart environments will enable designers to: (1) choose what strategy of smart environments to use in their SE services,(2) provide insights into the type of activities that need and could be supported, and (3) identify appropriate agents and mechanisms required to support and communicate smart environment design. Previous definitions and discussion of smart environments are found in the following sources [55]:

""Smart spaces" are work environments with embedded computers, information appliances, and multi sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers."

National Institute of Standard Testing

(NIST), USA

"A "smart environment" is a small world where all kinds of smart devices are continuously working on make inhabitants' lives more comfortable. A definition of "smart" or "intelligent" is the ability to autonomously acquire and apply knowledge, while environment refers to our surroundings. Therefore, a "smart environment" is defined as one that is able to acquire and apply knowledge about an environment and also to adapt to its inhabitants in order to improve their experience in that environment. "

D.J. Cook and S.K. Das (2005)

at University of Texas Arlington, USA

""Intelligent Space" is a denomination that encompasses several initiatives for creating an environment that is continuously tracking and sensing people and objects within a physical space while offering some type of feedback or help. "

The Media House Project,
Barcelona, Spain

Poslad differentiates three different kinds of smart environments for systems, services and devices: virtual (or distributed) computing environments, physical environments and human environments, or a hybrid combination of these [53]:

- *Virtual computing environments enable smart devices to access pertinent services anywhere and anytime*
- *Physical environments may be embedded with a variety of smart devices of different types and form factors ranging from nano- to micro- to macro-sized.*
- *Human environments: humans, either individually or collectively, inherently form a smart environment for devices. However, humans may themselves be accompanied by smart devices such as mobile phones, use surface-mounted devices (wearable computing) and contain embedded devices (e.g., pacemakers to maintain a healthy heart operation or AR contact lenses).*

Poslad Stefan (2009). Ubiquitous Computing

3.2 The Process of Interactive systems design

In essence the AmI and SE are typical interactive systems. The design process of interactive systems could be considered as the foundation for designing AmI and SE. Design process is a process concerned with creating something new and about conscious change and communication between designers and the people who will use the system. Benyon characterize the overall design process of an interactive system in terms of four articulated activities including *envisionment*, *understanding*, *evaluation* and *design*[reference missing]. As shown in Figure 3.1, evaluation is central to designing interactive system as every other component get evaluated at every steps. The start point of the design process is random, we can start with a prototype or understanding. And the order of the activities is not fixed as well [56].

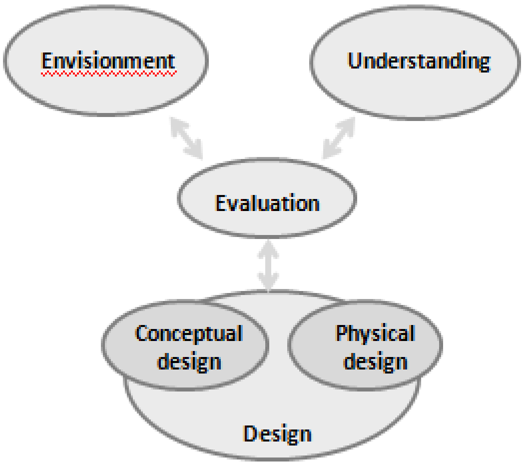


Figure 3.1 The process of interactive system design: *understanding*, *design*, *evaluation*, *envisionment*.

Understanding is concerned with generating the requirements of the system or service. Human-centred design focuses on generate requirements through communication and interactions with end-users or people who will be affected by the proposed system, the stakeholders. The definition 'stakeholders' is that people who will be affected by any system derived from the proposed interactive system.

From the *design* aspect, interactive system design composes of conceptual design and physical design. Conceptual design refers to figure out what functions and information are needed for achieving the system's purpose. On the other hand physical design aims at how things can work and detailing the look and feel of the system. It is about structuring interactions into logical functions from conceptual design.

For enable people to communicate and evaluate design they need to visualized in an appropriate media. This is what *envisionment* concerns.

As the centre of the design process of interactive systems, any of the design activities will be followed by *evaluation*. Evaluation techniques are various depending on the circumstances. We will employ mixed reality scenarios for representing envisionment to support user evaluation.[56]

3.3 MOTHODS FOR DEVELOPING AMBIENT INTELLIGENCE AND SMART ENVIRONMENTS

3.3.1 Using a Mock-house with Supporting Technologies as an Experiment Platform

Gator Tech Smart Home

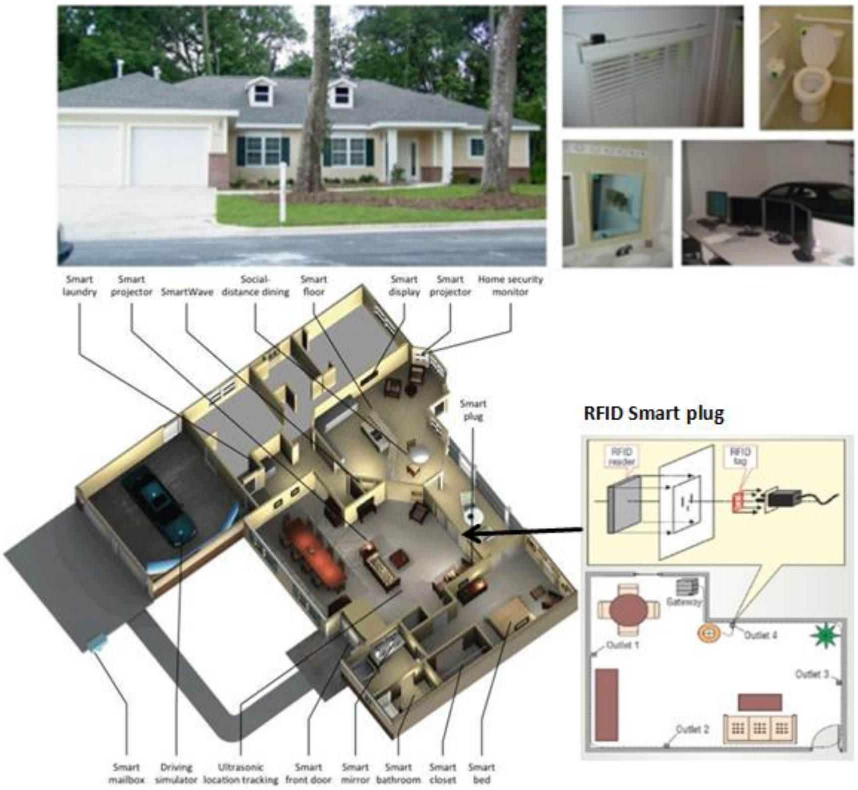


Figure 3.2 Gator Tech Smart Home.

Gator Tech Smart Home (GTSH) is an attempt at creating assistive environments using sensors and actuators [57]. As show in Figure 3.2 in this project, a 2500 square foot, free-standing house located in Florida serves as the test bed in which the research team deployed and tested various pervasive computing technologies developed for the smart home. Developing models, methodologies, and processes of creating programmable pervasive spaces is the main goal of GTSH. A smart home space exists as a runtime environment and a software library in addition to the physical house. Assistant services could be initiated by service discovery and gateway protocols and frameworks. A generic middleware is used to maintain a service definition of the sensors and actuators in the space.

The Atlas platform applied in GTSH seeks to create a sensor network platform which is fully adequate for the development of pervasive spaces [57]. This sensor and actuator platform is the basic building block to create a programmable assistant environment. In this platform physical nodes are provided to connect various heterogeneous devices for translating them into smart home services. Atlas is a runtime environment for accessing services and composing applications for the pervasive spaces. Elderly experiment participants were invited to test the home automations in this real environment equipped with ubiquitous computing.

Smart Kitchen

Domestic kitchens are natural candidates for augmented reality interfaces because there is a high need for users to remain in contact with physical reality while using a number of tools that could benefit from digital information [55]. By sensing the location of tools and ingredients, the temperature of surfaces and food, and the needs of the user counter Intelligence can provide information to coordinate and instruct cooks on the use of the kitchen. Although the physical aspect of the kitchen remains unchanged, useful information as show in Figure 3.3 and Figure 3.4 can be overlaid on nearly every surface of the space: the refrigerator door, range, countertop, cabinets, and faucet. In each case, the quality and quantity of information projection needs to be tailored to the amount and type of attention directed at each task.

In this case, five discrete systems gather information from the kitchen to help users know the status of tools and work surfaces [58]. Information is displayed on the door of the cabinets   in an intuitive manner with special consideration for directing the user’s attention. These interfaces through repeated evaluation and pilot studies, and built the systems to carry out a user evaluation of the environment in which users carry out a basic recipe in the augmented reality space. Counter Intelligence which is a knowledge database of cooking helps eliminate many steps of traditional cooking processes and gives users an added sense of confidence when interacting with the space and equipment.

Figure 3.3 A Smart Kitchen Project at MIT.

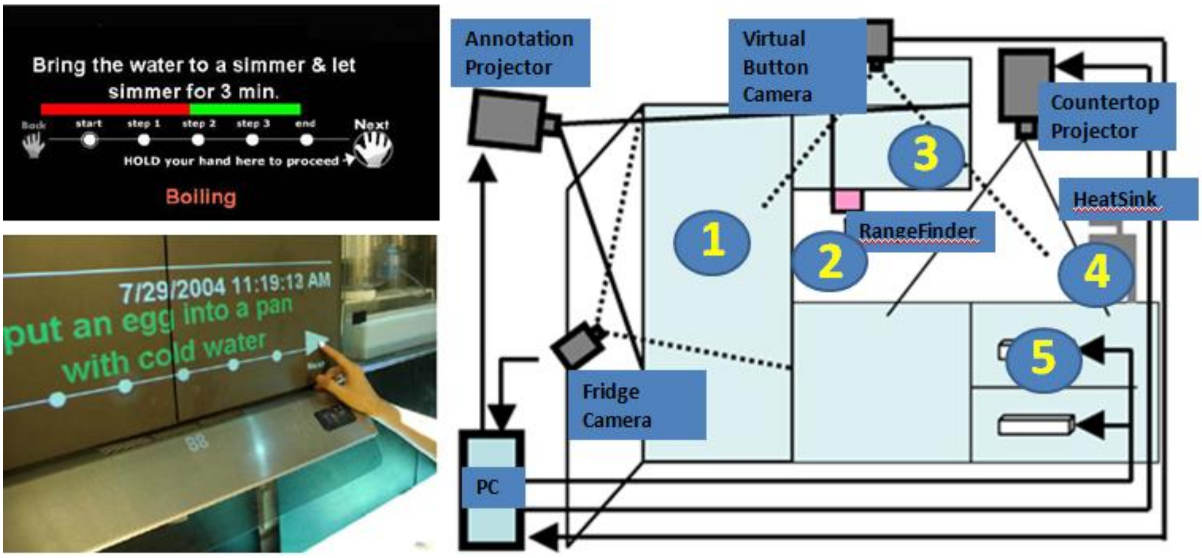


Figure 3.4 Virtual Recipe and the system diagram of the smart kitchen.

To design the augmented reality interface, the research team began with a careful consideration of the user’s attention and the best ways to present information in general. The space was designed according to several demonstrated principles of attention cues, and serial and visual searching. Existing kitchen interfaces like the faucet handle or the dials on the range require users to focus their attention away from the task of using the water or cooking food in order to read or adjust the interfaces. Augmented reality projection can show information and project interfaces directly on the task being performed.

This case presents an augmented reality kitchen with five digital augmented systems that reveal the status of tools and surfaces in the space in order to enhance the kitchen experience. The projection of digital information onto the objects and surfaces of the kitchen can increase user confidence; and can better orient a user in space. Pilot studies and user evaluations reveal that spatial, attention-sensitive projections were most useful. This project reveals two major lessons: the advantage of exogenous cueing in locating items in a familiar environment and the advantage of paper recipes over sequential, digital ones in allowing for a multi-tasking approach. The combination of digital augmentation technologies was proven to be generally as robust and reliable as traditional recipe interfaces.

3.3.2 Using a Scaled Model for Design Communication

The purpose of the Ambient Assistant Living (AAL) systemin this case study is to monitor the daily activities of elderly residents [59]. The questions addressed in this study are 1) What daily activities are liked to be monitored? 2) With whom the residents would want to share the monitored data? and 3) How this monitoring system should be designed with elderly residents?

Figure 3.5 Participatory design with a Dollhouse prototype.

To exemplify and understand desired AAL scenarios and information sharing needs, the researchers created an interactive scaled physical model (dollhouse)as a method for including the elderly residents in the participatory design process. The interactive dollhouse which is a scaled model embedded with sensors is used to exemplify AAL scenarios to include elderly in the design and requirements gathering process for residential monitoring. By this communication means, elderly residents can have a hand-on experience of the desired scenarios and so to increase understanding, acceptance and utility of the AAL system. The study focuses on gathering the monitoring data of the elderly residents' Activities of Daily Living (ADL) which will be used by physicians to benchmark physical and cognitive decline. For gathering honest and true opinions and attitudes in the participatory design process, the exact workings of ambient intelligent systems intended in the home must be clear to the users. In the investigated home aged care scenario, researchers planned to involve placing 15 simple sensors such as motion detectors and switches on door throughout elderly homes for tracking their activities of daily living. To explore perceptions the elderly on what activities to monitor researchers developed an elderly-centred design approach. Participatory design as a human-centred design method emphasizes the values and opinions of direct and indirect stakeholders and hence is helpful to uphold the ethical and democratic standards of the design process. However the invisibility and novelty of ambient intelligence system makes its data stream and itself difficult to be imagined. The interactive dollhouse is developed for requirements gathering through running example scenarios with the participants. This dollhouse is a scale model copy of the participants' home which has been equipped with motion sensors to simulate the actual monitoring environment. A number of activities, such as taking medication, movement and continence under tele-monitoring can be activated by the users in the dollhouse. And the elderly participants were being able to have their own say when experience the desired AAL scenario with the interactive dollhouse. And a graphical user interface is linked to the sensors to display simple feedback on what is being monitored in the dollhouse. The interface of the dollhouse's data representation was designed with elder users in mind and hence they allow non-professional to interpret the data. After using this interactive dollhouse in five participatory design sessions, this design approach was found to be helpful to provide the elderly a better understanding of the desired workings of the AAL system and its outputs. And this physical model based tool has also been demonstrated its effectiveness in helping communication between elderly, researchers and other parties involved in the design process.

3.3.3 Virtual Scenario Composer of Ambient Intelligence

3.3.3.1 A Multi-Purpose Scenario-based Simulator for Smart House Environments

The cost of implementation and evaluation process of developing smart house is potentially very high because of the variety and quantity of sensors, home appliances and devices available for a smart environment. This case introduces a multi-purpose scenario-based smart house simulator for designing and simulating services provided by a smart house before it is actually built [reference missing]. Using this simulator (show in Figure 3.6),researchers and engineers could design the house plan and equip this 2D model of the house with multiple virtual sensors and appliances. This simulator is also designed as a remote backstage application which can connect to any external smart house for evaluating a real smart house system [60]. New emerging sensors and devices could be configured and added into this simulator to meet the compatibility requirements of future simulations. The most import feature of this simulator is that users can define various potential combinations and configurations of devices states to simulate smart scenarios. By this means, different criteria and variables of the scenarios in the desired smart environments can be tested and evaluated without high-cost physical experimental constructions. The expensive home appliances together with standard or customized sensors or actuators make it difficult to work in the real smart home for researchers and engineers.

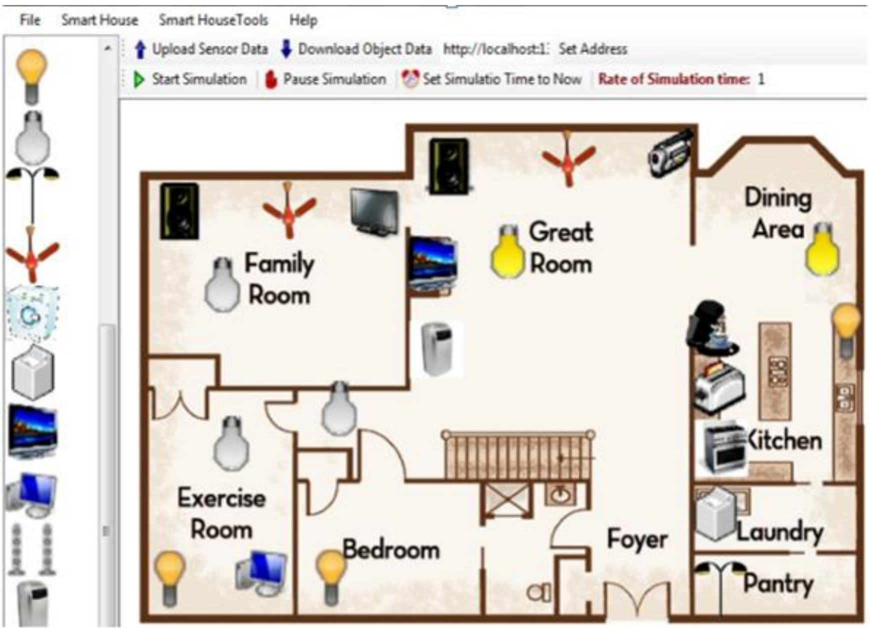


Figure 3.6 The IDE of the simulator consisting of top view plan of the house with virtual devices.

The main objective of this project is to decrease the obstacles in the way of developing and evaluating smart house, especially cost and time. The simulator aims to be a substitution for the corresponding real smart house. It provides any agent props of state-of-the art sensors and appliances for supporting scenario design. This simulator provides researchers and engineers with principle features such as defining scenarios, managing devices, managing sensor and designing house plan. The simulator has implemented five important characteristics which are considered as essential capabilities to support the design of smart house.

1. Top view plan of the specified house.

2. Supporting all kind of sensors and home appliances

3. Connecting to house remote controlling systems

4. Planning scenarios

5. Evaluating the proposed smart house

Based on these capabilities, this case project provides an example to illustrate the workflow of this simulator as show in Figure 3.7. To create a test plan of a smart house, the designer needs to design a house plan and define home appliances and assign related sensors to them. Then different tasks could be created via the "define scheduled task" on desired objects. The list of actions in a scheduled task can be saved for further use. With these pre-defined tasks scenarios can be created through combining a set of these tasks without defining their specific dates and times. In the evaluation phase, the updated status of the selective devices could be checked by clicking on a specific device and choose "Get Status" option. Through checking the updated status of each devices the designer can realise if the tasks or scenarios has executed correctly.

The capability of creating scenarios is most import function of this simulator. A scenario consists of specific scheduled tasks which defines a serial of tasks for executing on sensors or devices [60]. This capability is realized through defining the date and time of executing special sensors or devices with their own object ID. By using a scenario, designers could add a set of tasks to execute according to the defined time. By this means, various possible combination of device states and different criteria and variables could be evaluated.

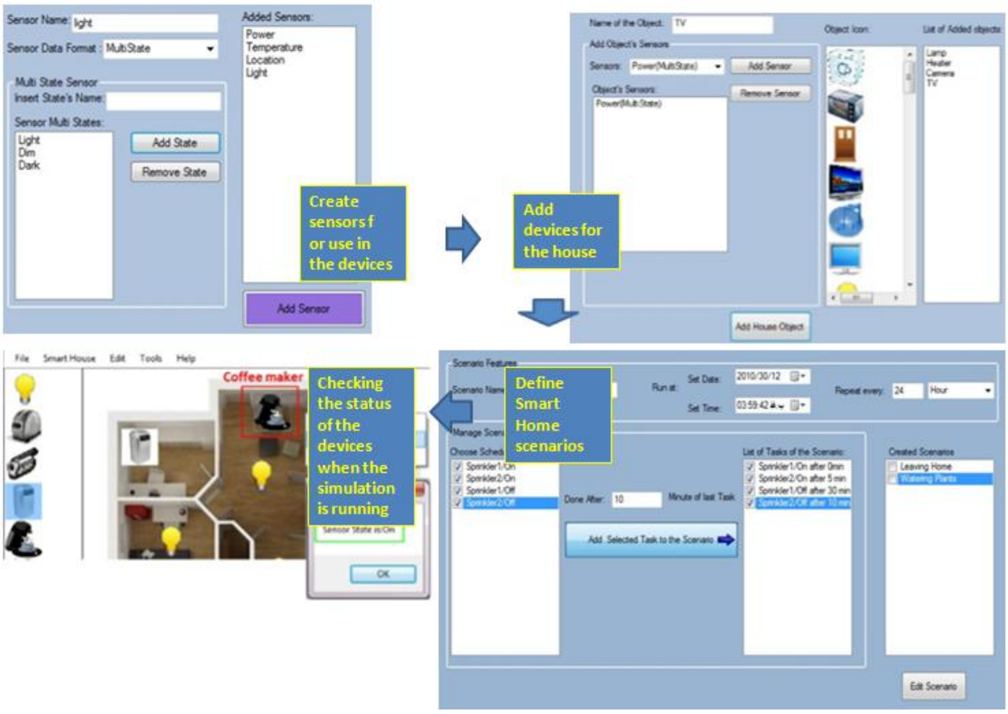


Figure 3.7 The schematic of the simulation process.

3.3.3.2 Framework for Visual Analysis of User Behaviour in Ambient Intelligence Environment

The ambient environment system in this case consists of two components : 1) a tracking mechanism for recognition of users' behaviour, 2) an application that used to set of AmI scenarios [61]. To ensure the usability and functionality of both components, the usability testing of the whole system must be carried out in early phases of the AmI system design. The reason is that correct design decisions are crucial for these phases given their importance influence on further development phases of the system. However, traditional approaches of usability testing are not suitable for testing the whole system like an AmI environment, because sub components in the AmI system are still under development or yet no-existent in the early design phases. Through combining the methodologies of desktop application usability testing with evaluation of user behaviour in an AmI environment, the researchers of this project have developed a framework for testing AmI applications. In this framework, the user behaviour recording can be visualized and investigated in a VR environment in order to analyse complex situations and detect usability issues of the desired AmI application.

Usability testing methodologies use observation of the test participant, while solving a task from the task list where the tasks use the tested application. Indirect observation is recorded and can be replayed several times. And typically a small group of participants (4-12) are tested and mainly qualitative issues are evaluated, interpreted, and used for suggested improvements [61] . Remote usability testing does not use observation of participant interaction but rather derive usability issues from user interaction data generated by application. This approach is suitable when observation is not possible due to technical limitation. For improving process of user behaviour analysis, this case focuses on a modification of this methodology which supports the needs to be solved. This methodology is also helpful to solve the ethical issues, because the process of usability testing adheres to research ethics as the video capturing from the desktop application only records the user interaction with the application but not the users themselves.

The framework (shown in Figure 3.8) encapsulates all essential tasks for usability evaluation of scenarios in AmI environment. Datasets from sensors (e.g. motion or noise level detectors) equipped in the AmI environment, are imported to the internal data storage or through the testing of detection mechanism accuracy task. And a module called User Scenario Creation and Editing can also create and edit data. After the data being edited by these two groups of tasks they are used for visualization in next two task modules which are depicted by rectangle with square corners.

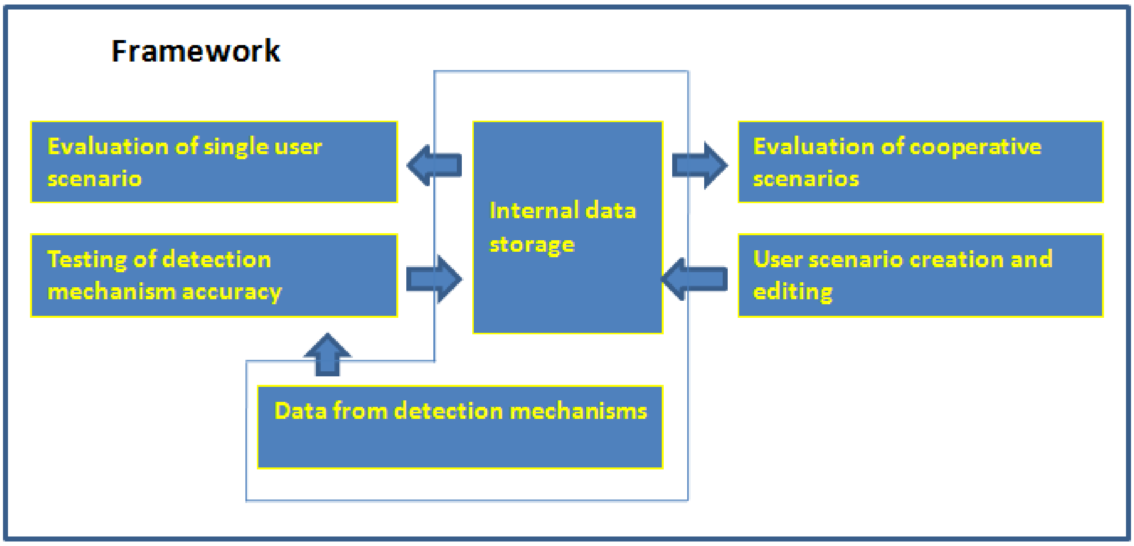


Figure 3.8 Scheme of the framework.

There were two applications using the framework for analysis of user behaviour in AmI environment. This first one is Situation composer (SitCom) which serves as a simulation runtime to support the development cycle of multimodal perceptual systems (Perceptual components map the information from sensors to real world objects.) [reference missing]. The other application is User Scenario Editor(USEd) [61]. SitCom as a context-aware application draws data from the real environment (such as there is an ongoing workshop in the classroom, body gesture, a person's voice, etc.) and their behaviour depends on the respective situation(e.g. while in the seminar silent the phone). SitCom consists of three input events sources: 1) physical sensor inputs (motion sensors, IP cameras, microphones...), 2) simulated data, and 3) mixture of simulated and real input. The environment characteristics generated from these sources are captured by Situations Models to construct higher-level meaning and reasoning functions such as event filtering, induction or aggregation. Through SitCom's 3D virtual environment IDE various scenarios can be loaded, ran or modified. These scenarios can be re-played to invoke relevant situations models.

Therefore, various context-aware applications can be tested systematically in SitCom. As show in Figure 3.9, visualization of the room in 3D virtual environment and in 2D visualization can be seen in the main window of SitCom. These visualizations are translated from data from input plug-ins. On the right of the SitCom IDE, there is video recording which is synchronised with both visualization of the virtual room.

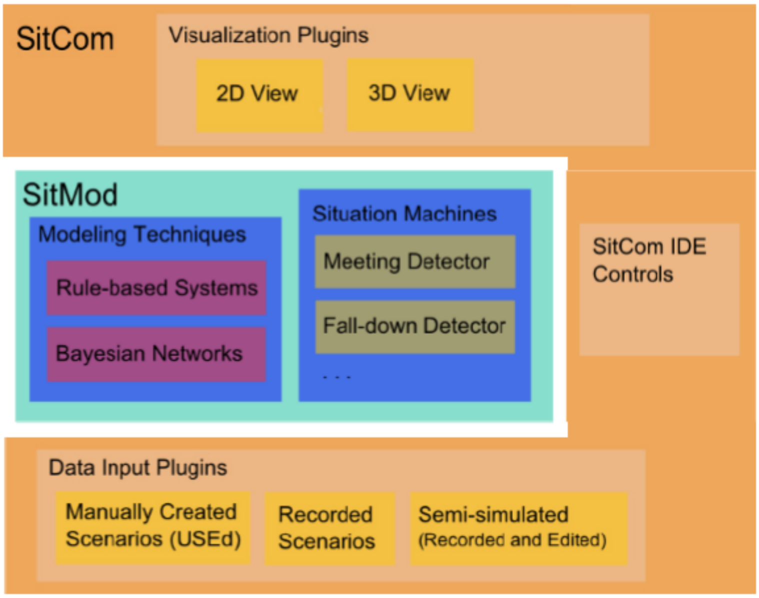


Figure 3.9 System architecture of SitCom.

USEd - User Scenario Editor

The purpose of User Scenario Editor (USEd) is to create, edit and tune user scenarios in smart environments. With this tool external sources such as audio/video recording can be used to create single user scenarios or cooperative scenarios [61]. And it also supports a usability expert to create single user scenarios. The term 'a user scenario' refers to behaviour of the user in the smart environment during usability evaluation. The data generated by USEd is compatible with SitCom in order to allow scenarios recorded in the USEd can be investigated in SitCom runtime. The user behaviour recorded by USEd is stored as events. As show in Figure 3.10, the USEd tool provides an IDE which has four parts. The virtual space display component in the middle allows full interactive control such as zooming, panning or rotation to support scenario editing. The timeline and buttons at the bottom are used to start and stop the recording of the scenario. The recorded scenarios can be replayed with time shift function. The person controls on the left of IDE allow researchers to control the number of people from the recorded scenario. The person in the person list could be selected to control. The actions list shows the actions the selected person is performing and the list of things represents the things held by the selected person. Researchers can confirm the selection of actions and putting the selected thing. Edit mode controls are on the right of the IDE.

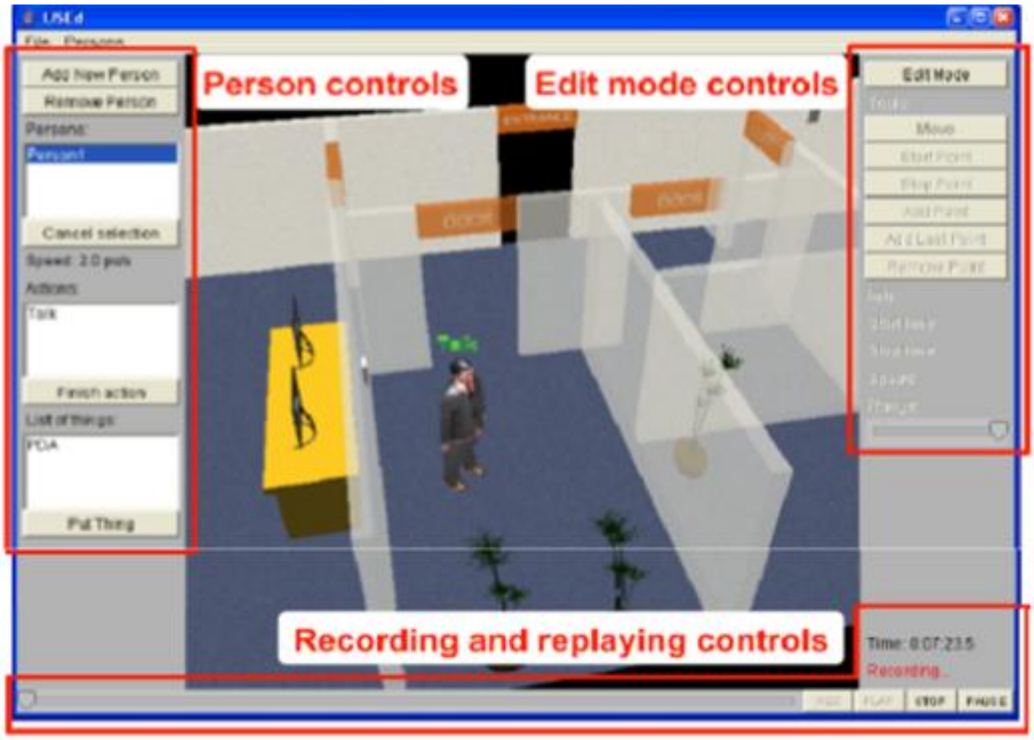


Figure 3.10 The IDE window of the USEd editor.

The Creation and Editing of User Scenarios

The process of scenario creation using the USEd is easy and intuitive. By pressing the REC button, a new scenario is started to be recorded and timing begins [61] . Then a new person in the virtual simulated environment can be added by pressing the Add New Person button. A dialog pops out for setting the profile of the added person. The routes of the person's movement is defined by clicking in the virtual scene. The virtual person in the scene walks to the point where the researcher clicked. To define the interaction between the person and other objects or person in the scene right mouse button clicking needs to be performed on the object. In the appeared dialog menu the desired action can be selected.

For correcting the recorded scenario, the USEd tools provides the Edit Mode to achieve that. The Edit mode displays an individual person path instead of the virtual person. With the new buttons available the movement of the navigation points can be edited with the timeline controller. Multiple pre-recorded single user scenarios can be replayed simultaneously to achieve collaborative scenario creation.

Typical Use Cases

To evaluate the proposed framework, this USEd research project provides several use cases to illustrate it's usability. The research team chose another project called CHIL (Computers in the Human Interaction Loop) to evaluate the rationale of the USEd and SitCom. The main goal of the CHIL project was to create a smart room which provides services to humans who are focusing on interacting with other people(e.g. in a meeting or a seminar). So a connector scenario with a connector service is considered. In this scenario, acceptable interruptions of a particular person can be detected by the connector service of the smart room. For example, a message for a member of the audience is allowed to be passed to this person during the presentation, whereas any calls for the meeting participants would be blocked.

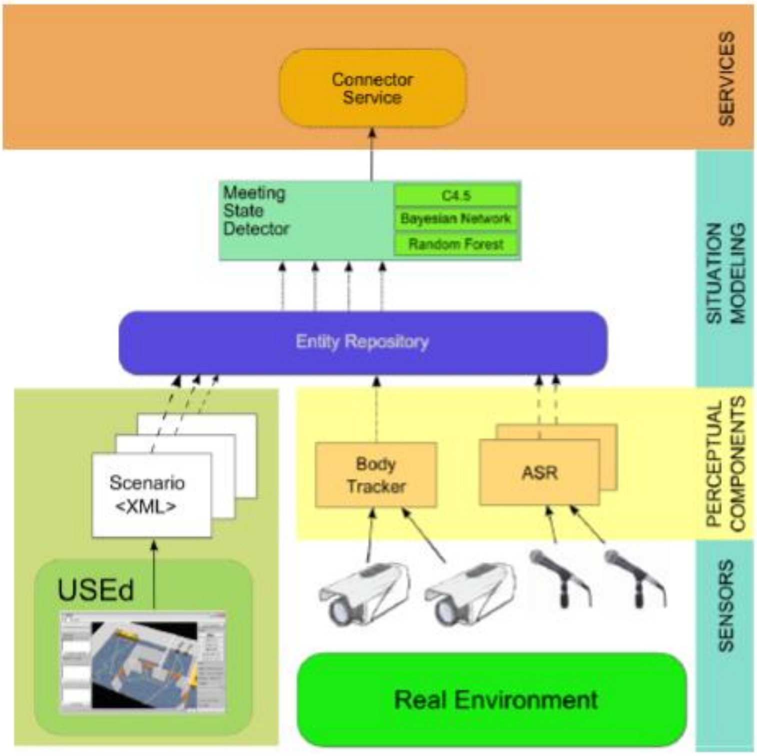


Figure 3.11 Data flow of the connector service case.

The situation modelling layer of the SitCom framework is responsible for processing and modelling the context information gathered fromaudio and video sensors. The context information is essential for calling better services. To perform suitable services, the situation model needs to provide the context information of the smart room such as: Is there a meeting going on in the room? Who is the speaker standing by the poster? Does this person the staff work in this room regularly?

At the early stage when the "emerging" technologies is non-existent yet, service providers are able to use USEd for the creation of prototypes with deployed smart functions. With the 3d virtual simulation in USEd, the prototypes and the "emerging" technologies could be discussed with potential clients easily.

As show in the schema in Figure 3.11, perceptual components are responsible for analysing the data collected by multiple sensors. The facts such as people's presence, location or voice activity are produced as labels by the perceptual components [61] . A set of statistical methods are developed through numerous experiments. These methods are used to detect the state of the meeting. The facts required by the situation modelling layer can also be produced by USEd.

Before applying sensor data from real environment the SitCom use the expert-created scenarios by the USEd to bootstrap the initial work. Five manually created scenarios on USEd were used to produce the feature and method sets for the situation modelling. The use case results shows that these could be applied to real data (the real video and audio recordings of a seminar) with only minor calibration. These calibrations include selected time thresholds and intervals as the USEd generated scenarios were not as dynamic as the real recorded scenarios.

3.3.4 Business Process Modelling Notation for Ambient Intelligence Service Blueprint

For customers AmI provides them with personalized and tailored services. In order to model and execute AmI based services, these services with sensors and actuators taking active roles must be treated as agents in the service package. For instance, an emergency detected by an AmI system leads to an intervention from a robot or an inspection from the user. To set up and facilitate such AmI services, AmI system designers need a methodology and notation for modelling the service process and information pool [62]. Service blueprint is used to visualize the activities between the customer and service provider. Business Process Modelling Notation (BPMN) is a favourite modelling language to visualize the modelled service process [missing ref]. It uses easy symbols of flow charts and concepts to model processes, events and activities with different abstraction levels. Both the processes and specific details can be modelled and included into the service diagram made with BPMN. Figure 12shows some of the key BPMN elements.

An example for smart home service called the VitalCheck visualised with BPMN is shown in Figure 3.12. In this case an outpatient care provider is involved to look after their client at a smart home. After defining the information needed from the client's home, the responsible sensors and actuators will be installed within the home environment. With all the offered services and their information content defined, the smart home services are able to perform on a service platform to establish the connection between the outpatient care provider and the home automation. The service platform will be part of the backstage activities, and the service platform will act independently.

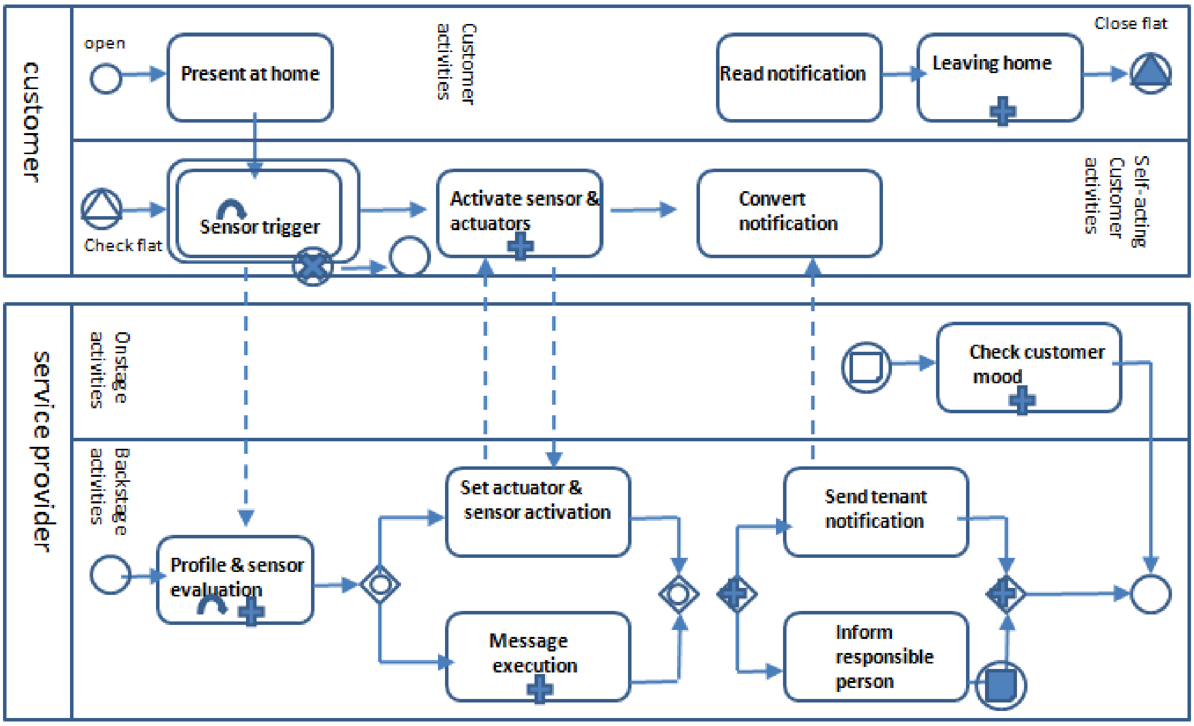


Figure 3.12 Service Blueprint of the care service example "VitalCheck".

3.4 Summary

This chapter reviewed the definition of ambient intelligence and existing development methods. And the importance of representations and communications approaches for AmI scenarios have been verified by the reviewed cases. The review suggests that current research of AmI are mostly conducted in computing and automation regions. However, these existing AmI design approaches are lack of the capability to allow architect and other stakeholders to be involved in the early stage of AmI scenario development.

The existing development methods of AmI includes: 1) AmI augmented full-scale sample house allowing participants to live and work inside, 2) scaled architecture model embedded with sensor for interacting with participants, 3) virtual reality based AmI scenario composer with prototyping and user evaluation functions and 4) BPMN based AmI service modelling approach. However, for involving stakeholders of AmI embedded space in the design process, these methods exist different problems. For example, for the first method it needs a real house as a test space which normal design project cannot afford, and for completing the test cycle it requires the participants stay in the house in a long period. The second method is low-cost and agile but lack of enough scenario detail to give the participants enough immersive sense of the AmI scenario and thus impacts the effect of the design involvement. Although the AmI scenarios composer could provide the participant realistic visual scenarios of AmI the interactions with these scenarios still rely on mouse and keyboard. For non-professional stakeholders BNMP could not be interpreted without explanations. In conclusion, a novel communication technology of AmI scenario is therefore required to be developed with rigid participatory design approach based on it.

CHAPTER 4 RESEARCH METHODOLOGY

4.1 A MIXED REALITY APPROACH FOR DESIGNING SMART ENVIRONMENTS

This chapter introduces the research methodology of this project and how this methodology is used to collect data and support the development of the theory framework. Firstly, we introduce underlying theoretical approaches of the research methodology. Then we introduce the research tool, the mixed reality approach, for supporting the design process of smart environments. The following part is the stage of data collection and analysis. This stage includes context investigation and stakeholders interview, design concept prototyping, participatory design of the smart environments and post experiment interview and questionnaire. This chapter ends with how to evaluate the research quality with criterions.

4.1.1 Underlying Theoretical Approaches

4.1.1. Supporting Participatory Design with Mixed Reality

Participatory design refers to involve stakeholders of the design project into the design process for guaranteeing the design outcome could meet their needs. Research shows unexceptional creative concepts could be generated from the collaboration among stakeholders with multiple backgrounds. And the findings of literature review have demonstrated that mixed reality technology could and has already been used to support participatory design helpfully.

4.1.1.2 Evidence Based Design

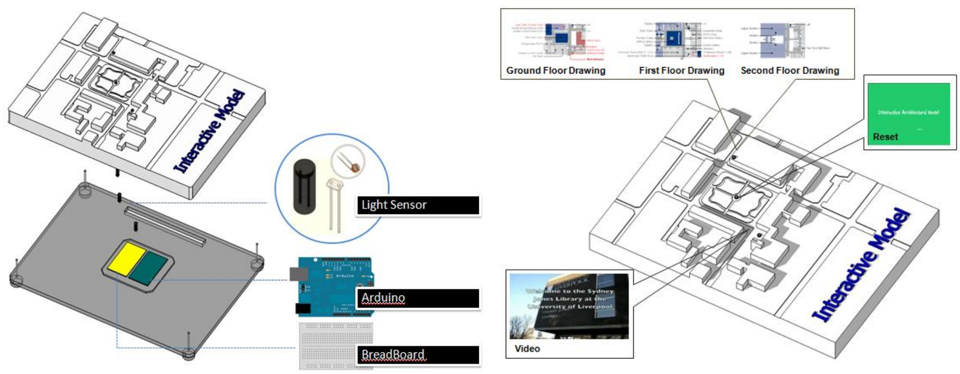
Evidence based design is a approach which emphasises the effect of reliable evidence on design outcome. It has been applied on planning, designing and construction by architects, interior designers and facility managers. Take healthcare as an example, as successful environment could affect patients' well-being, improve the therapy and relief stress. This approach is applied on healthcare to improve patients and staffs' well-being, the quality of treatment and safety. EBD emphasises that design decision should be made based on reliable information from research, post-occupation evaluation and other evidence search. For different project goals specific research should be carried out to provide reliable information to develop proper solution to meet design requirements. The result should be able to improve the economic effect, productivity and customers' satisfaction. Smart environments as a sort of architecture service similar to healthcare it also emphasises the users' well-being and satisfaction. Modified EBD method could be applied to the design of smart environments as following.

First step: Review existing literatures of smart environments, select key findings and recommendations. Second step: Match these referenced findings and recommendations with context investigation, stakeholders interviews. Third step: anticipate the results of the design decisions and build 3D interactive prototypes. The last step is evaluate the design outcome with participatory workshop on the 3D interactive prototypes.

4.2 Research Tool: Mixed Reality Modelling Platform

We carried out two pilot studies to explore a new approach for creating tangible use experiences of smart environments. How to represent the design of smart environments in a communicative way among non-professionals? We propose to evaluate the feasibility of augmenting physical interior model with mixed reality interface and multiple data sensor network for communicating interactive smart environments based service scenarios. The refined mixed reality platform will be used in the main experiment stages to test the feasibility of mixed reality approach for supporting the design of smart environments. The two pilot studies 1) Interactive physical architecture modelling 2) Sensor network for multi-data collection in real environment are implemented for finalising our mixed reality modelling approach for data collection in the following main experiments.

The pilot study is composed of two parts. The first part is interactive physical architecture modelling, and the second part is multi-data collection sensor network in building environments. The basic concept of interactive physical modelling is that users could trigger digital information related to the physical model through touching it or performing specific gesture on the physical model. In the initial test we built a university campus model with light sensors embedded in different spots of it(light sensor can generate different signal when a user cover it with his palm on different heights). For example, when you touch or cover a light sensor in a building block on the campus model the floor plan of this building will be displayed on the digital monitor as shown in figure 4.1. The user could also trigger different floor plans through changing the height of his hand above the sensor(the higher position of his palm the higher floor plan being displayed). Other interaction such as triggering introduction video clips of a specific spot of the campus is implemented by labelling the sensor dot with corresponding colours. A further development of this interactive model is that users could navigate in the virtual model through interacting with a specific sensor on the physical model(keeping the palm on different heights indicts moving to different directions).



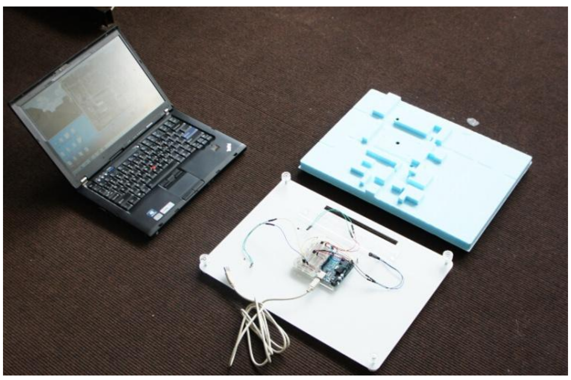


Figure 4.1 Physical computing embedded interactive architectural model.

The computational vision is introduced to the second stage of interactive physical model investigation. Computational vision here refers to fiducial based objects and gesture recognition. The research purpose of this stage is to explore the possibility of incorporating physical model, tangible table and virtual reality with the support of computational vision technology. So another larger campus model was built to be calibrated with fiducial marker recognition system. Compared to the sensor embedded version, computational vision incorporated interactive physical model could transform the whole horizontal surface to potential interactive user interface rather than limited number of spots. In this way, more multiple media information could be positioned on most places of the campus model. Not only the position of the fiducial but also its rotation could be tracked for creating extra interaction between users and digital information. And this also make the fiducial controlled VR navigation becomes more nature as the virtual camera can turn around with the user gesture to simulate the avatar's rotation at the virtual side. Architecture students involved in this pilot study agreed that this is an interesting and intuitive communication approach to represent dynamic digital information because it selects the physical model itself as user interface.

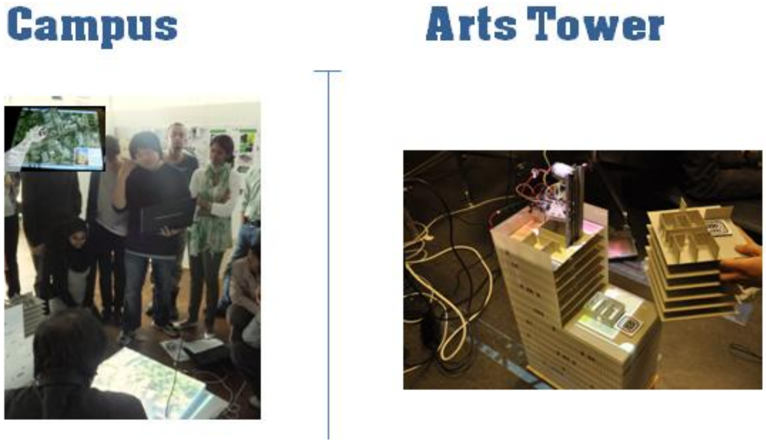


Figure 4.2 Computer vision incorporated physical architectural model.

In the Environmental Sensor Network project of the pilot study several sensor stations were installed in different positions on the floor 16 of the arts tower and its elevator for collecting multiple environmental data and occupants' motion. With these raw data designers are able to create data visualization for a specific area in the building for a specific period . For designing smart environments designers need a variety of environmental and users activity data as design evidence. The purpose of this project is to evaluate the feasibility of installing data sensing network in a real environment as an effective solution for generating essential data. There are two types of sensor stations in this sensor network. One was installed in the elevator. It is equipped with a barometer and a PIR sensor to detect the vertical position and the occupation situation of the elevator car. The other one equipped with multiple environmental sensors such as temperature, humidity, motion and sounds were deployed to selected positions on the floor 16. All the collected data by the sensor network could be collected by a workstation with the wireless Xbee modules on sensor stations and a Xbee dongle on the workstation. However this data collection approach encountered two critical issues. The first issue is that a sensor station with Xbee module could drain the battery in just 3 hours. It means that we are not able to collect enough environmental and human motion data without replacing batteries all day long. Only two hours' data is not sufficient to further data processing work. The second one is about ethics and safety. As the sensor stations have the capability to collect people's motion data on that floor there is a possibility that a specific person's pathway could be recorded and extracted from the collected data. A even more serious problem is that some sensor stations deployed to the building were reported to the porters as unidentified hazardous article.

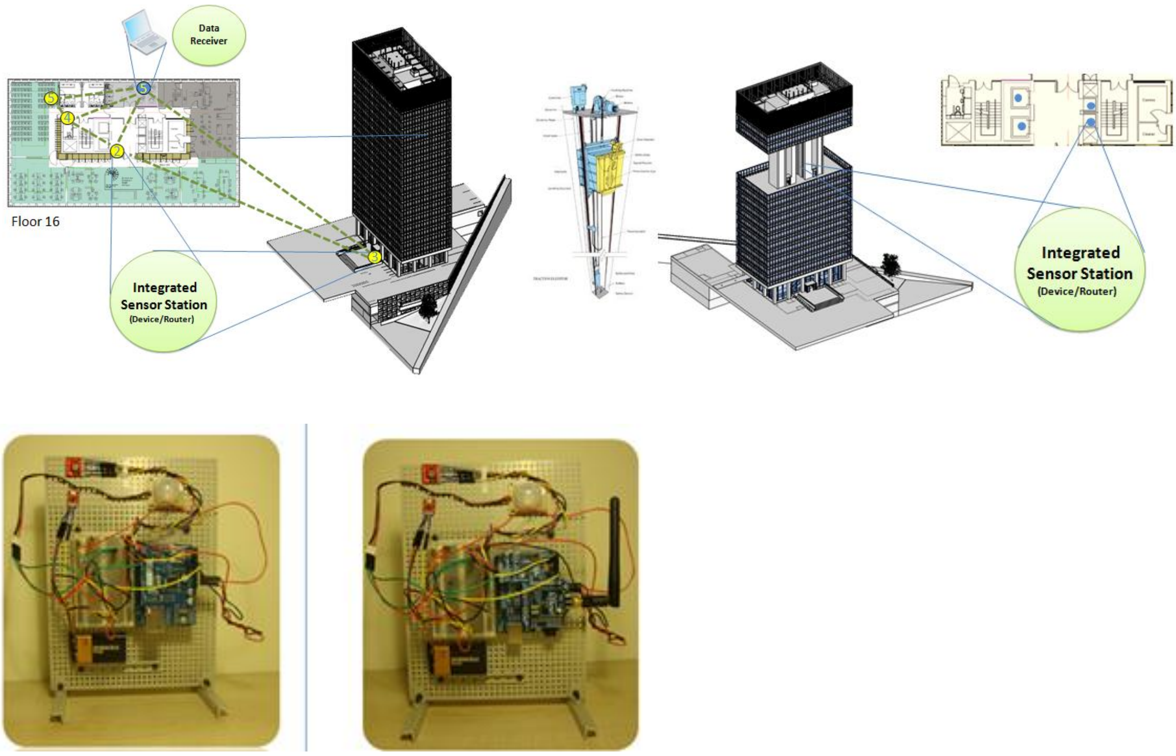


Figure 4.3 Environmental data sensor network.

In sum, given the financial limitation and ethics issues we have to abandon the solution of setting up sensor network in a real building environment to collect essential data for the design of smart environments. However, the working sensor station is able to be modified for being incorporated into to scaled physical interior model for prototyping smart environments.

4.3 Data Collection and Analysis

To answer how to communicate the design of smart environments in an architecture context, we decide to design a smart laser cutting workshop using the proposed mixed reality modelling based participatory design approach. Based on the outcome of literature review and pilot study, we will create a mixed reality modelling platform on which context inquiry, 3D interactive prototyping and participatory design workshop could be carried out.

4.3.1 participants selection

All the selected participants of the experiments are the stakeholders of the proposed smart environment. Specifically, people in the architecture school whose work are related to the existing laser cutting workshop will be selected to participate the study. They are architecture student, workshop technician, facility manager, cleaner and academic staff. And architecture students could be divided into experienced and non-experienced of laser cutting technology. We plan to invited five participants from each of these clusters to represent stakeholders of laser cutting workshop.

4.3.2 Data Collection Process

Data collection process is composed of four stages, the first three stages are all carried out on mixed reality modelling platform. Data generated in each of these stages will be passed to next stage in order to carry out further development work in this stage.

4.3.2.1 Context Inquiry and Working Modelling.

To collect data for context inquiry and working modelling each stakeholder representing for their cluster will be invited to an individual interview which is carried on mixed reality platform. They will be asked to explain their activities in the laser cutting room through manipulating the artifacts and widgets inside the interior model on top of the tangible table. After this round of experiments, efficient data about the typical activities of the stakeholders in this space, their opinions on the existing space related to their activities as well as their preferences of typical smart environments and related ethics are aimed to be collected.

4.3.2.2 Developing Mixed Reality based Prototypes of Smart Environments

According to the recommendations from literature review and collected data from the first round experiments, we will propose a set of smart environments design to meet the requirements of different stakeholders. Mixed reality modelling platform will be used to create an tangible interior model on which users could experience the proposed smart environmental scenarios. Also an experiment documentation setting up which including text, audio and video recording is planed to be developed.

4.3.2.3 A Participatory Experiment and Group Discussion

In this round of data collection we will invite all the stakeholders who have been involved into the first round experiments to a participatory experiment. In this group experiment the stakeholders will be requested to experience smart environmental scenarios on the mixed reality prototypes which are developed based on the data of first round experiments. These mixed reality prototypes of smart laser cutting workshop include multiple smart environmental scenarios focusing on supporting different types of stakeholders. Each participant will be requested to experience the scenarios developed specifically for his role as a stakeholder. When one participant is experiencing his/her scenarios other participants' task are observing and asking any of their questions about this scenario. After each scenario test participants will have a group discussion of this scenario with supports from the experimenter. There are two cameras set up to record the participants' interaction with the mixed reality prototypes and their group discussion. One camera is set up in the left front of the mixed reality platform, and the other one is mounted on the top of the large monitor in front of the tangible table for recording the details of participants' tangible interaction in the interior model.

4.3.2.4 Post-Experiment Questionnaire and Interview

After user experience experiment and group discussion, participants will be requested to complete a questionnaire for evaluating their understanding level of the design of smart environments which they have experienced and also their opinions on the effectiveness of mixed reality modelling approach.

4.3.3 The criterions of successful support for design communications of smart environments

We will match the collected data with a set of criterions of successful support for design communications of smart environments to discuss the effectiveness and limitation of mixed reality modelling approach.

CHAPTER 5 A FRAMEWORK OF MIXED REALITY MODELLING APPROACH

5.1 Introduction

AmI can provide assistance in many circumstances to freeing people from regular routine tasks. For example parents may never lose track of their children in crowds, because of location sensors and miniature communication devices sewn into the fabric of clothes. Blind people may be guided in unfamiliar environments by intelligent signposts and public transport timetables that may communicate via wireless headsets. Our washing machines may query our dirty clothes for the required washing programs. Traditional memory aids can remind the user about activities on their daily schedule, but more sophisticated memory aids, on the other hand, can be context-sensitive. They [63] could observe the user in their activities, guess their desired tasks and on that basis issue reminders and guidance. AmI has potential applications in many areas of daily life, including in the home, office, transport, and industry; entertainment, tourism, recommender systems, safety systems, e-healthcare, and supported living of many different variations

AmI applications such as smart home, assistive living, health care, shopping recommendation systems, museums, and tourism are all based on specific architecture spaces that host them. This sensitive and responsive electronic environment could be seen as another layer of the building fabric. However, in current research and development AmI is still largely considered within the engineering domain bearing very limited relationships with architectural and urban design processes. The fact that architecture design also addresses the requirements of supporting people in carrying out their everyday life activities, tasks and practices common to the AmI’s objectives and purposes, we should consider the possibilities or even necessities of architectural or urban designers’ participation in the design and development of AmI applications. The starting point of this research project is to inquire how the design of AmI can be communicated from an architectural viewpoint that addresses domains of concern different from those of the electronic and computing engineering.

With the recent developments in physical computation, mixed reality and 3D rapid prototyping, we are now in a better position to consider the development of an experimental co-design process and platform capable of sustaining the dialogue between AmI and architectural design [64]. This research project intends to develop and test a novel conceptual framework and prototypical system such that the communication of AmI design can be enriched by architectural design thinking and discourse and vice versa.

The recent popularisation of ‘Tangible Interfaces’ and ‘Tangible Interaction’ driven by breakthroughs in the fields of human computer interaction, interaction design, and internet of things (IoT) [65] has opened up further opportunities for architectural researchers and designers to explore possible fusion between physical model making, data sensing & processing, and 3D virtual modelling, which is referred to as Mixed Reality Modelling (MRM) in this research. We believe that MRM could provide an effective way to support communication of AmI design that is considered integral to architectural design. In our view, at present AmI has not been really fused into architecture which aims to accommodate people’s everyday life activities. We envisage that more and more architectural designers will be interested in knowing what AmI is and what it can offer, and thus in pursuing AmI design as integral part of architectural design in the foreseeable future.

The main objective of the research is to present a new theory and design framework which fuses AmI design and architecture space. And an IoT based Mixed Reality Modelling platform to support the design process will also be developed as a research tool. This platform is used for developing and discussing AmI design with the prospective users based on a comprehensive series of hardware and software infrastructures and application prototypes. Also an AmI architecture design process of Mixed Reality Modelling for such systems and establish the matched methodology will be defined.

5.2 Why Is AmI Difficult to be Communicated?

As we will show in the literature review, there is not much of a range in terms of the stakeholder engaged design process of AmI concept and correspondent communication approaches. Existing cases have primarily focused on engineering implementation and generally only present final outcome to subject for user evaluation. The main reason why cases have not covered the range of stakeholders participatory design is that AmI design is difficult to be communicated. AmI have the following properties that lead to the difficulty in design communication:

1. Current AmI design lacks of communication techniques to represent services design to intuitive experience to involve stakeholders in the design process.

2. AmIcomposes of non-standard equipments and new services, with which we have limited experience.

3. AmI acquireinformation from multiple distributed and heterogeneous sources.

4. AmI scenarios is dynamic and interactive.

Despite these difficulties, researchers have been able to build prototypes of AmI. But, the prototypes are typically built without stakeholders and architects evolved in the conceptual design stage. Using concepts purely designed by engineers may not humanistic and even be with safety risks.

5.3 Why MRM could to be applied to support the participatory design of AmI?

There is growing use of a form of computational technology that brings virtual world and physical world together, called “Internet of Things” (IoT). Arduino which is an open-source electronics prototyping platform provide the possibility for artists and architects to link physical environment to 3D design and simulation software such as Rhinoceros with grasshopper, Processing, Ecotect and Quest 3D. And through a free IoT platform called Cosm (a platform that connects devices and products with applications to provide real-time control and data storge) all interactive 3D works produced by these software could be interacted with ambient computing in a real-time way. IoT based physical computing objects with virtual 3D agents could be a shift from the design of the ambient intelligence to replace and enhance the traditional drawing process and information system design in the production of real-time experiment and monitoring. Similar with the idea and principle of “Building Information Modelling” (BIM) the “Mixed Reality Modelling” which is based on IoT starts from the point of view that best way to design and to produce information is from the same source-the mixed reality interactive physical model.

IoT based Mixed Reality Modelling (IoT-MRM) allows people in an AmI team to create an “intelligent tangible model” where each element and space within the model can control and represent the corresponding component in physical world and has AmI properties that can be extracted and interacted in different ways depending on the type of information needed. Essentially, in using IoT-MRM the AmI team builds a scale-down AmI physical environment for design development and user experience. In this way, the potential users could identify the invisible interaction of AmI and visible physical components as the built in the future.

IoT-MRM system/platform has some additional benefits for AmI design, beyond the further acceleration of the process of producing and communicating the project information. Because for an AmI design the expertise involve many members of a number of other professions [66], the possibility that all parties in the project including architects, engineers, clients and consultants could work from the same model or its agent online the IoT-MRM system ensures that there are fewer conflicts within the design (e.g. a logistics ceiling that cannot be designed because the addition would cause the story height reduces below the standard for the specific function area, etc.)

Because the IoT-MRM model and site complex can be started early in an AmI project, the project team could create a AmI model based only on the overall mass physical model reading data from the site and add detail design information to the model for deepening the design. With the support of the real-time 3D printer and scanner which will be integrated with the IoT-MRM platform it is possible to use a series of physical models in a development chain model throughout the whole design and documentation phases of an AmI project. The MRM model can also be used to create virtual experience tour or presentations for clients with the confidence that the clients could understand the design intuitively and accurately. To achieve such a complex AmI programme and design requires considerable coordination throughout the design, production, installation and testing process. By applying IoT-MRM design system the research will investigate the feasibility of managing the entire project through the physical model platform, ensuring that the ambition of the AmI design is achieved.

As a database-centric architecture based technology AmI design needs an interactive computational mapping system that allows variables to be seen, analyzed, simulated and manipulated from a 2D or 3D view. In other word AmI design needs support from a data representation and operating approach with the characters like GIS and graphic programming. At present maps in GIS [67] often appear as static 2D layers that contain individual features. Each layer is linked to a specific feature. The researcher apply the aggregation of these layers to cross-analyze and consider a multitude of variables, and then makes informed decision. Similarly, in a AmI design site there are multiple invisible/hidden and overlapped patterns, relationships, and trends required to be pictorially demonstrated within a common spatial-graphic boundary for design collaboration.

5.4 Physical Computing and 3D Mapping Projection based Mixed Reality Modelling

5.4.1 System Components and rationale of Mixed Reality Modelling

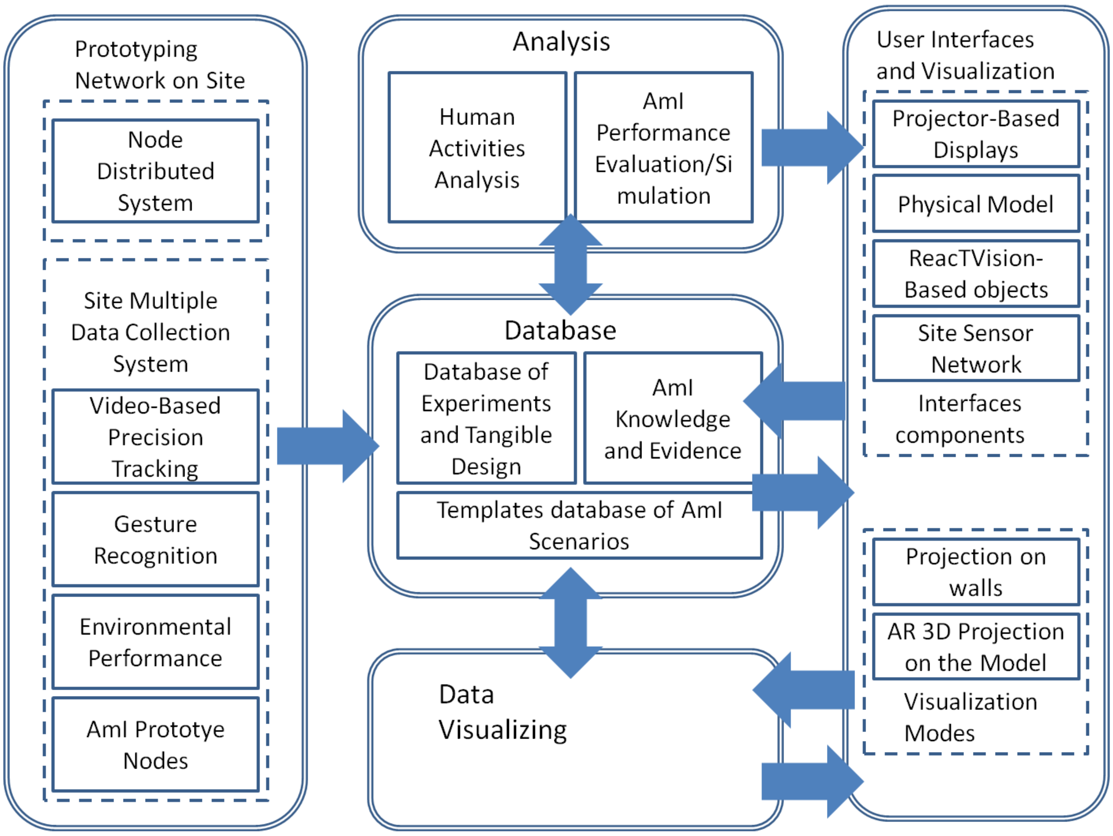


Figure 5.1 IoT-MRM AmI Design Platform Architecture

The Mixed Reality Modeling based AmI Design Framework (see Figure 4.1) is organized around a central AmI Scenarios that connects all other components. This AmI Scenario is composed of three parts which are evidence base, brief templates, raw database, multiple scenarios base (recipe). In addition to the database, there are four other major blocks: field flexible AmI network, data analysis and management, two way behavior synthesis, and User interfaces and visualization.

Each block of the system can be easily understood in terms of the data that it consumes or produces for the central database. The field AmI network [68] is responsible for producing real-time data on multi-information which cover human activities and environment performance. This includes web-based multiple function sensors and physical computing nodes and fusion of GPS. The data management block reads data from the database, and then use it to generate performance assessment data, which is then returned to the database. The two way behavior synthesis block supports the user with alternative AmI scenario of design. It can invoke the specific scenario template from the database, reads an initial situation and real-time data streams [64] from the database, and then facilitate the simulation and development of an AmI design under the interaction with the user. The interface and visualization block reads data from database and renders it in an interactive form on various target platform, such as MRM, Geo-AR tablet, distributed kinect based VR projection.

An AmI information modelling database-centric architecture has both pros and cons. Its attractive feature are several, and for us, ultimately compelling. It provides enhanced modularity of the system as a whole, yielding dividends in ease of development (particularly over multiple physical development sites), ease of managing (browsing, storing) system data, flexibility in adding new sensors and support for developing evidence base for multiple building types [69]. This helps us fulfill our goal of realizing a prototype that is extensible, for example to allow reorganize sensor and actuator network, new templates, and new interactions.

5.4.2 The Rationale of IoT-MRM Approach

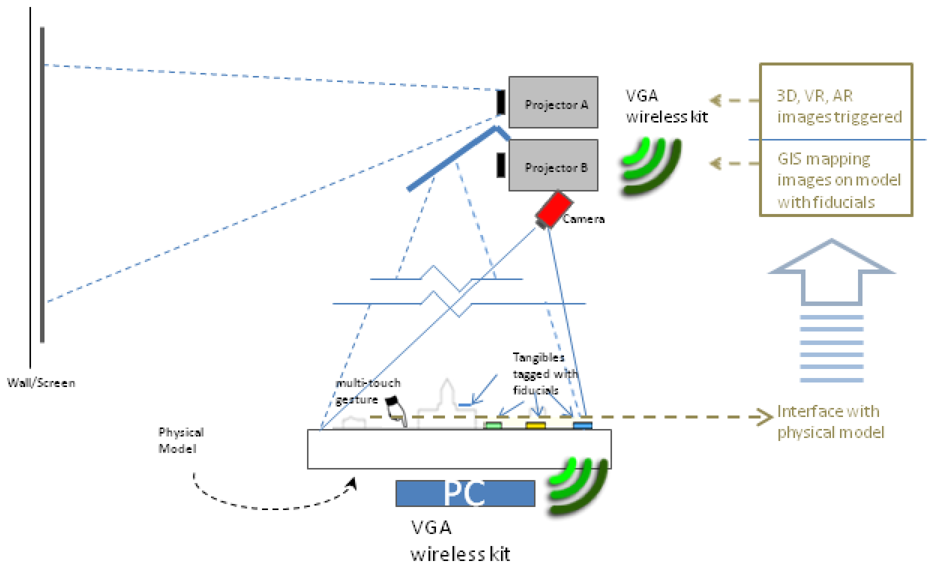


Figure 5.2 Mixed Reality Modelling Platform

As a user-centric design approach when designing AmI systems for the users, end users should be very much involved in the process. Human-centric design methods such as participatory design and value sensitive design, which emphasize the values and opinions of direct and indirect stakeholders, are key [70] to upholding the ethical and democratic standards of the design process. Participatory design also plays a valuable role in creating an experiential simulation for end users and hence acceptance of technology.

The design process on how to involve users and other consultants in AmI design are still unclear. Furthermore, the near invisibility and novelty of ambient technology makes it difficult to imagine the design tasks or outcome. Providing users with example scenarios are imaginative ways for requirements gathering [71]. The challenge is to develop novel methods for AmI requirements gathering and cater for the diverse ideas and agendas of multiple stakeholders and users involved. Furthermore, enabling users to experience technology in site and present appropriate feedback on diverse AmI data from the site would help to improve designing of the system, and so help collect data.

The MRM based participatory design process would apply an interactive physical as a platform to aid design team's design representation of AmI. This model (a scale model copy of the site) would be equipped with simple sensors that are able to sense users' gesture and also simulate the actual AmI environment. This model would communicate with a tangible GUI that displays multiple AmI components. The representations of AmI proposal derived from this tangible programming are designed and visualized both on the physical model and virtual reality environment. Mixed Reality Model for AmI is aimed to be a helpful platform in providing the whole design team and other stakeholders a better understanding of the desired workings of the system and its output.

How to involve the users in accepting AmI scenarios? MRM approach (Figure 4.2) is taken to discuss challenges for designing AmI. The interactive model is a useful technique to engage the users and appeared to be an effective tool to familiarize the end user with AmI hardware currently being installed, and so to engage them in accepting and influencing the proposed AmI solution. MRM system inherently includes the digital AmI design content to facilitate an interactive version of the physical model through employing projector and ReacTVision to render textures, tracks, moving icons, and training-related information onto a physical model of the site. MRM combines physical models with computer-generated projection through tangible interaction. Designed for AmI design, the physical model [68] is a copy of the site, illuminated 3D projection adding AmI geo-information imagery, with an additional set of GUI components for AmI design. Interaction with the tabletop scene is enabled through reacTVision objects and gesture interaction on all surfaces. The targeted building environment currently uses a 3D printed building model to plan the AmI components design and simulation. This platform could also support design reviews and presentation.

In an AmI design project there are a number of collaborative tasks that require a shared interactive 3D display for use by a small group of people. [72] A display of this type, which long predates the advent of electronics, is a physical scale model. MRM approach presents a digital interaction augmented physical model, with blended dynamic imagery from multiple projectors.

The design was driven by a number of requirements. As with traditional physical model, a 3D presentation is necessary for viewers to get a sense for visibility and lines of sight. The device must be autostereoscopic because conventional stereo technologies for individuals, such as shuttered or polarized glasses, do not scale beyond multi-users. Furthermore, dynamic and invisible AmI action such as proximity range must be displayed, and operators must be able to interactively sketch on the surfaces for developing the design. To obtain auto-stereoscopy, a Spatially Augmented Reality display by projecting computer graphics onto a physical 3D model that is painted white will be built [73]. In designing the augmented physical model platform, the main task is to build a display system that would be useful for planning and simulating of ambient intelligent of the target existing environment. A 3D mapping technology is applied to illuminate a 4-sided building oriented in any direction. For interactive AmI design, MRM platform enables the users to design AmI on the physical model in a dragging and dropping virtual and physical object way. A taskbar is provided on the perimeter of the display allowing the user to select multiple functions for AmI design. Sketch drawing and annotations is performed into an off-screen, image layer dedicated to annotations.

5.5 Participatory Design Process of AmI based on MRM

5.5.1 Stakeholders of an AmI project

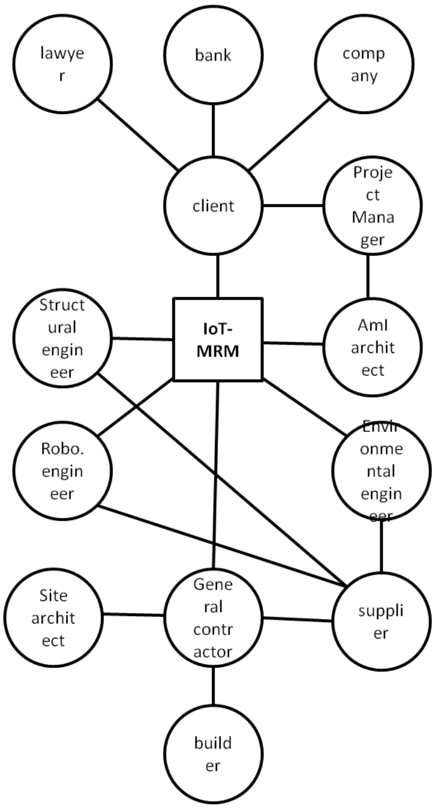


Figure 5.3 Proposed Design Team Structure in an AmI Project

According to the specific activities needing to support in an AmI project, the structure of a project team is assembled driven by specific requirements. The structure of an AmI team (Figure 4.3) essentially has a team of people associated with each stage of a project. For such a structure to work well it requires that the person leading a project be familiar with each phase in order to brief each party as the project transitions between phases [74]. In the proposed project there will be a single chair architect alongside a series of consultants. At the meantime the AmI architect will play the part of the lead consultant or captain of the MRM system, as they are act as the design information manager and authority distributor through IoT MRM. A typical AmI team structure includes client, architecture team (principal) and consultants. A proposal of the cooperation between different parties is facilitated through IoT-MRM serve. Using web-based system [75] geographically dispersed team members could cooperate efficiently. As a user-centric and task driven system in an AmI design team clients and users of the building play the most import part across the entire project communicating through IoT-MRM platform, and act as subjects of the ongoing site prototyping. Thus a specific team structure as Figure 4.3 will be apply to the proposed project [77].

Because the proposed AmI design process incorporates IoT base MRM design and real-time site operation a site architects who is commissioned to install/regulate AmI nodes and monitor operations on site would be essentially. The IoT-MRM design platform has virtual pre-built AmI components derived from the AmI Database that allow the design team to connect and program the AmI network on site through internet. And in the other way round multiple data from the site and parties of the team could also be connected and shared through MRM platform.

5.5.2 The MRM based AmI Design Process

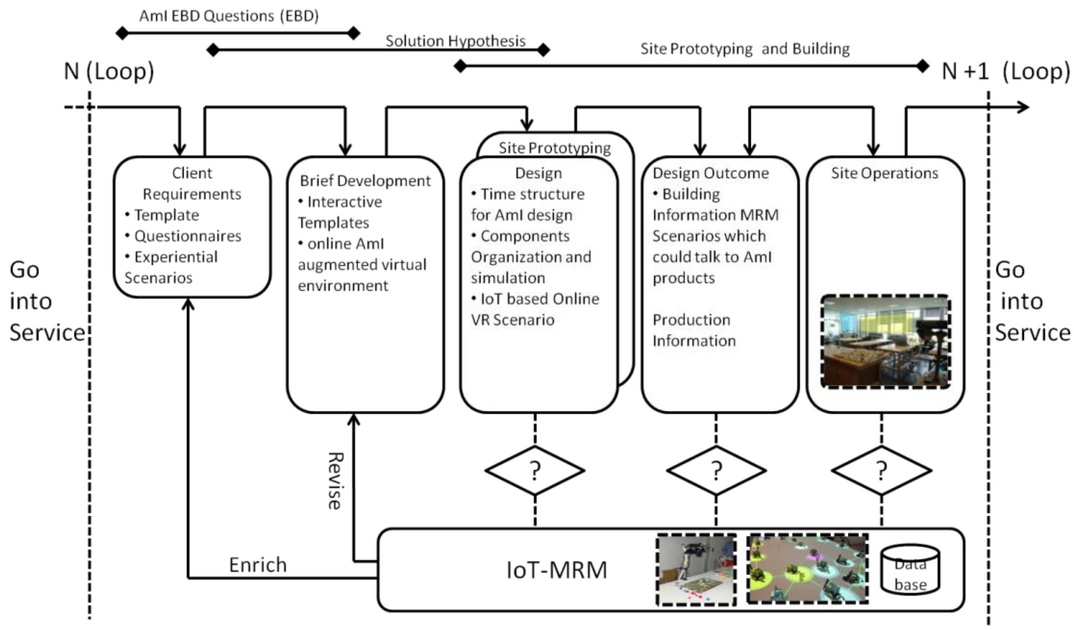


Figure 5.4 The Proposed IoT-MRM Based AmI Design Process

In order for an AmI project to commence the design team needs some idea of what the client requires and analyze if these requirements could be met through AmI strategies. How to define the AmI requirements, say an AmI design brief, is one of the most important task for initiating a project. According to the specific characteristic of AmI design the development of brief will be conveyed in a set of novel methods but not only regular meeting. A distinguishing characteristic of AmI project of an existing building is the approximate synchronization of design and prototyping. The client's brief which will be represented by an interactive tangible game on MRM platform. Applying IoT-MRM platform can guarantee all parties in the project are clear about what is to be considered in the project and the way in which it is represented and described is accessible. The initial brief may provide only a general overview of the client's needs, without any specific detail. As a novel design brief which is an user experiential scenario with feedback it can provide enough guidance for the architect to be able to begin work on the feasibility stage of a project. And in the proposed project all these process (see figure 4.4) will be achieved and documented using MRM system.

In an archi-AmI project the key mission and outcome of the design would be adding multiple components to the existing 3D physical space and testing/evaluating the design. Thus the concept of information layers cannot satisfy the design requirements. Through bringing together geographic information system and 3D modelling AmI design team is able to make link between their design proposal and a large context with multiple data and information layers for exploring the design and share it with clients, consultants and others in the project team. So what is the better approach of embedding visualized AmI design information in a virtual space?

Like designers who explore new geometry using graphical algorithm editor Grasshopper the proposed AmI design platform will draw lessons from Drag & Drop Programming technique [76]. But different from the existing visual programming tools which normally work through PC GUI the MRM approach allow users create AmI design and evaluating the simulation and visualization results through interacting with the physical architecture model by gesture. It combines a specialized set of AmI design components with a novel communication protocol which together enable both database and real-time feedback between hardware devices such as microcontroller and modeling or virtual reality environments. With this instant design technology, you can design AmI in a real time way, communicating and prototyping AmI rapidly.

As a new method for interaction between AmI designer/consultants and their clients, Mixed Reality Modelling system provides a tangible programmable and flexible templates representing design intent allow the design team to develop and evaluate design options in regard to inform design decision making in ambient intelligence design. Through working from MRM platform as a united platform AmI designers and consultants could share information for collaboration very early.

One of the essential design tasks of AmI is embedding multiple sensors and actuators in the existing environment in a human friendly way. Parametric modelling function [77] of MRM design can help the team produce a quick turnaround of design options by reprogram the site AmI network and generating multiple design alternatives to keep the project in a flexible controlled state. By experiencing the 'recipes' which representing in the format of IoT based physical or virtual simulated environment AmI performance-based rules and criteria would be better related across disciplinary boundaries. Adopting the motion sensing online game strategy for design evaluation could provide the freedom to truly explore design intent within pre-built or site AmI interaction.

One crucial aspect of operating efficiently in IoT-MRM design system is the participants facility for embedding parameters or feedbacks into the MRM system (Matrix) via motion sensing input or tangible interaction. In this sense creating a series of design communication method to adjust and explore the design would be necessary. During the search for optimized AmI design, it may be hard to decide on the most appropriate among a large set of solutions. A Multi-criteria decision making method from MRM is used to help to evaluate complex problem due to a high degree of uncertainty. Performance optimization based on specific AmI algorithms that can facilitate designers to solve complex multi-objective problems is another core module in MRM.

Through fusion of 3D building space information (environmental and social information) and calendars systems from the occupancies in the building, a set of flexible and tangible programmable templates that communicate design intent across project teams and site with AmI networks act as design start point.

In order to streamline the decision-making process between AmI designers/consultants and users it is necessary to provides multidisciplinary design teams with a common ground to represent, analyze multiple criteria. MRM design system as a data/evidence base centric system has considered such requirements. The MRM design system [78] plays the part of communicating between the multidisciplinary parties and by storing design data for 1. simulation 2 comparison 3 decision support 4 data / evidence visualization.

CHAPTER 6 EXPERIMENTAL DESIGN

6.1 Experiment Phase 1: Context Interview and Work Modelling of a Laser Cutter Workshop with a Mixed Reality Modelling Approach

Physical architectural models have the potential to provide a natural means to convey architectural review or tactical plans related to the positions and movements of components over time. Naturally user-friendly physical model have the potential to facilitate the involvement of people without design training and discipline [79]. In this chapter we present a mixed reality interface augmented physical architecture model, with the capacity of tangible interaction to support carrying out contextual inquiry and work modelling as the first phase for developing a smart Laser Cutter Workshop (LCW in short) at the Sheffield School of Architecture. With the support of mixed reality platform a new user study process for the design of an AmI system as a case study of testing the process will be presented. The chapter closes with a set of proposed AmI conceptual scenarios derived from the user study carried on the MRM platform for the next round's participatory evaluation experiment of the AmI design for the LCW.

We describe a mixed reality platform that combines physical model-making with computer-generated tabletop projection and analogue-virtual modelling through a marker-tracking system. Designed for context inquiry and work modelling for further smart environment conceptual design, our platform consists of a physical interior model of the LCW(with scaled furniture and related equipment inside it) and a set of widgets (physical user interface components linking to the functional agent in the virtual 3D scene) on the projection table. The position and rotation of all the assets on the table are tracked by the system for invoking interaction and software functions in the virtual model. Interaction with the physical model and accessory objects is enabled through dragging and rotating them in the interior model. The conventional contextual inquiry taken in field will be performed on the mixed reality model. Understanding in the design process of an AmI system is concerned with identifying problems and challenges of the current system or service [80]. Within the first rounds' experiments with the stakeholders of the LCW presented in this chapter, we focus on identifying existing problems and defining requirements for the later AmI design with the support of a mixed reality platform.

6.1.1 The Laser Cutting Workshop in the Sheffield School of Architecture

The LCW was selected as a case study for testing the proposed AmI design approach with MRM platform. Before designing AmI system for the LCW with stakeholders we made a field trip to investigate the basic context of the LCW (see Figure 5.1 and Figure 5.2). The passive observational investigation provides us with the real-life data we need to prepare MRM sessions for further contextual interview and work modelling.

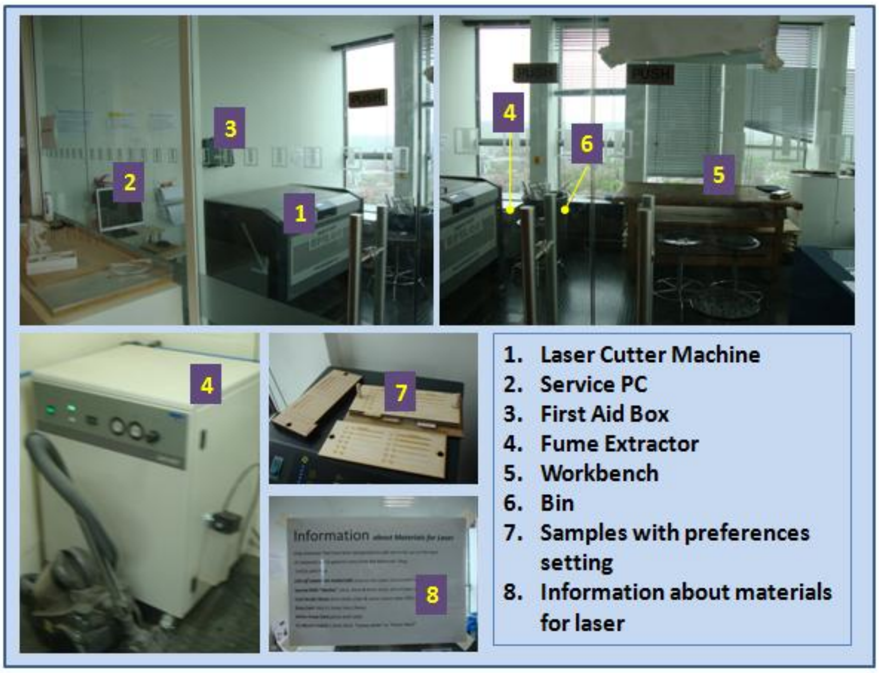


Figure 6.1 The laser cutter workshop in the Sheffield School of Architecture

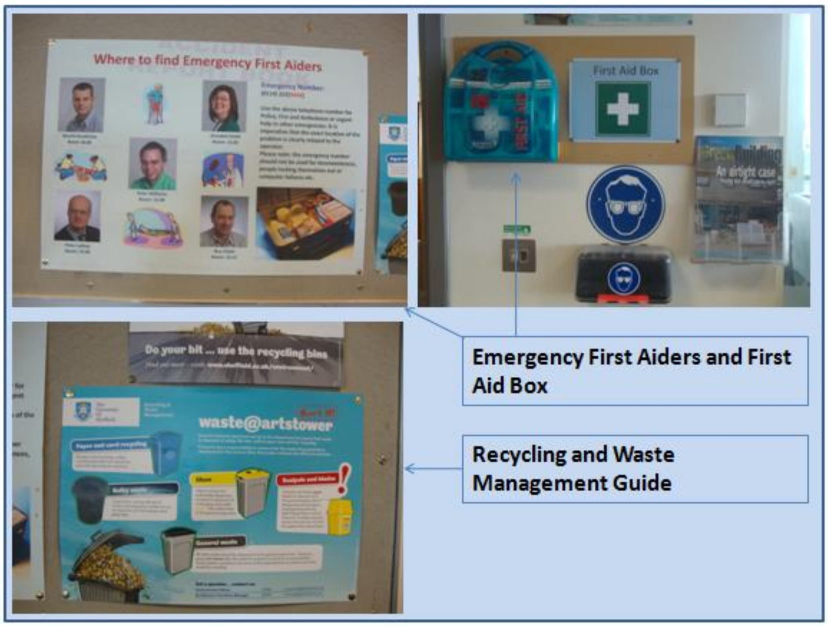


Figure 6.2 Information related to the LCW outside the room.

Observation Results and General problems of the LCW by fieldwork

The LCW's stakeholders' routine activities and some general problems are identified and recorded from the field visit:

Routine Activities

LCW users (architecture students and staff): 1) inquiry about modelling materials for laser cutting and buying them, 2) request technical support from the technicians, 3) book time slots for accessing the laser cutter, 4) post processing of materials after laser cutting, and 5) report if any health and safety issues encountered when using the laser-cutting machines.

Manager and the technician of LCW: 1) arrange the work environment of LCW and keep it tidy, 2) order and store material for the laser cutter, 3) provide training for students,4) manage bookings of the laser cutters, 5) sell materials, 6) induction of Health & Safety regulations and offer first aids (see Figure 2), and 7) monitor the operation of the laser-cutting service.

General Problems

Technicians: the workshop manager and technician are responsible for looking after the equipment and tools, ordering new equipment and materials, providing training programmes for new students, selling materials, managing laser-cutting booking and monitoring safe operating procedure of the machinery and equipment. And all these works are very repetitive and are often overlapped on each other.

LCW users: A lot of time wasted on queuing up for ordering material, booking equipment, and technical enquiries. Students often lack of approaches for learning from each other in terms of the knowledge and skills of using the equipment and tools in a more efficient way.

Space: lacking more effective capability for detecting the safety issues occurred in the LCW.

6.1.2 The Contextual Interview and Work Modelling on Mixed Reality Platform

We will initiate the AmI design for LCW from contextual design which consists of contextual inquiry and documenting the data with mixed reality model of the LCW. Contextual design method developed by Consultants Karen Holzblatt and Hugh Beyer is a mixture of contextual interview, prototypes with scenarios, novel modelling and data sharing techniques [80]. The tasks of contextual inquiry is very simple as Holtzbaltt and Beyer observe,

"The core premise of contextual inquiry is very simple: go where the customer works, observe the customer as he or she works, and talk to the customer about the work. Do that, and you can't help but gain a better understanding of your customer."

Contextual Inquiry could be a combination of techniques such as interview, artefact collection and observation under one unifying theme. About whom to interview, stakeholders from different organizations for representing diverse needs should be interviewed for each work role. The stakeholders of our smart LCW project includes architecture students, facility manager, technician and design tutor.

The characteristics of our Mixed Reality Modelling (MRM) platform provide a possible solution to integrating the process of contextual inquiry with work modelling (see Figure 5.3). With the manipulative objects the stakeholders could simulate their activities within an interactive interior model of the LCW. As the contextual inquiry on the MRM platform is recorded by a video camera, participants could be asked to explain what he or she is doing. By this means, the data gathered from the contextual inquiry could be documented both by the mixed reality modelling and the video recording as well.

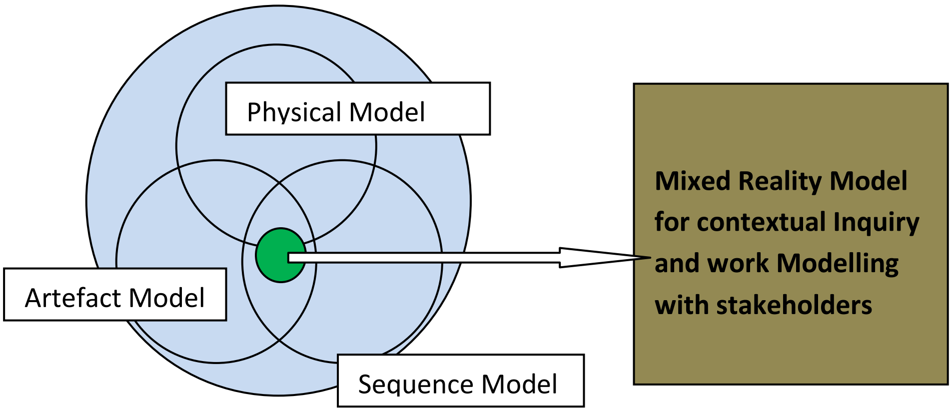


Figure 6.3 A mixed reality modelling approach offers the advantage of integration of three different modelling methods for carrying out contextual inquiry and work modelling.

6.1.2.1 The Physical Modelon the MRM Platform

The physical model in the context of interactive system refers to a representation of where the work takes place. It is not necessary to be an exact floor plan, but the key features of the workplace such as the size, a network or open plan of the workspace [80]. Is there a focal point where the users occupy frequently? Is equipment supporting users' work activities conveniently located? Designers can figure out why work is carried out in a particular way with the help of the physical model as a shared display. For instance, perhaps users forget to switch on the extractor very often because it is located far away from the laser-cutting machine. An equivalent in a ubiquitous computing system can also be integrated into physical model to augment physical features - perhaps the manager of the workshop could check lab occupancy by looking at an application linking to the IR sensor network in the lab.

For carrying out our design experiment, we made a 1:16 scale physical model of the LCW. This interior model can be viewed and moved around much as we view and move around the object of everyday life. it also includes all essential components of the physical model in the context of interactive system design. As it is a physical model with 3d representation, the physical structures of the workplace could be visualized and communicated effectively. Through moving the objects (models of artefact in the lab) inside the physical model, the path of users' regular movements between the parts of the lab and the movement of the artefacts could be described and discussed. Other key components include digital equipment, the location of key artefacts and the layout of the workplace. Insofar as they affect the way work could be carried out, they should be classified into the components of the physical model. The physical model of Round 1 experiment is shown in Figure 5.4. This is a very simple model but it contains essential components for stakeholders to describe their work activities in the LCW.

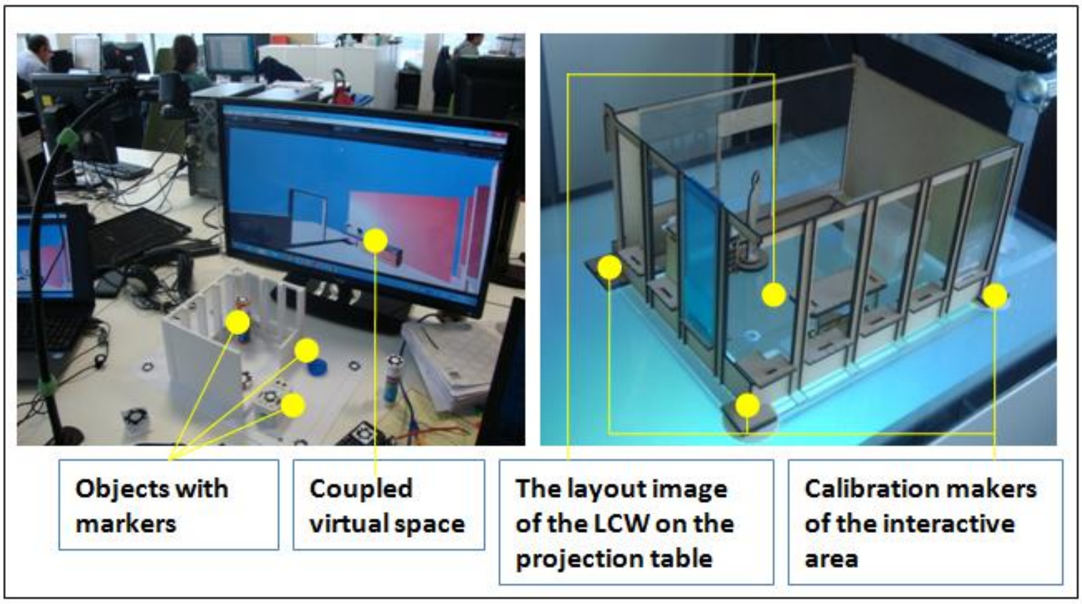


Figure 6.4 Physical interior and artefact models coupled with virtual reality through tangible functional objects and a projection table.

6.1.2.2 The Artefact Model on the MRM Platform

Artefact models refer to the things people create or use in daily work. Collecting artefacts and interpreting artefacts is an effective technique for contextual inquiry [80]. Artefacts here could be the artefacts themselves, or photographs or photocopies of the objects, or simple sketches of them. Here we attempt to physically model the artefacts in the laser cutter workshop together with the interior model of the LCW itself for provide the participants a scaled model of their work environment. In the participatory experiment, the participants were asked to describe and move these artefacts to illustrate how everyday tasks in the LCW are actually carried out, and the experimenter stands by the participant to provide essential support. Relevant artefacts are of a variety of types. In our LCW case study, the artefacts in the mixed reality model includes:

1. The interior model

2. Furniture: workbench, chairs, PC stand, rubbish bin, storage shelf

3. Modelling Material Sheets

4. Equipment and tools: computer, laser cutter machine, fume extractor, vacuum cleaner

5. User Guides both on the LCW website and on the wall

6. Safety signs and information

Also, the interface to the computer system of laser cutting machine is another key artefact. The artefact model in our project consists of the scaled physical model and digital photos and videos embedded in the virtual model. The model has two main uses. Firstly, it was used to tease out details of how work is done currently, preferably with participants. In the later design stage, it could provide basic information such as what and how activities currently are performed, the LCW's management and existing problems. After completing the contextual inquiry experiments the artefact models could be stored as a base for the latter creation of AmI scenarios. We worked with each stakeholder individually to create her/his specific user scenario data with MRM platform.

Step 1

Collect images and model the artefacts of the LCWand then using these raw data to set up a mixed reality user scenario for carrying out an infotainment-style context inquiry. Before the start of the experiment, the experimenter has to identify the most significant and typical artefacts in consultation with the stakeholders (e.g. architecture students, technician, facility manager). The detailed procedure of the mixed reality based contextual inquiry is described in the evaluation section.

Step2

Provide basic introduction and a brief user training of the MRM platform. We then asked the participants to illustrate their activities in the LCW using the tangible widgets provided for this experiment. A set of tasks were designed to allow the participants to walk through the process of using the artefact widgets within the mixed reality model on the platform’s tabletop. As the whole experiment was video recorded, the workflow of using these artefacts is recorded by the on-site video camera and the screen capture software. Also, a 3d sequence diagram of these activities were also generated in the virtual model for later analyses and the further design of proposed AmI services. When the participants carried out the tasks, the functions of the artefacts in the LCW and their affordances and limits could be generated and stored by the sequential widgets.

Step3

Annotate the digital model with comment widgets to highlight the significant components of the artefact model as following:

1. The information content related to the LCW;

2. The structure of the objects grouped into different parts, showing different usages, who gets involved, and the information intended for different users;

3. Informal annotation of the artefact which is often a clue of the artefacts' existing problems;

4. Note any aspects that change over time; and

5. Note when it was set up, what it is used for and by whom.

6.1.2.3 Sequential Models Produced by the MRM platform

A sequence model is used to represent ordered work tasks over time. They can model user's activities as a sequence of steps of actions [80]. However, they may be drawn from different points of view from different stakeholders, and some tasks are likely to be constructed in several different versions. A typical sequence model composes of three main components, including the intent(or purpose), the trigger and a series of steps that achieve the intent.

MRM Platform provides the participants a set of widgets to construct mixed reality sequence models embedded into the virtual model scene. The sign stand widget is to instantiate a 3d input-field dialog in the virtual model. Through placing it in the desirable position of the interior model, a virtual dialog box can be constructed in the corresponding position of the digital model. The other type of widgets is used to instantiate the 'arrow sign' in the virtual model. Through deploying these widgets into the floor of the lab, the participants can construct a 3d sequence model while performing the process of how they do their work. The sequence model generation function and its workflow are designed for carrying out in four typical steps for constructing a sequence model outlined as follows:

Step 1. The participant places an input widget in the physical model, type the name of the task she wants to carry out in the input field named 'Intent'.

Step 2. Input the event that sets off the sequence in the 'event field'. In Figure 5.5 the event is a laser cutting operation request. (Events can also be time-based - at the fabrication lab, the manager locks the lab at 6pm every day, for example).

Step 3. Place more input widgets for constructing the steps taken to achieve the intent, link the steps widgets with arrows widgets (loops or brunches can also be shown by arrow widgets).

Step 4. Review and add subsidiary intents using input widgets if any.

6.1.3 SYSTEM HARDWARE AND SOFTWARE

Based on the requirements for the mixed modelling approach, a method of user study which combines the tasks of context interview and work modelling was developed and programmed. This middleware serves as an interface between design(the physical model and tangible objects on the tabletop) and the support design props (simulations and agents). Based on a modular building block principle, the configuration of design support tools can be customized as they can dock on to the middleware. Therefore designers can develop and program more tools accordingly to meet requirements emerging in the design process. As shown in Figure 5.5, the elements of the MRM platform for the individual experiments are as follows:

1. 3D object capture (edddison [81] + markers)

2. Physical model of the interior space

3. Models of the Artefacts in the interior space

4. 3D game engine (Unity3D)

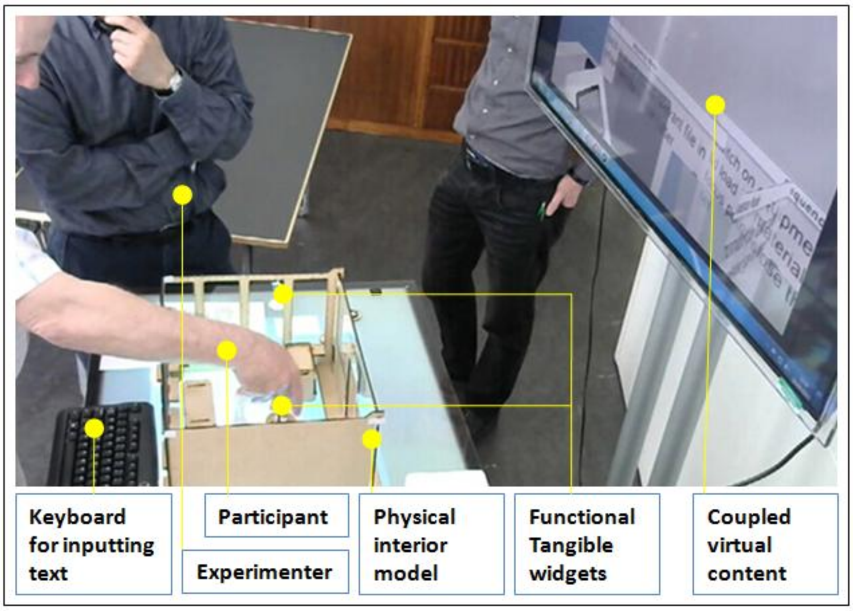


Figure 6.5 Elements of the Mixed Reality Platform coupled with a 75 inch Sumsung TV monitor for displaying corresponding VR scene

The basic idea of the Mixed Reality Modelling (MRM) platform lies in facilitating real-time interaction between interactive simulation in Unity3d game engine and analogue physical interior model and other tangible objects. It makes it possible to carry out a real-time simulation through changing the setting up of the physical model. This real-time interaction, allows any member in the design team to immediately experience the impact of design decisions. Examples of this includes the real-time simulation of the layout changing, or the simulation of different artificial lighting or the other artefacts' motion. Rather than calculated numerical values, the simulations using a game engine provide easily comprehensible 3d visualisation. With the help of this platform, simulation of the smart environment design that is normally undertaken at the end of the design phase can be applied in order to prototype and experience the interactive AmI scenarios at the conceptual design stage. For instance, the sensor or actuator's physical constraints such as detection range or limit can be incorporated into the agents in the game engine. This provides the designer with objective assistance that can inform the design, but the subjective process of assessment, evaluation and exploration remains in the hands of the designer. The MRM platform is conceived as a prototyping and communication tool for participatory design of AmI and assists the designer in carrying out contextual inquiry and work modelling. One can imagine the boundary between prototyping, simulation and user experience blur into a continuous, creative collaborative design process based on the MRM platform. Participatory Design Platform aims at providing a tool on which a new participatory design process of AmI system could be developed and carried out. Seamless integration into the participatory design process is achieved with marker tracking based, physical computing embedded 3d object recognition in combination with intuitive tools that have no prior-learning required.

6.1.3.1 Multi-touch tabletop

As shown in the Figure 5.6, we modified an Edddison projection table as our mixed reality platform. The mixed reality table(1000 cm * 60 cm) has a glass slab with rear projection film on the side facing the projector. This glass slab enables the interactive projection to be seen and will also be used as the navigation area for tangible objects with makers. The housing of the table is an inverted truncated pyramid which is designed for a small group people standing around it while presenting [81]. Inside of housing a high-resolution (1920*1080) projector is horizontally mounted with a mirror a the bottom to reflect the image on the glass slab. The glass slab with projection film is additionally illuminated by a lap of LED infrared strips from the inside. The camera for tracing the marker has a daylight filter so it only takes a picture physical marker on the glass slab rather than the projected images. The markers on the glass plate are illuminated with the IR light. The infrared camera video stream captures the motions and positions of objects with markers on the bottom. A computer with Edddison middleware processes the camera video stream and generates an interactive projection image. The automatic physical object tracking is achieved using marker tracking system and the live video processing framework Edddison.

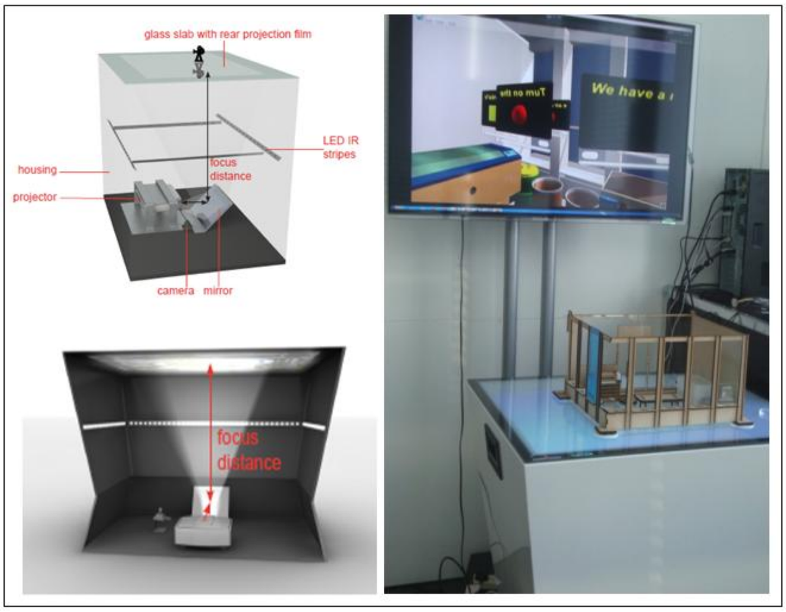


Figure 6.6 Left image shows Edddison projection table with a multi-markers tracing system. The right image shows Mixed Reality Model with a 75 inch Samsung TV monitor for corresponding VR scene.

A second display, paralleled to the tabletop projection, that on a 75inchSamsung TV monitor, makes it possible to display additional interactive information for the participatory design process such as perspective navigation, animations, functional props in the virtual model or further 2D contextual images [82]. With the help of the marker tracking system, it is also possible to produce a better indication of three dimensional representation characteristics. Through tracking the position and rotation of the navigation object coupled with the virtual camera in the virtual model participants could adapt the view angle and height of the virtual camera in the digital model. The parallel display is also intended for use in the participatory design process. This makes it possible to involve more stakeholders to illustrate their personal experiences and leave comments in within the model.

6.1.3.2 Multi-functional Widget Recognition

The automatic tracking of the physical model and widgets on the tabletop employs IR camera to capture the gesture movements on the objects with marker by users, such as picking, placing, moving or rotating. All these gesture data is received and processed by Edddison middleware and then sending to the analogue digital scene hosted by Unity3D game engine. In this way, we integrated for our system Unity3D with tangible interfaces which is physical model and tangible objects on the tabletop. Unity3D has been designed to allow users to create their own 3d environments which can simulate places of the real world, as well as new designed agents, thus helping designers to prototype the interactive system design which are not able to be experienced with physical model. The real-time interaction between Unity3D environment and the physical object on the tabletop makes it possible to mixing the advantages of physical and virtual representations. For instance, the user can review an explosion effect in the virtual model just rotate an object on the tabletop.

6.1.3.3 Middleware for the Tangible table

On the software side of the study, the middleware called Edddison (see Figure 5.7) serves as an interface between the hardware configuration and the Unity3d game engine. Edddison is used to interpret the tracking events that are captured by the IR camera [83] (e.g. the recognition of inputs such as the placement or motion of an object on the tabletop). Similar to TUIO(Tangible User Interface Objects) Edddison is a customized protocol designed originally by KOMMERZ to meet the requirements of tabletop tangible user interfaces. However, unlike TUIO which defines both common properties of controller objects and user's finger gestures, Edddison only supports marker based objects tracking. To allow developers to create their own mixed reality project, Edddison also provides a plug-in for Unity3d engine, NavisWorks and SketchUp. Developers can integrate their existing virtual reality projects with tangible interaction on tabletop using this plug-in. In our platform we developed multiple agents linked to the object to meet the requirements of the participatory AmI design.

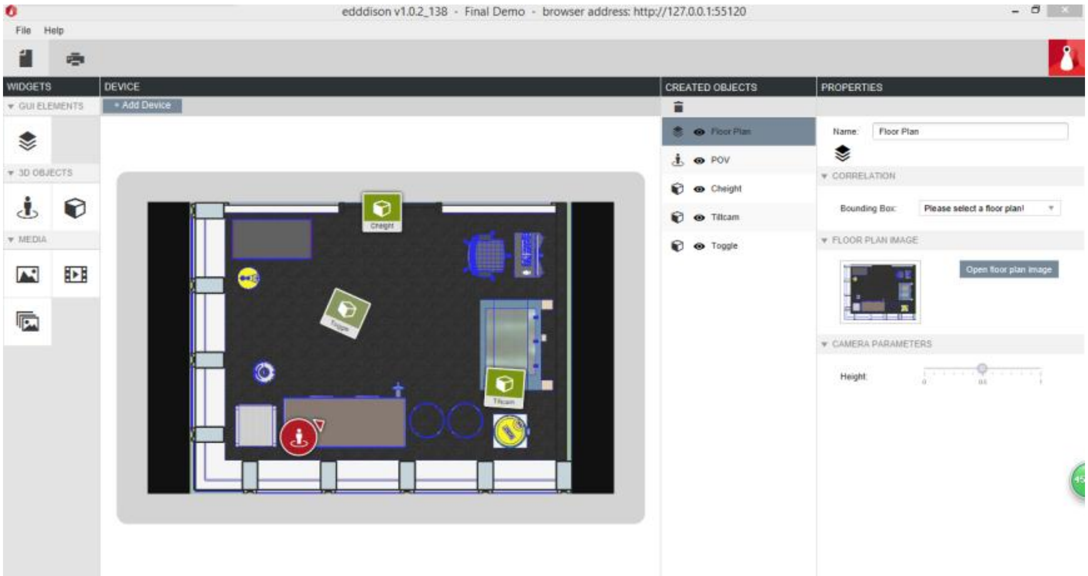


Figure 6.7 The tangible tabletop editor of Edddison

6.1.4 SYSTEM EVALUATION

We conducted a laboratory-based user study to evaluate how well the Mixed Reality Platform based context inquiry and work modelling addresses the design goals before the prototyping of AmI system for the LCW.

1. To build the stakeholders' scenarios in the LCW for further AmI system design, and

2. To collect the participants' feedback about the mixed reality interface for the improvement of the system.

6.1.4.1 Participants

A focus group of stakeholders (a design student, the manager of 3D Print Lab and a technician from the Material Workshop), between the ages of 21 and 55, were recruited from the school of architecture. All participants were frequent (4+ hours per day) computer users. All the participants had no previous exposure to Mixed Reality Interfaces before. Their educational level varied from college to post-graduate. They participated the Round 1 experiment individually at different times. No compensation were offered (refer to the research ethics approval in the Appendix).

6.1.4.2 Apparatus

The experiment took place in a controlled laboratory setting. Participants completed the study while standing around a horizontal, top-projected 60*100cm Edddison MRI table with a 1024x768 pixel projected display, and facing a 75-inch Samsung TV monitor in front of the table. Participants could interact with the tabletop setting through manipulating tangible functional widgets, furniture objects, navigating avatar figure and equipment models. As depicted in Figure 5.8, individual participant was asked to stand at the long side of the MRI table with the experimenter next to him or at the short side of the table.

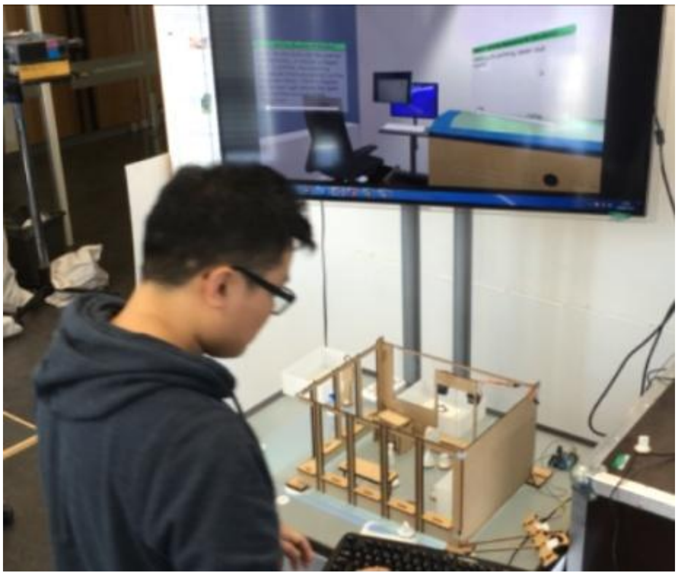


Figure 6.8 Evaluation setting.

6.2 Experiment Phase 2: Participatory Workshop for Evaluation the MRM Prototyped Smart LCW

6.2.1 Conceptual Design of the AmI Scenarios

With the data from the individual experiments with stakeholders we developed an AmI solution to implement the smart LCW. This solution consists of a set of conceptual AmI scenarios together with conceptual implementation technologies. These AmI scenarios are pre-programmed to perform intelligent actions triggered by sensing and reasoning system. For each of the following user scenario a problem or challenge is identified from the data from the previous experiments. Afterwards potential AmI design is described how it should cope with this challenge.

6.2.1.1 Scenario 1 (Using the Laser Cutter)

Problem Identification: A new student is going to use the LCW to cut parts for his or her architectural model. The student is in the LCW for the first time and does not know how to use the equipment and related rules. And additional challenge is that the responsible technician will move around the material workshop instead of being in the LCW premises all the time.

AmI Solution: In order to realise this scenario, the AmI system should provide means for tracking students while working in the LCW. Determining positions of the student in the LCW is essential in order to provide information feed useful to the laser-cutting tasks. The AmI system could then deduce which operational step the student is working and provide corresponding support. In general, the new student will not be familiar with the environment, meaning for the AmI system to provide him /her instructions about where to go and what to do. For this purpose an interactive map of the LCW could be displayed at the wall which the student will most likely perceive. In particular, a personalised guide on the map will be confined to what is the most relevant content for the given state of the student.

In short, the AmI system will lead the student to perform the tasks for cutting material by laser step by step.

6.2.1.2 Scenario 2 (Working in the LCW)

A student needs help when he or she is experiencing technical or usability difficulties in the LCW. A student is injured in the LCW, requiring as fast as possible a first aider to be called and provide the first aids.

The AmI system has to equip the LCW with a convenient and fast means of communication between students in it and the technician in his office. It also needs to consider whether the technicians are available and show them effectively what kind of help the student needs in the LCW. Furthermore, it can provide students and technicians with as much meaningful information about the situation of the LCW as available. The AmI system will provide the real-time video streaming and the playback of the situation of the LCW with additional analysis. This will help in customising response resolutions.

6.2.1.3 Scenario 3 (Managing the LCW)

It is not only of responsibility for the technician to provide technical support for students in the LCW but also to monitor how they carry out their activities in the LCW for the purpose of ensuring students' safety.

The AmI system has to track and monitor how the student perform the cutting task and correlate his locomotion and behaviour with the operating step. The AmI system will tell the technician whether the student executes the operation of the equipment properly. This might take place in the office of the technician where a display will show the technician whether a nonstandard or an accident happens in the LCW.

6.2.2 Implementation of the Smart LCW and Prototyping the AmI Scenarios with the MRM Platform

6.2.2.1 System Architecture of the Smart LCW

The AmI system of LCW composes of input and output systems. The input system consist of multiple sub-systems: a pressure sensor based smart floor which is linked to smart projection and knowledge database, IP camera to observe the user behaviour and checking the situation by the technician, and multiple sensors embedded into equipments and furniture in the LCW (see figure 5.9). Output systems consist of an interactive projector which projecting digital instructions and annotations on the wall, an alarm and actuators installed on curtains, windows and the door of the LCW. The software and middleware are developed in Unity3D with Edddision framework and C for Arduino.

6.2.2.2 System Components for Implementing the AmI scenarios

The AmI scenarios we have designed for the participatory design workshop compose of a series of discrete context aware and actuation systems to monitor and inform the routine tasks in the LCW. These three scenarios monitor the user's behaviour in the LCW and project task-specific gesture-based interfaces on the wall which is in front of the laser engrave and the PC unit. Smart shelf, smart window, smart curtain, automatic extractor, smart door, smart floor and smart projection, these smart objects work together under the control of the smart logics to reduce the complexity of interacting with the LCW and detect any situation that can endanger the LCW's users.

The design of smart projection interface started with a careful consideration of building an intuitive link between the desired task and the user's attention. The AmI interaction was designed based on exogenous and endogenous cues. In the existing LCW the physical objects and the information related to them are separated. Physical objects like materials in the shelf require users to refer to the manual to know the laser preferences for specific material. And these setting data are needed for selecting material and configuring the laser when users send file to the laser. In many cases rechecking these setting often interrupts users' task of configuring the laser engraver on the PC station. And moving the user's away from the main task even can cause operation errors.

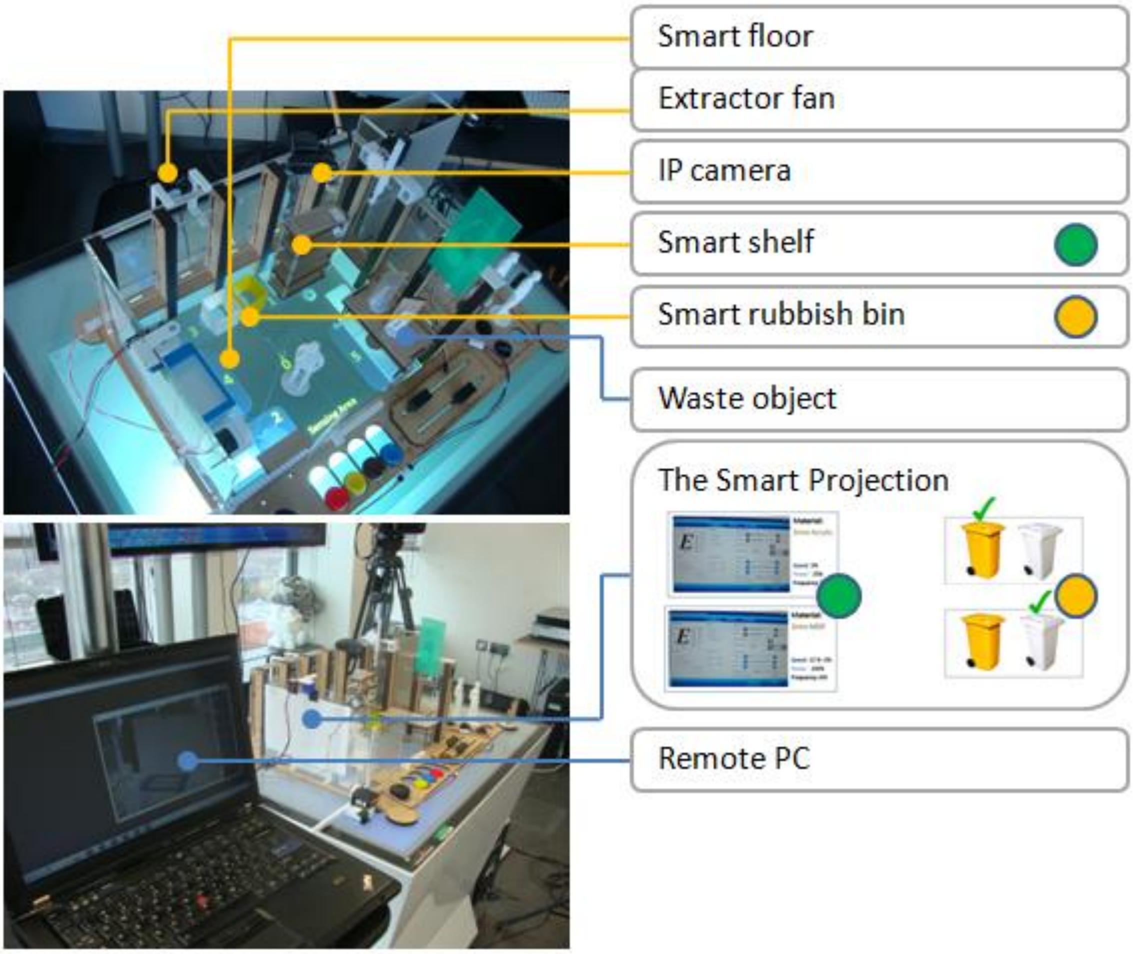


Figure 6.9 3D interactive prototypes of the AmI components on the MRM platform.

6.2.2.2.1 Smart Shelf

A smart projection which is integrated with the pressure sensors in the material shelf can display setting information according to the material the user has selected for cutting. This type of interactive interface and exogenous attention cueing eliminates potential repetitive activities with the least mental processing. In the case of the smart shelf, the smart projection display the material type and laser preferences when the user take the material sheet from the shelf. This will help users without any knowledge about the material have a reference for selecting material and setting the laser. Pressure sensors are proposed to be installed on the bottom of each deck of the shelf. The pressure changes when a material sheet is taken from the stack of a type of material. Then a signal will be sent to the smart logic of the shelf to identify what material is picked up by the user. The result from the smart logic is used to trigger smart projection to display related information.

6.2.2.2.2 Augmented Reality based Instructional Projection

After the first phase of experiments we've proposed an AmI solution which consists of three conceptual scenarios to make the LCW to be intelligent. In order to control these scenario-based AmI system to perform various intelligent actions, an ubiquitous function(UF in short) services are developed to enable the AmI system to realise context aware [84], to interact with users, and to share information with stakeholders. We use the smart object, smart logic, and smart discovery services of the UF service to blueprint the proposed AmI scenarios . Through integrating objects with inherent functions in the physical space new smart functions could be created. For instance, a smart door could be made through integrating a door object, an actuator object and a face recognition system for security. To define the relationship between the door, actuator and the face recognition system a logic which controls the door actuator by the feedback information produced by the face recognition system is needed. The control algorithm of this smart door belong to the AmI system is the UF smart logic service. In this section we will apply the UF services to illustrate the service blueprint and implementation of the first AmI scenario we proposed in Chapter 5.

A smart projection physically works together with multiple external component: IP camera, speaker, smoke sensor, smart floor, gesture sensor, etc. The essence of AmI design is define the relationship between them in a way of distributed control. Thus logics which control output components by the feedback and reasoning results from the knowledge engine are also needed. Smart logic integrates and controls UF components of the AmI system in order to provide smart services. Figure 5.10 shows an example for the proposed smart projection, where the smart object are linked to smart logics through compatible input/output data flow. By linking different smart object and smart logic a variety of smart service can be designed and represented. Thus the typical smart projection service can be modified and extended through the reconfigurable combination of the physical smart object and virtual smart logic [85].

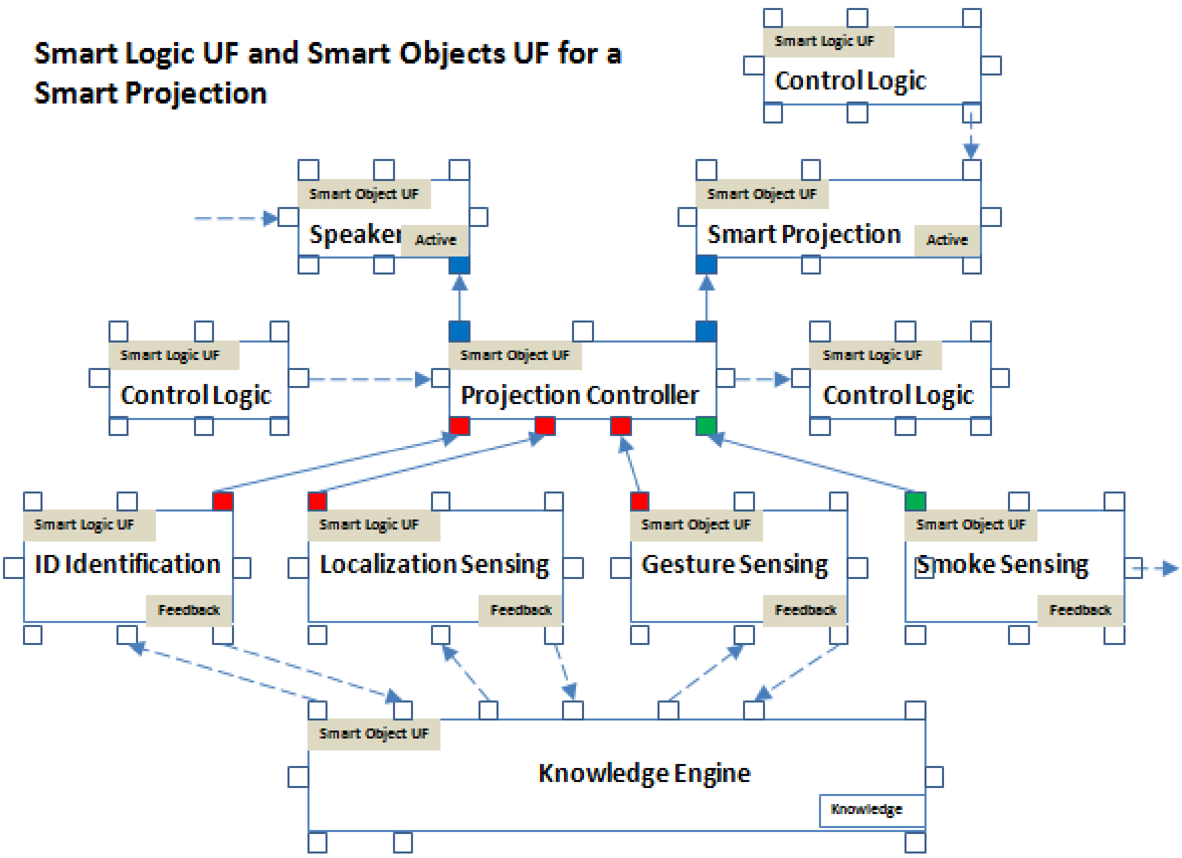


Figure 6.10 UF logic Case of Smart Projection

For more complex tasks with more steps the AmI system provides an augmented reality based instructional projection (see Figure 5.11). To simplify the process of finding items in the LCW the background of this projection displays a 3D image of the LWC. As show in the Figure 5.12, a step by step instructions with arrows could be pops out on specific elements in the 3D image to guide users to perform the task. The specific instructional projections can only be triggered when the user stands on the specific area and the smart logic has confirmed he has completed the previous task within the whole workflow. This means users can navigate the steps of the instructional projection by walking between different operational space monitored by smart floor. The smart projection is displayed in the front of the laser engraver unit in order to provide an endogenous cue mid-way between the user and their task. Although this semi augmented reality projection require more processing than exogenous cues, it still have been shown to reduce the training time by intuitive interactive instructional projection with respect to expert along training. With corresponding real time instruction projection the users are expected to be more confident with the tasks. After completing one task the user can confirm it through waving his hands. As an integrated smart object the smart projection also interfaces with other smart objects like smoke sensor or range finder of the workbench to cue any types of accidents, such as blinking alarm when the user forgets to switch the extractor or violates process. Other object such as IP camera and colour detector could also be attached to the smart projection object. Knowledge database as a smart object for reasons is responsible for fusing and analysing environmental data produced by the AmI system. For example, the AmI system could launch a video chat between the technician in his office with the user in the LCW if the reasoning result of the knowledge DB detect any violation operation.

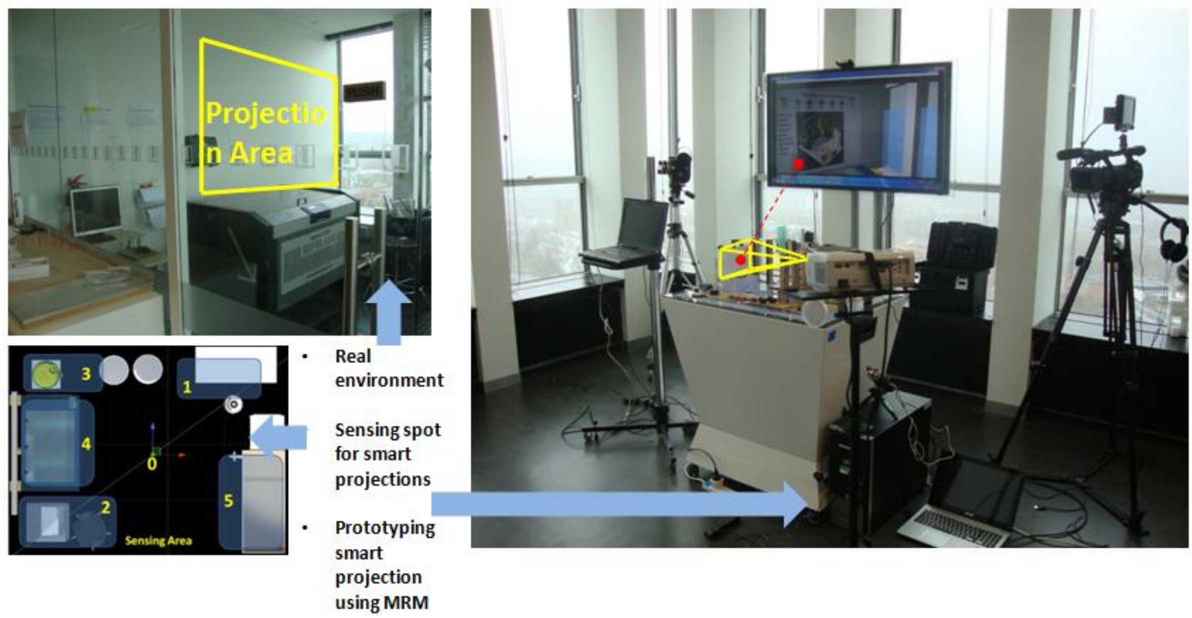


Figure 6.11 The smart projection can be prototyped on the MRM platform with a wireless linked short throw projector.

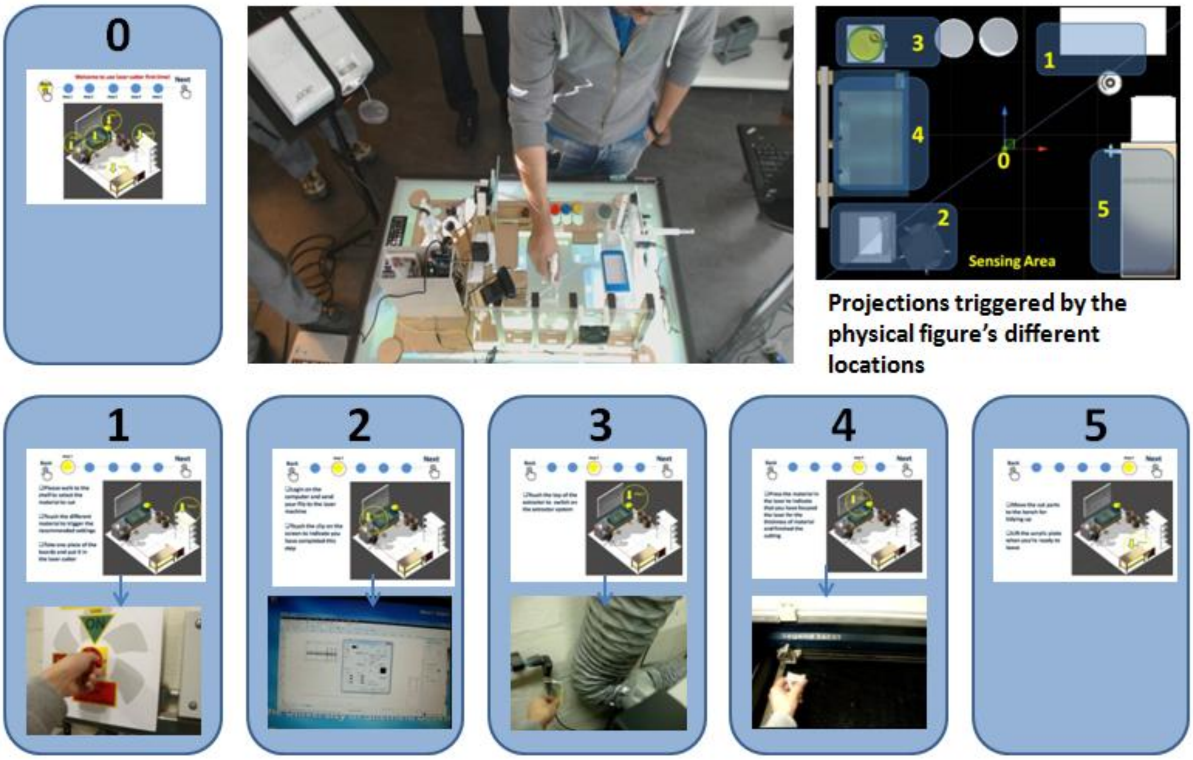
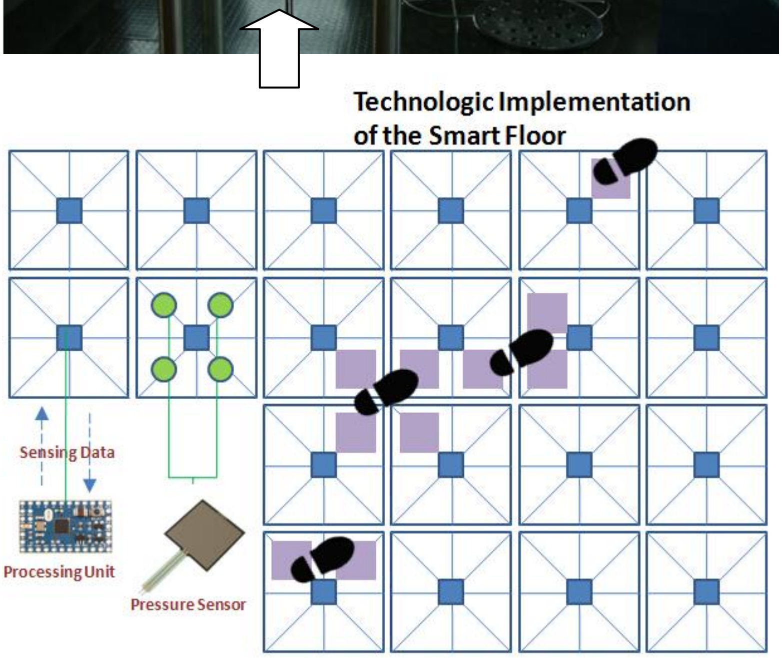


Figure 6.12 The participant is allowed to trigger instructional images and videos of the smart projection by navigating in the physical model with a physical character

6.2.2.2.3 Smart Floor

In order to realise the scenario 1, the AmI system should provide means for tracking students while working in the LCW. Only with the information of the user's position in the LCW the AmI system is able to decide what information is essential to provide for more instructions and feedback. The smart floor we designed for the LCW integrates sensor electronics into the floor invisibly. When the user walks across the floor the embedded sensors will recognise his location and movement behaviour. Figure 5.13 shows in the schematic of the smart floor. When the user steps on the smart floor the sensors embedded in the textile are triggered and the sensor events are broadcasted and received by the knowledge database object of the AmI system.


PUSH
PUSH
EPILOG


Technologic Implementation
of the Smart Floor
Sensing Data
Processing Unit
Pressure Sensor

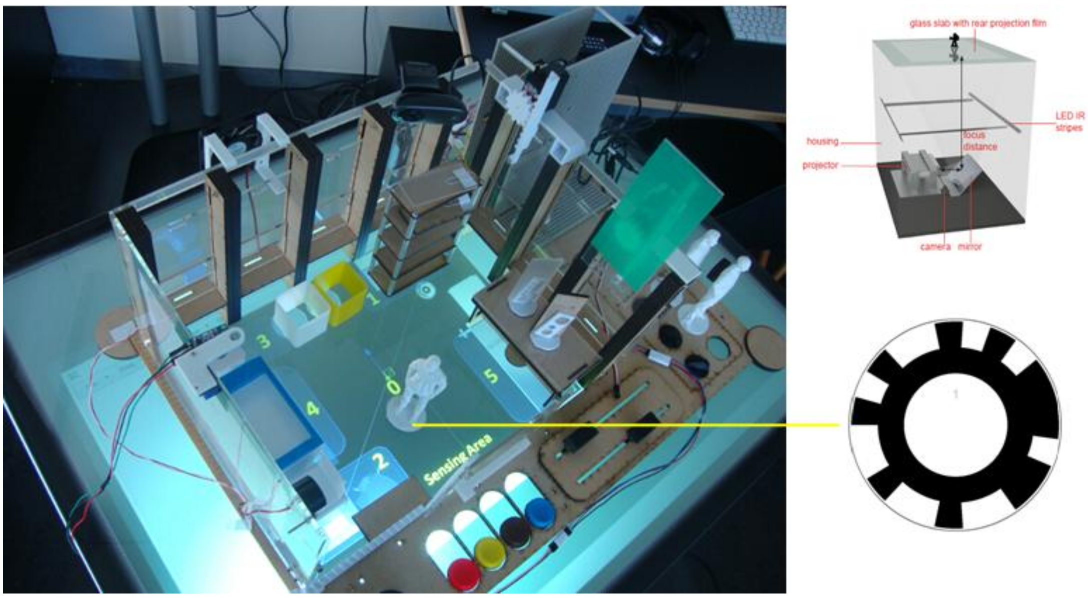

Sensing Area
glass slab with rear projection film
LED IR
stripes
housing
projector
focus
distance
camera
mirror

Figure 6.13 On the MRM platform we use a physical figure with a tracing marker on the bottom to prototype the function of smart floor. The spots labelled by numbers on the floor of the model are sensing area which could trigger AmI interaction.

6.2.2.2.4 Knowledge-based Inference Engine of the Smart LCW

The smart LCW with enough knowledge and commonsense to coordinate the input and output system deployed in the lab is essential to improve the usability of the AmI applications. Users usually become strange to the operation of the equipment after they haven't work in the LCW for long time (a student usually use the laser engraver less than three time per semester). This makes them often to spend extra time to familiar with the workflow again and may cause potential danger such as forgetting to switch on fume extractor. The knowledge DB in our project is a scenario-based system programmed to coordinate the input and output system to perform a single or a serial of actions based on its analysis results of the input data. Currently our system still needs precise manual design of the procedures. Future version of the smart LCW will be able to learn basing on observation of users' behaviour and environmental feedback over a period of time. The smart LCW is design to be capable of monitoring operational tasks and the user's behaviour in order to provide instructional projection or alert at the right time. This operation process and safety knowledge-based inference engine is built into the smart LCW. The smart LCW can analyse the user's behaviour and infer user's intention with the support of the knowledge DB. Based on the reasoning results from the knowledge DB the smart LCW is able to provide interactive information and feedback by the smart projection. Therefore, users' behaviours are used as data source for the knowledge DB without any intermediate interface. Figure 5.14 presents an example of the knowledge diagram in the smart LCW.

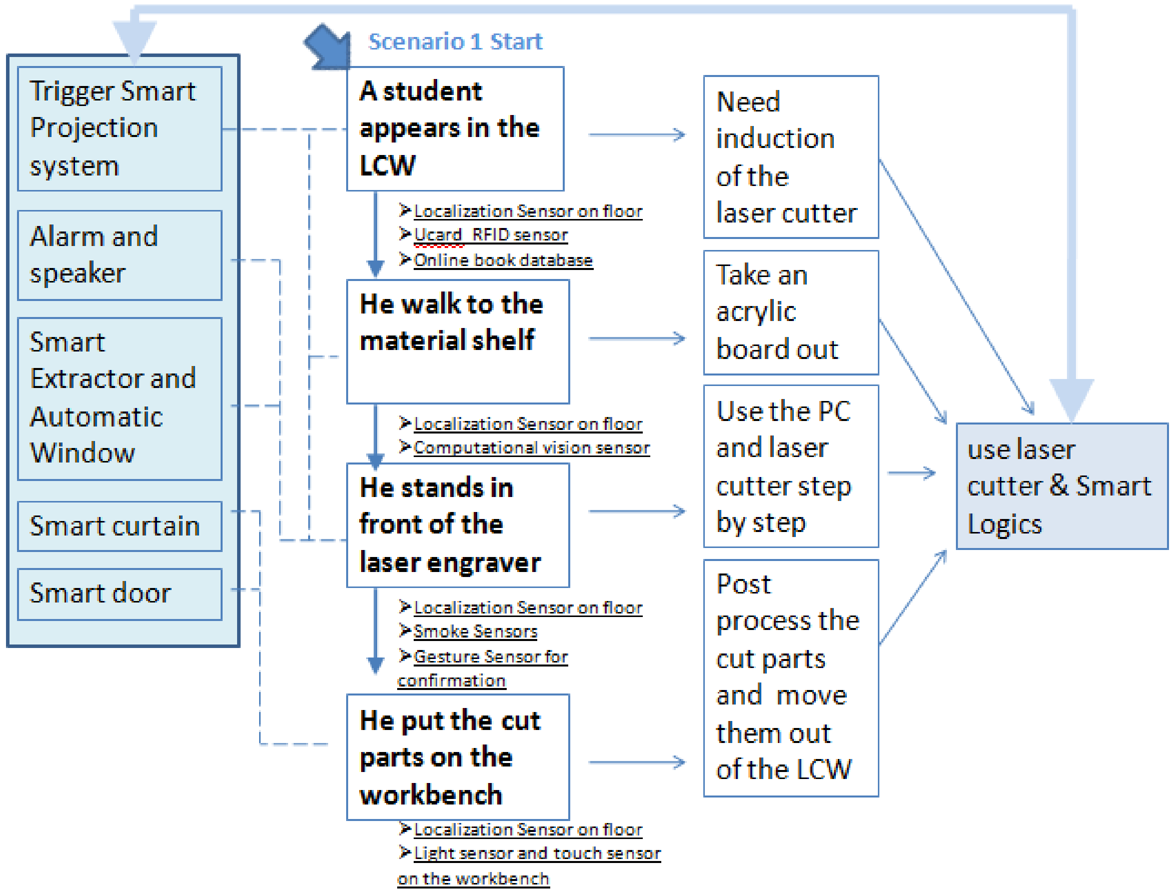


Figure 6.14 The knowledge diagram of the AmI scenario designed for supporting a new student to work in the LCW.

A main objective of the smart LCW is to find out potential risks when operational tasks were undertaken by the user. Its knowledge-based engine dynamically generates models of potential safety issues related to the user's current behaviour [86]. A safety agent in the knowledge-based engine is used to rates the danger level of the user's activity by analysing the current status of the LCW. For instance, there are two bins in the LCW to sort recycling card and sharp offcut. The sensor embedded in the bins can detect the colour the objects dumped in them and send the data to the safety agent. Then the safety agent will start to analyse if there is illegal material put in the specific bin(the knowledge database stores the colours of all the material in the shelf). The reasoning result is used to decide what is the next task for the AmI system (e.g. display the safety instruction with audio alarm). The smart LCW retrieves ambient input from the user's behaviour and the environmental status, and the knowledge reasoning engine and the output system (i.e. smart projection, alarms, embedded actuators) are responsible for analyse the input data and generate articulated physical feedback to support the on-going tasks.

The Rationale behind MRM Experiments:

Taking AmI scenario 1 as an example to explain the rationale behind participators involved experiment on MRM platform. In this experiment, the participant is requested to experience the proposed AmI scenario of the Smart LCW on MRM platform as an inexperienced student.

Firstly, the participant is asked to pick a physical figure model which represents a new student and put it on the floor of the LCW model near its entrance. At the meantime the IR camera under the slab of the tangible table is triggered by the marker on the bottom of the figure and starts to track its position in the LCW model. By this means MRM can simulate the human tracking function of smart floor. An corresponding virtual avatar of this figure appears in the VR scene when the IR camera detecting the marker. With the geo-position information of this figure the knowledge engine begins to compare the profile information attached to the marker (representing student card) with the facility booking information. After logic judgement of the booking information the knowledge engine of the smart LCW inform the smart projection system to project the instruction diagram and further instruction on the wall behind the laser cutter. On the MRM platform this interaction is implemented by both the texture image on the virtual model and the 3d projection mapping on the physical model. Then the participant moves the figure in the LCW model to next position for carrying out next tasks instructed by the smart projection. For instance, the first step instructs the participant to move the figure to the shelf storing materials. When the figure being moved close to the shelf the attached virtual colliding box of its avatar collides with the shelf's colliding box in VR scene. The generated colliding signal will be send to the knowledge engine to inform the status of the user. This will trigger an instruction image asking the participant to touch different materials in the shelf on the smart projection.

When the different material in the shelf are touched by the participant the conductive sensor attached on the material will inform the knowledge engine which type of the material is picked by the user. Subsequently, the setting parameters of this material on the laser cutter will be projected on the wall behind the laser cutter to support the operation of the machine. In a similar manner, the smart LCW prototype on the MRM platform will lead the participant through a sequence of AmI scenarios for instructing new users of the smart LCW.

6.2.3 User Evaluation

We conducted a formal laboratory-based user evaluation of the MRM approach to determine that it was capable for communicating the design of AmI in a participatory scenario. The evaluation aimed to gather stakeholders' feedback from their user experience of the MRM prototyped AmI scenarios.

The user study which consists of three AmI scenarios on the MRM platform was carried out as a participatory workshop.

6.2.3.1 Participants

Each of the three AmI scenario evaluation involved different participants depending on which type of user the scenario caters for. The stakeholders of the LCW who were involved in contextual inquiry experiments were invited to the workshop, and they were encouraged to be creative to make use of the MRM to evaluate the AmI scenarios. Before each test of the AmI scenario the participants were explained of the tasks which they need to perform on the MRM platform.

6.2.3.2 Apparatus

The MRM approach we used in the participatory experiment was evaluated and revised in the user study phase of the smart LCW project with its potential users and stakeholders. A participatory workshop allowed us to investigate the feasibility of evaluating the smart LCW on MRM based successive prototypes and which aspects of this participatory format were appropriate and appreciated by the participants. The participatory workshop still took place in a controlled media studio setting. All the evaluation process were video-recorded using three cameras: a video camera behind the TV monitor of the MRM platform which covering participants' action around the MRM platform, a camera mounted on top of TV monitor, which captures the user's interaction with the interactive prototypes on the tabletop, and the third one is a virtual camera which records the corresponding virtual content on the TV monitor. An additional microphone mounted on the experimenter is used to capture the soundtrack of the workshop. This soundtrack of participants' conversations and interviews was recorded for producing a verbatim transcript after the evaluation session. The video material were inspected and analysed to select and edit significant scenes for responding the research questions and the MRM framework.

The controlled MRM studio (See Figure 5.15) provides a MRM platform centred collaborative setting for the participatory evaluation. In this MRM studio the AmI prototypes for the Smart LCW can be interactively experienced and illustrate, debate and experiment with different interests perspectives among the stakeholders of the smart LCW [87]. The smart LCW prototypes on the MRM provides participants with the possibility to interact and experiment with the scaled AmI system on the physical model of the smart LCW. An additional short-throw projection renders the physical model for prototyping the smart projection in the LCW.

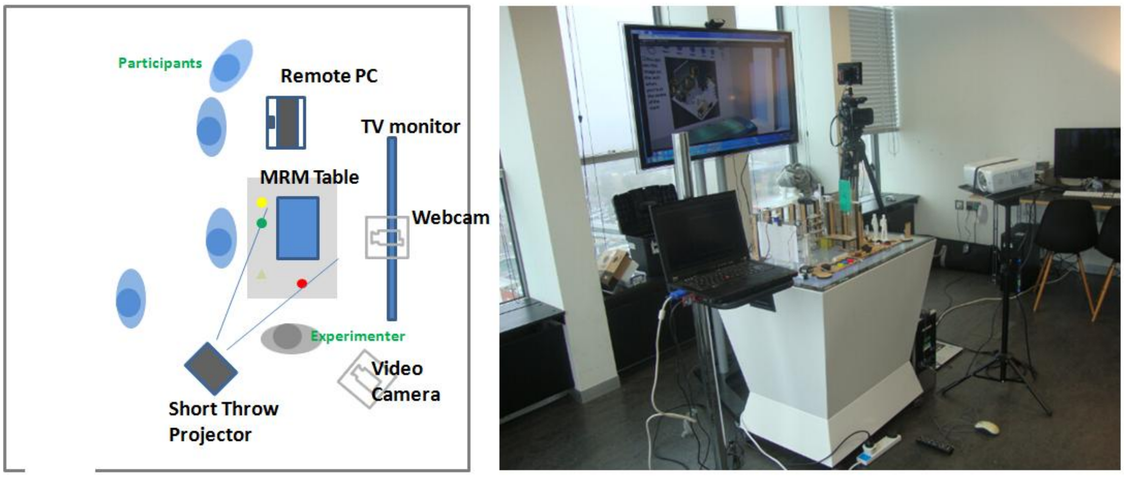


Figure 6.15 Participatory experiment Layout

CHAPTER 7 EVALUATION AND RESULTS

7.1 Experiment Phase 1

7.1.1 Participants' Tasks

For collecting data to model user's activity in the laser cutter room, each participant was asked to perform a series of interaction tasks. Task 1 was to deploy the furniture and equipment models in the room model according to the top-projected layout image, and also practice navigation in the virtual model with a physical figure. After the warm-up, Task 2 asked participants to perform their daily activities through dragging the physical avatar in the model and typing the detail s of the behaviour in the 3d digital dialog box in the analogue VR model on the Samsung screen. Task 3 involved designing a new layout of the room and changing the layout in the model accordingly. In Task 4, participants were asked to use the MR input widget to leave comments on any of the elements in the model they had problems with.

7.1.2 Procedure and Design

Participants performed the tasks individually at this round of experiment (Round 1). Each participant was asked to complete the sequence of the four tasks described above. They were given as much time as needed to complete each task and were free to ask questions about the system to the experimenter. Each task presented a different function or interaction method of the MRM platform, including performing and describe participant's own activities in the LCW by dragging the figure (avatar) in the interior model, typing specific text in a corresponding position of the physical widget in the virtual model and change the layout in the virtual model through picking and placing physical objects. When the participants finished their tasks, they were interviewed by the experimenter to gather their opinions and experiences on using the MRM system. Once the interview was completed, participants were also asked to complete a post-study questionnaire which asked participants to assign an overall rank to each of the different interaction metaphors and some questions about their opinions on possible smart-environment technologies. The participants rated the ease of use of each interaction metaphor, using a 5-point Likert-scale(1=totally agree, 5 = totally disagree). During the study, participants' interactions were observed by the experimenter who took notes about their interaction with the Mixed Reality Model during the experiment.

7.1.3 Results

Each experiment with an individual participant has generated a set of data which includes sequential models and annotations attached to the objects in the LCW model. These scenarios saved in the virtual model can become messy and difficult to be interpreted. In order to document the scenarios a structure is needed. The PACT framework (people, activities, contexts, technologies) is used to critique scenarios collected from the experiment [1]. In this section, we provide the example scenario for documenting the data from the experiment with the student. And the scenario document for other experiment participants are provided in the appendix.

SCENARIO(Student)

Tile

'How does the student work in the LCW?'

Scenario type

Activity scenario

Overview

People = Xinzhu Zhu, a male student, MArch course.

Activities = Using the facilities in the LCW to cut model parts

Context = the LCW (Laser Cutter Workshop) with laser engraver unit and workbench for model fabrication. A PC station and fume extractor system are also equipped as an accessory system.

Technology = the laser engraver unit and PC.

Rationale

The substantive activity here is the whole workflow that the student performs to complete the laser cutting task. The detailed descriptions of each step of the workflow are provided and structured as UML styled sequential model as Figure 6.9 below. Some usability problems identified by the student are also described.

S1: Switch on the computer and load the EPS file and open the software CorelDraw and send the file to the laser with epilog software.

S2: Switch on the equipment and focus. Close the lid and load the material and go back the PC.

S3: Switch on and monitor the laser cutting progress. Once finished switch off the laser cutter.

S4: Check cutting complete and remove the material then switch the machine off. Clean equipment, tidy the area ready for next user.

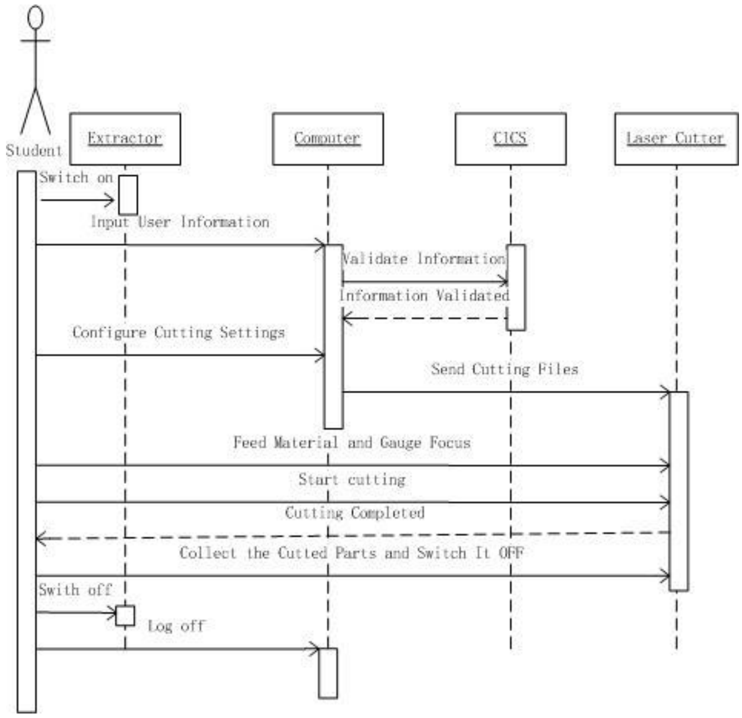


Figure 7.1 The UML model of the student's activities in the LCW produced from the data generated in the virtual space and the recorded videos.

Comments attached in the model by the student

C1: Working on large models is difficult to move around in the room. So the door can be opened automatically or simply a bigger door, or single side door.

C2: The arrangement between the computer and laser cutter is good, because you can simultaneously look at the digital model and the progress or your physical model.

C3: The working bench is directly face to the sun, so the working plane is over lit. It causes a glare, so rearranging the position of the bench or adding a shutter might be helpful.

C4: As we said, when you sit down, you can look out. Your eye level is right above the kind of sitting. It's quite nice for view.

C5: Maybe it needs a ventilation fan for the room.

C6: On the wall behind the laser you could put on instructions. Currently, the instruction brochures are left on the computer table. I think a display on the wall right above the laser cut machine is more convenient.

C7: What would you do when you need support in this space? Currently, getting technical assistance is done by getting out of the room and ask help from specialist.

C8. This MRM model is a lot of fun. You can even how to arrange the furniture. I can even imagine if this model is my house. I can discuss the arrangement with my girlfriend or it would be a really good experience.

C9. I did notice that there is some furniture missing. My concern is the user as me is still a bit too dimensional also it can move my view up and down when it is a more complicated model it would be nice to move across the level and look down and up so that would be a more realistic human feeling. Above that it's amazing.

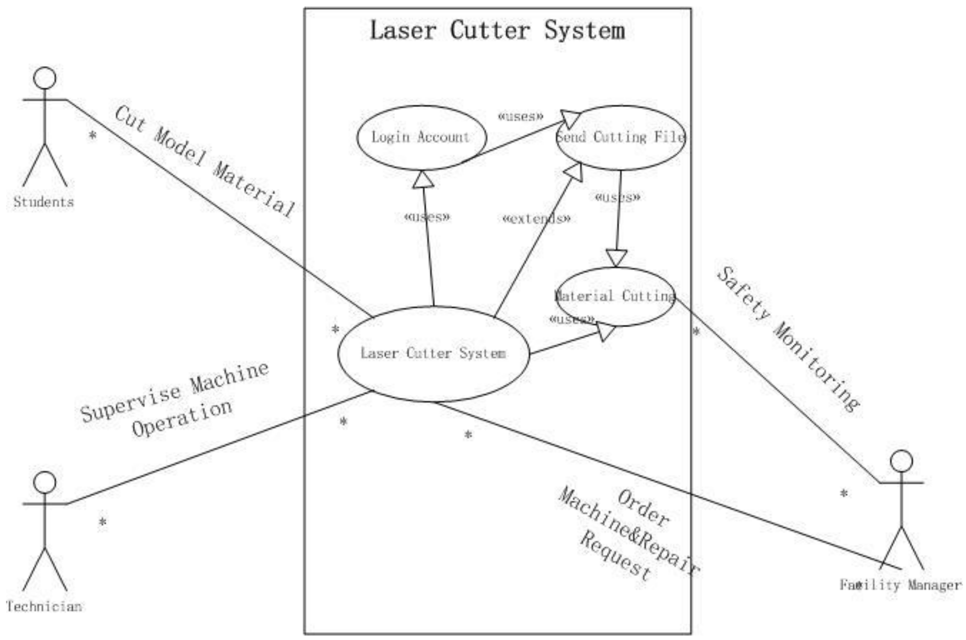


Figure 7.2 The system of the LCW with multiple stakeholders based on the scenarios produced on the Mixed Reality Platform from the experiments.

7.1.4 Questionnaire

A post-experiment questionnaire asked the participates to consider some of the possible smart environment technologies that may be applicable in the future design as shown in Figure 6.3.

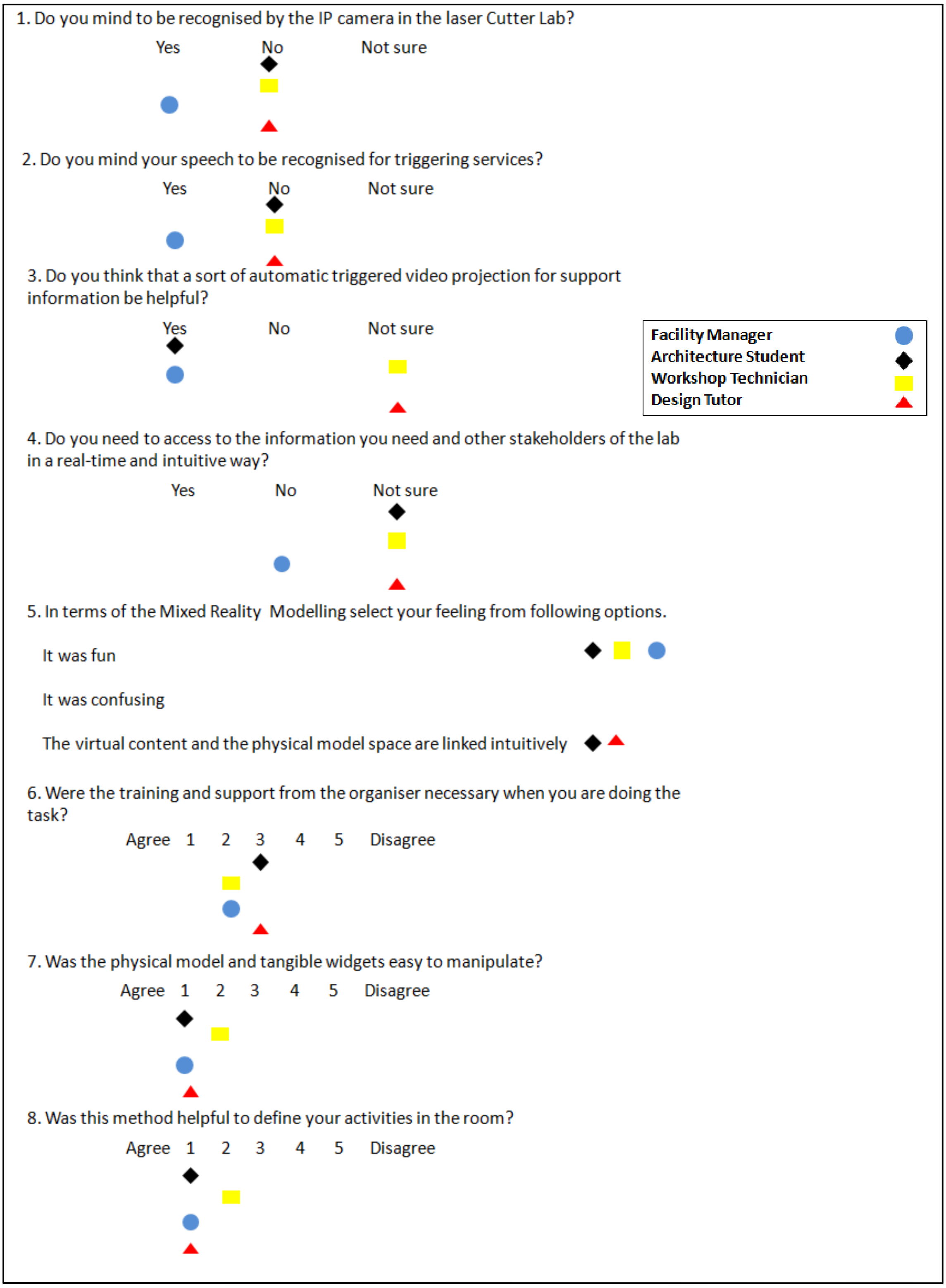


Figure 7.3 Participants responded to questions for further creation of AmI scenarios

Overall, participants responded very positively to the MRM system. All but one participant rated the platform negatively. Most participants also found the interactive physical interior model metaphor highly useful for recalling and visualizing their routine activities in the LCW and related issues. Only one person reported preferring a conventional user study method. Participants also liked the look and feel of the mixed reality l interface; none of the participants had problems with using the platform after only a little verbal remind and thought that the system was easy to use. However participants sometimes lost their orientation within the physical model while concentrating on the virtual content. Participants also created their own techniques to interact with the model during the experiment.

7.1.5 Observation from the experimenter (researcher)

The results of observation of the experiment reveal that the mixed reality modelling can basically achieve the tasks for user context inquiry and work modelling context inquiry and work modelling. However, a number of problems about the current prototype system design revealed by the experiment in this round are discussed as follows:

1. Physical models and their coupled virtual content should be calibrated precisely. It sometime confused the participants and interrupt the experiment process when the digital information was out of sync with participants' gesture on the physical objects. The orientation of the marker on bottom of the navigation figure must lineup with the orientation of the digital avatar.

2. A step by step demonstration/training before the experiment is required, interferences from the researcher during the experiment often distract participants from immersion of the demo. A video tutorial could be considered for non-expert participants. And a set of videos projected prompt signs for the components inside the physical model is also needed.

3. When put two features in the scene, a question about which one is used to control the navigation in virtual reality were asked by two participants.

4. For the analogue model in the Unity3d engine lacking a skybox wraps the space reduced the quality of participants' user immersive experience.

With the data from these experiments we will develop AmI solutions to make the LCW to be intelligent in the next chapter. The proposed solution will consist of a set of AmI scenario design together with conceptual implementation technologies. The AmI scenarios refers to those scenario-based systems programmed to perform intelligent actions triggered by sensing and reasoning system.

7.2 Experiment Phase 2

7.2.1 Participants' Tasks

Participants were asked to perform different types of user experience tasks depending on their relationship with the LCW.

User study Scenario 1

In this scenario, a new student without any experience of the LCW will go through the basic operational workflow of cutting material using laser engraver. The AmI systems in the smart LCW will be triggered by the user's interaction on the MRM platform.

Roles and tasks:

Architecture student: pick up the student figure and put it at the centre of the physical LCW model. Then drag the figure around to see what would happen on the MRM platform. The interactive information from the smart projection is supposed to guide the student to complete every step according to his action.

Technician, Facility Manager: Observe the student's interaction with the smart LCW on the MRM and comment this AmI scenario from their perspective.

After the student completes the operation tasks, all the experiment participants are requested to have an open discussion about this AmI scenario on the MRM platform.

User study Scenario 2

This scenario contains two parts: 1) An experienced student accidently started to operate the laser cutter without switching on the fume extractor. 2) Technician and facility manager test the smart bin scenario together.

Roles and tasks:

1) Student: Pick up the student figure and drag it in front of the laser engraver model directly. And then move up the blue toggle on the tangible control panel which represents the switch button on the laser engraver.

Technician and Facility Manager: Stand in front of the remote PC monitor in their office(the laptop on the tripod stand in this experiment) to see what will happen after the student's action and are provided with a option to launch a video chat through the smart projection in the LCW's model(Click 'C' to establish a video connection).

After completing this scenario, the participants are requested to have a open discussion of this AmI scenario and then fill a questionnaire.

7.2.2 Procedure and Design

Five participants (see Figure 6.4)with the experimenter performed the workshop around the MRM platform. After a brief introduction by the experimenter each participant was asked to complete the two user experience tests as described above. They are allowed to ask questions and seek supports when performing tasks. Each user experience test presented a specific AmI scenario of the smart LCW, the student and technician staff completed the experience of these interactive scenarios with the support of the scaled and semi-immersive MRM interface. After the participants were finished with their tasks, they were requested to have an open discussion about their opinions and experiences on the MRM prototyped smart LCW. When the discussion and brainstorm were complete, a post-study questionnaire which is used to evaluate the participants' acceptance of the MRM prototypes and their understanding degree of the AmI scenarios. In the first half part of the questionnaire the participants rated the ease of using the MRM prototypes to experience AmI designs and the necessity of physical and digital representations within the MRM prototypes. Besides the initial introduction of the intention of the workshop the experimenter observed participants' interactions with the MRM prototypes and took notes about the design and technical status of the MRM platform.

Figure 7.4 The video recordings from three different perspectives of the participatory workshop.

7.2.3 Results

Experiencing, understanding and evaluating the AmI scenarios of the smart LCW was facilitated by the possibility of interacting with scaled MRM based prototypes to simulate the dynamic reality. For instance, a participant experienced the smart floor by dragged around the physical figure in the scaled model whilst the camera inside the table were tracking the marker on the bottom of the physical figure constantly. Then the data projection on the physical model and actuators of the prototypes started to react to the position of the physical figure according to the pre-programmed AmI service. The corresponding virtual reality view provided simultaneous first person view for display the details and interactions which cannot be represented on the physical interactive model. The physical interaction in a bird view and the virtual interaction in a first person view worked correspondingly to evoke the impression of physically experiencing in the smart LCW. Remarkably, participants as stakeholders of the smart LCW gathered together to evaluate and discuss the AmI scenarios prototyped by MRM approach, with an emphasis on inspecting the AmI design from multiple perspectives and enacting their own ideas of future AmI design. The MRM platform acted as a mediator to allow stakeholders to gesture, comment and visually modify what was on the AmI prototypes on the MRM platform.

7.2.4 Questionnaire

The overall feedback of participants on the MRM approach are very positive. However, most participants found that more prior training of using the MRM platform are needed given the complexity of the setting on the tabletop. All of them strongly agree that interacting with MRM prototypes of the smart LCW is helpful to understand and give feedback on the proposed AmI scenarios (rating it 'strongly agree'). Most participants liked the physical interactive model on the tangible table because they think that it connects the user with virtual model in a first person view and allows physical interaction within it. Only the technician reported that physical interactive model on the tabletop can sometime cause confusion between VR and physical world to understand the AmI scenarios. They also think that the corresponding virtual environment displayed on the TV monitor is necessary as it can give a strong immersive experience to the user. Although participants thought the prototypes of the AmI scenarios were easy to be interacted with they still recommended to add more direct clue for guiding them towards next interaction steps. The second part of the questionnaire is a set of questions to test participants' understanding of the AmI scenarios. They are asked to select what would happen after specific user behaviours in the smart LCW. The results of their answers reveal that all of them had possessed basic AmI service knowledge to work within the smart LCW.

F	Facility Manager
A	Architecture Student
T	Workshop Technician

1. A lot of training and support is necessary for participants to experience the proposed smart scenarios using the Mixed reality Approach?

Strongly agree				**Strongly disagree**
1	2	3	4	5
	T	**F**	**A**	

2. This prototype approach is helpful to understanding and giving feedback on the smart scenarios proposals

Strongly agree				**Strongly disagree**
1	2	3	4	5
T, F,A				

3. The physical model is necessary to be in the system for facilitating the understanding of the smart environment design.

Strongly agree				**Strongly disagree**
1	2	3	4	5
F,A		**T**		

And why do you think so?

:

T- Can sometimes cause confusion between VR + Physical World

F-It connects the user with the virtual model and allows interaction with the equipment

4. The virtual reality is necessary to be in the system for facilitating the understanding and discussion of the smart environment design.

Strongly agree **Strongly disagree**

1	2	3	4	5
T,F,A				

And why do you think so?

:

T-More can be seen with what would happen whilst interacting with the smart environment

F- It gives a strong visual experience to the user

5. What would happen if you touch any of the material in shelf in this lab?

- ❑ Alarm being triggered
- ❑ Recommended setting of this material being projected on the wall **T, F,A**
- ❑ The door open

6. Which actions would happen if the user in the lab breaks the operation rules?

- ❑ The window would shut down automatically
- ❑ Alarm light would be on **T,A**
- ❑ The computer would be switched off

- ❑ The alarm buzzer would be on **T, F,A**
- ❑ Images from IP cam would be passed to the technician's office **T, F**

7. For a new student how could he get operation instructions for using laser cutter lab?

- ❑ Check the manual on the computer in the Laser Cutter Workshop
- ❑ Walk to any spot in the room which needs information for this spot **T, F,A**
- ❑ Break any instructions or rules of Laser Cutter Workshop

8. What was your experience of the physical computing interaction(e.g. buzzing, dynamic window door etc)?

- ❑ It was interesting **A**
- ❑ It was confusing
- ❑ The virtual reality and physical interactions were intuitively connected **T, A**
- ❑ They are helpful for understanding the scenario proposals **T, F, A**

9. Any other comments:

T- More instruction for Scenario 1 required

F- Walking into the room, the system could give a fine example of what the student is going to expect, to give a better picture of equipment inside the virtual environment.

AmI system could go beyond the classroom, probably be used in hospitals, also new staff to the university would have a better understanding of the new work environment and what/how to operate the equipment they are about to work use.

A-I would suggest adding audio instructions in addition to projected instructions

It was great and really an interesting experience using a physical model to control the virtual environment

It was really clever and inovative detecting the movement of someone's ID and keeping track of the movement for changing each instructional step on the screen.

7.2.5 Open Discussion of the AmI scenarios of the smart LCW

7.2.5.1 Group Discussion of the AmI Scenario 1

Key point of the facility manager: still there's a little glitch, but the AmI scenario is very good. Actually, if you were there you will see that was working. Is that possible for demonstrating the smart projection on a big screen? An additional screen to display the information on the smart projection just for demonstration purpose. I know in reality the projection on the well is what you will look at if you were in the room. For a scaled demonstration, I couldn't see from the back of the participant who are working on the MRM platform. For a demo set up. on the wall maybe on a big screen would be better. that's possible. For step by step interaction maybe put a cross if things were wrong, remind the participant to go back and redo it or retouch this if it didn't work. I think somebody still comes in absolutely not know anything about that specific room or area and struggles with the instructions. I think the prototype still needs more instructions. As to the different touch the materials: you could ask questions : do you want to cut card, MDF, acrylic? if so, touch shelf A, B, C. great to break it down to more specifics rather than just general walking in the room and people cannot just looking around. I think need more instructions in depth. you can't assume that people will follow the guides naturally.

Key point of the technician: so the videos comes up with telling you what to do. Put a tick function on the screen in the corner to confirm the user's operation. You can't assume the user can interact with the AmI scenario naturally. they always do things different to what you tell them. A user stand in the middle when the user come in the room, instead of step by step instruction when you move to each point you can maybe give an overview like a Powerpoint slide to go and then you could do a video of this point . Any audio? could that help? Even for this demo, it is not necessary. But for the real environment.

Key point of the PhD student 1: agree with an additional screen because there are lots of the instructions and videos. And I think audio instructions would be helpful. For designing school with children with physical modelling, I don't think MRM would practically go well. I mean, let's just say, it needs a lot more protection, or things will just go everywhere. so I wouldn't use them under 12 years old. My experience with models and instead in the way of experimenting and trying things not limiting to what you tell them, otherwise it has a lot of potential .

Key point of the master student: If it was me, I would try to put the physical model outside the room, the user could use it before they enter a real workshop. Because just by using the physical model by hand they memorize in brain how to use when you go in. It likes that you are doing a presentation of your physical model. So I think it would help a lot to have this model before you go inside the room: do the exercises first. then working in the room to do the real work.

7.2.5.2 Group Discussions of the AmI Scenario 2

Part 1: smart security monitoring

Key point of the technician: I like the idea that we can sit in our office and see instantly as soon as it flags up the problem before we have smelled it or hear something like that. So you can know all of them in the same room when things go wrong in the workshop. Could it be done with mobile as well. so if we walking around the whole material workshop the real time video of the LCW can go to phone. So could have a remote switch to allow me to turn the laser or any related equipment off. we wanted to book a camera in the LCW to watch, keep an eye on for the safety reason like what exactly you try to do. But because the policy of the university we told we couldn't use the CCTV in the LCW. It had to be done from security department, they have to do their own cameras and control them by their department. So it could come up with issues like that. In the industry environment obviously that is not going to be a problem. For the responses of the alarm , it could just activate the video saying turn on the extractor and turn on the air system . Could have audio maybe , so you can speak to the user in the LCW directly.

Key point of the facility manager: so could you have the systems switching things off remotely? Such as witching laser cutter off. When student uses the machine wrong, sets the alarm, you can push on to shut down the machine. This smart video system is very practical, good practical use for life safety and risk. Would it be ok to monitor people, is it a class of surveillance? Maybe just activate the tele-video image when the alarm going off. not running in the rest of the time. If the alarm goes off it triggers the windows open, just have it specifically for that emergency.

Key point of the master student: I like the idea about to window' opening because if it's firing or something nobody can open that fast. I like the tele-instruction from the technician. Because I've never use laser cutter before, so I think if I had the guider to find my mistake it would be very helpful. I wouldn't feel my privacy is been exposed because I'll feel safe if I know someone is watching (specially the technician himself, because you don't need to introduce yourself when something goes wrong. we can be alert and call paramedic if we can be informed automatically.)

Part 2: smart bin

Key point of the facility manager: Again coming back to the instructions, the bin could come up with audio like: this is the wrong bin, please... maybe the bin with voice, bin can speak. Like the electronic lift. Some audio instructions like: this is the wrong bin, use the other one. I think if you want to take it extend after the classroom, to take it to the hospital, because it is a good idea to save patients' life like that.

Key point of the master student: audio would help tremendously, I mean that people they don't like to read.

CHAPTER 8 CONCLUSION AND FUTURE WORK

8.1 Conclusion and Contributions

We conclude from the results of two rounds experiments that the MRM approach is effective to provide stakeholders a communication platform for the participatory design, which enables participants to contribute to the contextual design and interact with the AmI scenarios. In this thesis, we explored participatory design of AmI with MRM approach in an architectural context. Literature review confirmed the lack of prototyping and communication technologies for involving stakeholders in the design of AmI and the potential of employing mixed reality to support AmI design. Mixed Reality Modelling based participatory design approach is proposed and tested to develop a smart laser cutter workshop.

The research objectives have been achieved as following:

General objective: To identify a novel participatory design approach for communicating Ambient Intelligence Scenarios:

The experiments data has demonstrated that non-professional stakeholders can be involved into the conceptual design process of smart environments effectively with the support of MRM approach. The MRM platform based participatory design approach has successfully integrated context investigation, concepts prototyping and user experiencing and evaluation of smart environments scenarios.

Specific objectives:

To indentify the requirements to participatory design of Ambient Intelligence:

The literature review work suggests:

- Needing to collect spatial data such as the layout of the room, geo-positions of the furniture and equipments and information of the artifact in the room. Besides these, designer needs to collect invisible data such as space users' daily tasks and behaviours in this specific room at in different time.
- The representation and experiencing of AmI scenarios require a interactive communication technology which could provide real-time feedback from AmI system.
- The mock-up of real space from full-scale room to scaled model can help to facilitate the communication of AmI scenarios among end users.
- The service models of AmI needs to be translated to a universal language to be communicated between stakeholders.

To establish a framework of mixed reality modelling approach:

In chapter 4 we proposed a MRM based participatory design framework which includes context investigation, design brief, 3D interactive prototyping and participatory evaluation and discussion for AmI design.

To develop an experimental mixed reality modelling platform to evaluate its feasibility to support the design communication of Ambient Intelligence:

Based on the proposed framework we developed a Mixed Reality Modelling platform on which design team could carry out context interview, prototyping AmI concepts and group evaluations. Then we use the LCW in the SSoA as a real case to evaluate the MRM approach.

To evaluate the effect of mixed reality modelling approach on supporting Ambient :

Intelligence design by participatory experiments for designing a laser cutter workshop with focus stakeholders

In experiment phase one stakeholders provided sufficient and effective behaviour data and preference of AmI concepts through interacting with the MRM platform. Experiment phase two allowed different stakeholder use the MRM platform to experience and evaluate specific designed AmI scenarios for different roles. After the group experiment the investigate also organised the stakeholders to have an open discussion about the smart LCW on MRM.

To analyse participatory experimental data and collect the stakeholders' feedback:

The observation of the experiments and the feedback from the participants demonstrate that MRM based AmI design approach is able to support the design communication between stakeholders with different background. The stakeholders can understand and interact with AmI scenarios effectively on MRM platform. MRM approach is also proved to be an inspirational tool to help stakeholders to propose their own AmI ideas.

8.2 Limitations and Future Works

According to the observations and analysis of the two rounds experiments, the MRM platform lacks of capabilities to prototype participants' immediate idea of AmI on it. For example, one participant mentions that he prefer to natural audio instructions rather than reading texts on the projection. And the manager of LCW also suggested a video talking system when accidents happen in the LCW. Currently we just document these new ideas with video camera for next design iteration. If participants could prototype their own AmI ideas just through dragging and dropping models and objects on the tabletop,   the participatory design process could be accelerated. And the involvement level of the stakeholders deepen. This real time feedback to the participants' ideas is expected to inspire their passions of creation and be helpful to enrich the knowledge base of the smart LCW.

In this work the knowledge engine of the LCW assumes only one user will appear in the LCW. And all the AmI scenarios only serve for this individual. However, in real user scenarios there are many chances the LCW are used by more than one person. For instance, the previous user of the LCW remains in the room when next user walk in. Or the user come to work in the LCW with his fellow students. Due to the time limit of this project, we have not carry out any research about the potential clashes between different AmI services for different person in the LCW. Therefore, in future work how to coordinate concurrent multiple AmI services in the LCW should be investigated.

Based on current MRM approach, AmI scenarios for other architecture function spaces such as kitchen, patient room could be developed and evaluated through participatory workshop on MRM platform. With the increase of AmI service scenarios a MRM based AmI scenario library could be built as references for designing other smart environments projects.

APPENDIX : RAW EXPERIMENTAL RESULT

Appendix 1 Audio Transcripts of the Participatory Workshop

Facility Manager: still there's a little glitch, very good. I like the way you were walking with the man like , you were really good into that. Actually, if you were there you will see that was working. For a demonstration that on the big screen is that possible? Everybody cannot do like this. otherwise, two screens you could. side by side. Just for demonstration purpose, maybe. All right, I know in reality that's what you will look at if you were in the room. For a demonstration, I couldn't see from the back there. You know just for a demo set up. on the wall maybe on a big screen. that's possible. otherwise if two screen were called . And maybe you could put a cross if things were wrong, go back and redo it. retouch this if it didn't work. I think somebody still come in absolutely not know anything about that specific room or area. and struggle with the instructions. I think still need more instructions. As to the different touch the materials: you could ask questions : do you want to cut card, MDF, acrylic? if so, touch shelf A, B, C. great to break it down to more specifics rather than just general walking in the room and people cannot just looking around. I think need more instructions in depth. you can't assume that people will follow the guides naturely.

I'd like to see when you put the extractor look the fan coming on and something like that

Technician: so the videos comes up with telling you what to do. so on the last one, you do the extraction/instructing and settings, but the last one just say to get (it) out. what is the focus? the focus is that all the information is in the video from the front.

Put a tick on the screen in the corner, and that on the screen.

can't assume. they always do things different to what you tell them. I mean you can do. when you stand in the middle when you come in the room, instead of step by step instruction when you move to each point you can maybe give a picture of word to go and then you could do a video of this point . like a power point presentation. For actual changes once she looks at it just give her an overview

Any audio? could that help? Even for this, it is not necessary for the real environment

PhD student: agree with an additional screen because there are lots of the instructions and video b. And I think audio instructions.

For designing school with children, I don't think it would practicelly go well. I mean, let's just say, it needs a lot more bulet proof and secure, or things will just go everywhere. so I wouldn't use them under 12 years old. My experience with models and instead in the end you know experimentation and trying things not limiting to what you tell them, otherwise it has a lot of potential

Master student: If it was me, I would try to put the physical model outside the room, the user could use it before they enter it. Because just by using the physical model by hand they memorize in brain how to use when you go in. It like you are doing a presentation of your physical model. so i think it would help a lot to have this model before you go inside the room: do the exercises first. then working the room. to do the real work

Scenario 2 (Part 1):

Technician: I like the idea that we can sit and see instantly as soon as it flags up before we have smelled it and hear it something like that.so you know all of them in the same room. Could it be done with mobile as well. so if we walking around the workshop, so it goes to phone. you can an app whatever in your phone.

so could you with the laser for the laser you can could just have a plug through , thing like light life switch then. so the last result to turn it off.

survellience.

well it could be classical ? CCTV, because the policy of the university. we wanted to book a camera in to watch, keep an eye on for this reason what exactly

you try to do. we told we couldn't.

it had to be done from security, they have to do their own cameras. so it could come ups with issues like that.   in the industry environment obviously that's not gona to. cause you want to prototype examples for other workshop not neccessary here.

for the rest of the clicks, it just activate the video saying, turn on the extractor. turn on the air system

could have audio maybe , so you can speak to them without replyphy, that could get around where there are issues

Facility manager: so could you have the systems swithing things off, swithing laser cutter off, swithing the computer, swithing the power. when student use the drill was wrong, sets the alarm, you can push on to shut down the machine.

yeah, very practical, good practical use for life safty and risk. would it be ok to watching you know monitoring people, is it a class of survelliance survellience?

It's funny you should say ,the last coming hour we got a new factory they put cctv camera up, you know, like productive department , warehouse, that people complaint that invaded their privercy. but they are arguing because it's security, you don't want people to steel stuff. similar to security reasons.

Maybe just activate when the alarm going off. not running in the rest of the time. If the alarm goes off it triggers the windows open, just have it specifically for that emergency plan

student: I like the idea about to window' opening because if it's firing or something nobody can open that fast. I like that the interaction instruct the user, because I've never use laser cutter before, so I think if I had the guider to find my mistake, would be very helpful. assuring that somebody watching. That I wouldn't feel my privacy is been exposed because I'll feel save if I know someone is watching (specically the technician himself, because you don't need to introduce yourself when something goes wrong, straight alarm, I just open the window if it got the fume coming out. we can be alert and call paramedic if we can be informed automatically.

Scenario 2(Part 2)

Facility manager: again coming back to the instructions, for like it open comes up with, : this is the wrong bin, please... maybe the bin with voice, bin can speak. like the lift. something like that. this is the wrong bin, use the other one.

I think if you want to take it extend after the classroom, to take it to the hospital, because it is a good idea to save patients' life like that.

Student: audio would help tremendously, I mean that people they don't like to read.

8.1 Conclusion and Contributions

We conclude from the results of two rounds experiments that the MRM approach is effective to provide stakeholders a communication platform for the participatory design, which enables participants to contribute to the contextual design and interact with the AmI scenarios. In this thesis, we explored participatory design of AmI with MRM approach in an architectural context. Literature review confirmed the lack of prototyping and communication technologies for involving stakeholders in the design of AmI and the potential of employing mixed reality to support AmI design. Mixed Reality Modelling based participatory design approach is proposed and tested to develop a smart laser cutter workshop.

As laid out in Section 1.4, this thesis makes the contributions which can answer the research question and hypothesises raised in section 1.3 as following:

- Identification of a novel participatory design process for developing AmI scenarios of existing architecture spaces.
- Identification of the requirements to support prototyping of AmI design, resulting in a conceptual framework that both "lowers the floor" (i.e. making it easier for designers to build the AmI prototypes) and "raises the ceiling" (i.e. increasing the ability of stakeholders and end users to participate in the design process deeply).
- Prototyping an state-of-the-art experimental Mixed Reality Modelling platform to facilitate the participatory design of AmI which supports the user study, design process, and scenarios prototyping.
- Case study of applying MRM approach to participatory design of a smart Laser Cutting Lab which used to evaluate the proposed MRM based AmI design approach. The result of the research shows that the MRM based participatory design approach is able to support the participatory design of AmI effectively.
- Evaluation and discussion of various aspects of the MRM approach for AmI design.

Appendix 2 Consent Form and Questionnaires of the Participatory Workshop

Model Participant Consent Form

Title of Research Project: Communicating Smart Environment Scenarios with Mixed Reality Interface

Name of Researcher: Yang Yu

Participant Identification Number for this project: **Please initial box**

1. I confirm that I have read and understand the information sheet/letter (delete as applicable) dated *[insert date]* explaining the above research project and I have had the opportunity to ask questions about the project. R.C.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. *Insert contact number here of lead researcher/member of research team (as appropriate).* RC

3. I understand that my responses will be kept strictly confidential (only if true). I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. R.C RC

4. I agree for the data collected from me to be used in future research

5. I agree to take part in the above research project. R.C.

Roy Childs	5/11/15	R. Childs
Name of Participant *(or legal representative)*	Date	Signature
Name of person taking consent *(if different from lead researcher)* *To be signed and dated in presence of the participant*	Date	Signature
Yang Yu	5/11/15	Yang Yu
Lead Researcher *To be signed and dated in presence of the participant*	Date	Signature

Copies:

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/pre-written script/information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be placed in the project's main record (e.g. a site file), which must be kept in a secure location.

Date: Name of Applicant:

University of Sheffield

Model Participant Consent Form

Title of Research Project: Communicating Smart Environment Scenarios with Mixed Reality Interface

Name of Researcher: Yang Yu

Participant Identification Number for this project: **Please initial box**

1. I confirm that I have read and understand the information sheet/letter (delete as applicable) dated *[insert date]* explaining the above research project and I have had the opportunity to ask questions about the project. [SM]

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. *Insert contact number here of lead researcher/member of research team (as appropriate).* [SM]

3. I understand that my responses will be kept strictly confidential (<u>only if true</u>). I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. [SM] [SM]

4. I agree for the data collected from me to be used in future research

5. I agree to take part in the above research project. [SM]

Stuart Moran	5/11/15	[signature]
Name of Participant (*or legal representative*)	Date	Signature
Name of person taking consent (*if different from lead researcher*)	Date	Signature

To be signed and dated in presence of the participant

Yang Yu	5/11/15	[signature]
Lead Researcher	Date	Signature

To be signed and dated in presence of the participant

Copies:

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Name of Researcher: Yang Yu

Participant Identification Number for this project: **Please initial box**

1. I confirm that I have read and understand the information sheet/letter (delete as applicable) dated *[insert date]* explaining the above research project and I have had the opportunity to ask questions about the project. ✓
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. *Insert contact number here of lead researcher/member of research team (as appropriate).* ✓
3. I understand that my responses will be kept strictly confidential (only if true). I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ✓ ✓
4. I agree for the data collected from me to be used in future research
5. I agree to take part in the above research project. ✓

Michael Philippou	5/11/2015	[signature]
Name of Participant *(or legal representative)*	Date	Signature

Name of person taking consent *(if different from lead researcher)*	Date	Signature

To be signed and dated in presence of the participant

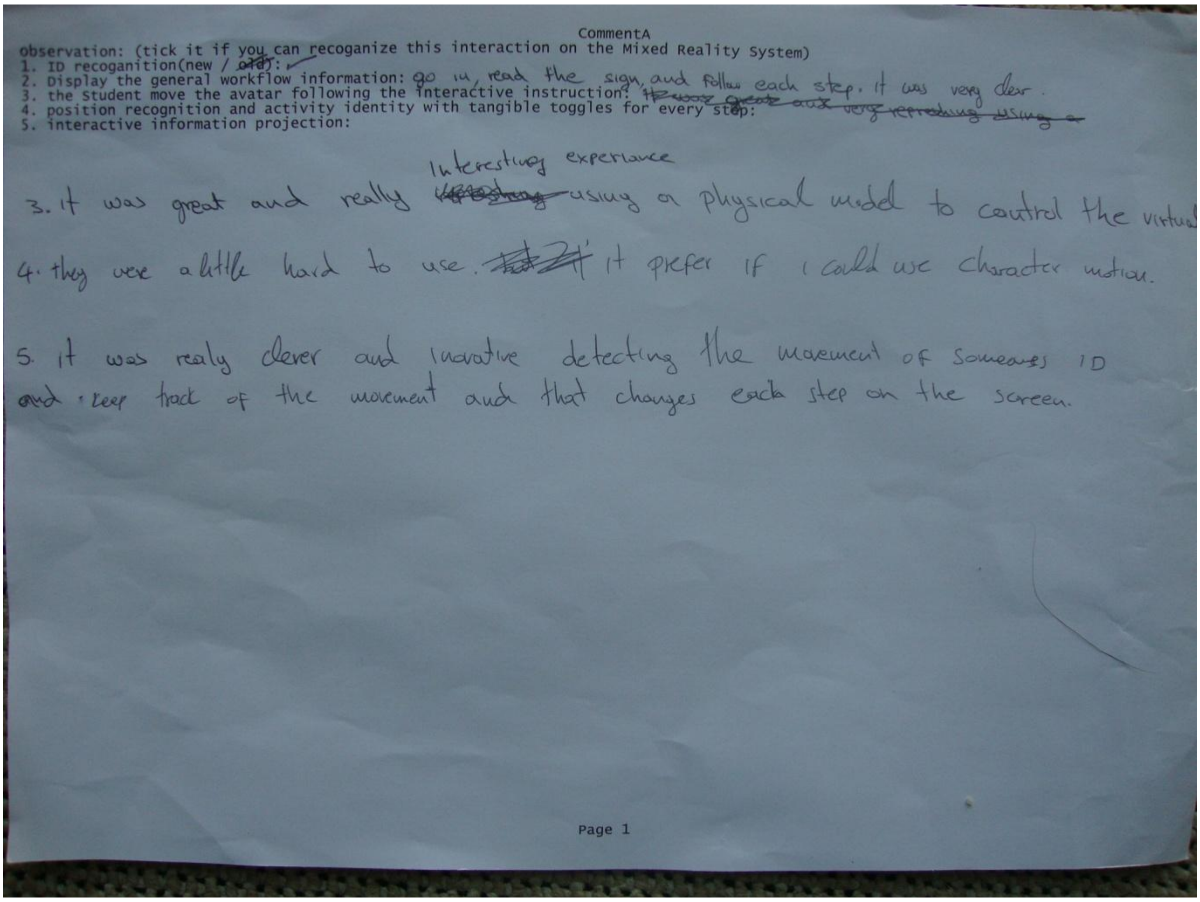
Yang Yu	5/11/2015	Yang Yu
Lead Researcher	Date	Signature

To be signed and dated in presence of the participant

Copies:

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/pre-written script/information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be placed in the project's main record (e.g. a site file), which must be kept in a secure location.

Date: Name of Applicant:



CommentA

observation: (tick it if you can recoganize this interaction on the Mixed Reality System)

1. ID recoganition(new / ~~old~~): ✓
2. Display the general workflow information: go in, read the sign, and follow each step. it was very clear.
3. the Student move the avatar following the interactive instruction: ~~It was great and very refreshing using a~~
4. position recognition and activity identity with tangible toggles for every step:
5. interactive information projection:

3. it was great and really ~~refreshing~~ Interesting experiance using a physical model to control the virtual

4. they were a little hard to use. ~~that~~ it prefer if i could use character motion.

5. it was realy clever and inovative detecting the movement of someones ID and keep track of the movement and that changes each step on the screen.

Page 1

Questionnaire

1. A lot of training and support is necessary for participants to experience the proposed Smart Scenarios using the Mixed Reality Approach.

Strongly agree | | | | Strongly disagree
1 | 2 | 3 | 4 | 5

2. This prototype approach is helpful to understanding and giving feedback on the Smart Scenario Proposals

Strongly agree | | | | Strongly disagree
1 | 2 | 3 | 4 | 5

3. The physical model is necessary to be in the system for facilitating the understanding of the smart environment design.

Strongly agree | | | | Strongly disagree
1 | 2 | 3 | 4 | 5

and why do you think so?

:

4. The virtual reality is necessary to be in the system for facilitating the understanding and discussion of the smart environment design.

Strongly agree | | | | Strongly disagree
1 | 2 | 3 | 4 | 5

and why do you think so?

:

5. What would happen if you touch any of the material in shelf in this lab?

. Alarm would be triggered
. Recommended setting of this material will be projected on the wall
. the Door would open

6. Which actions would happen if the user in the lab breaks the operation rules.
. The window would shut down automatically
. Alarm light would be on
. The computer would be switched off
. the Alarm buzzer would be on
. Images from IP cam would be transfered to the technician office

7. As a new student how can you get operation instructions for using laser cutter lab?
. Check the instructions from the computer in the room
. Walk to any spot in the room which needs information of this spot
. Break any instructions or rules of this room.

8. What was your experience of the physical computing interactions(e.g. buzzing, dynamic window door etc)
It was interesting
It was confusing
The virtual reality and the phsical interactions were intuitively connected
They are helpful for understanding the scenario proposals

9.Any other comments:

[redacted]

Questionnaire

1. A lot of training and support is necessary for participants to experience the proposed Smart Scenarios using the Mixed Reality Approach.

Strongly agree — Strongly disagree

1 (2) 3 4 5

2. This prototype approach is helpful to understanding and giving feedback on the Smart Scenario Proposals

Strongly agree — Strongly disagree

(1) 2 3 4 5

3. The physical model is necessary to be in the system for facilitating the understanding of the smart environment design.

Strongly agree — Strongly disagree

1 2 (3) 4 5

and why do you think so?

: Can sometimes cause confusion between VR. + Physical World.

4. The virtual reality is necessary to be in the system for facilitating the understanding and discussion of the smart environment design.

Strongly agree — Strongly disagree

(1) (2) 3 4 5

and why do you think so?

: More can be seen with whats would happen whilst interacting with the smart environment.

5. What would happen if you touch any of the material in shelf in this lab?

- Alarm would be triggered
- Recommended setting of this material will be projected on the wall ✓
- the Door would open

6. Which actions would happen if the user in the lab breaks the operation rules.

- The window would shut down automatically
- Alarm light would be on ✓
- The computer would be switched off
- the Alarm buzzer would be on ✓
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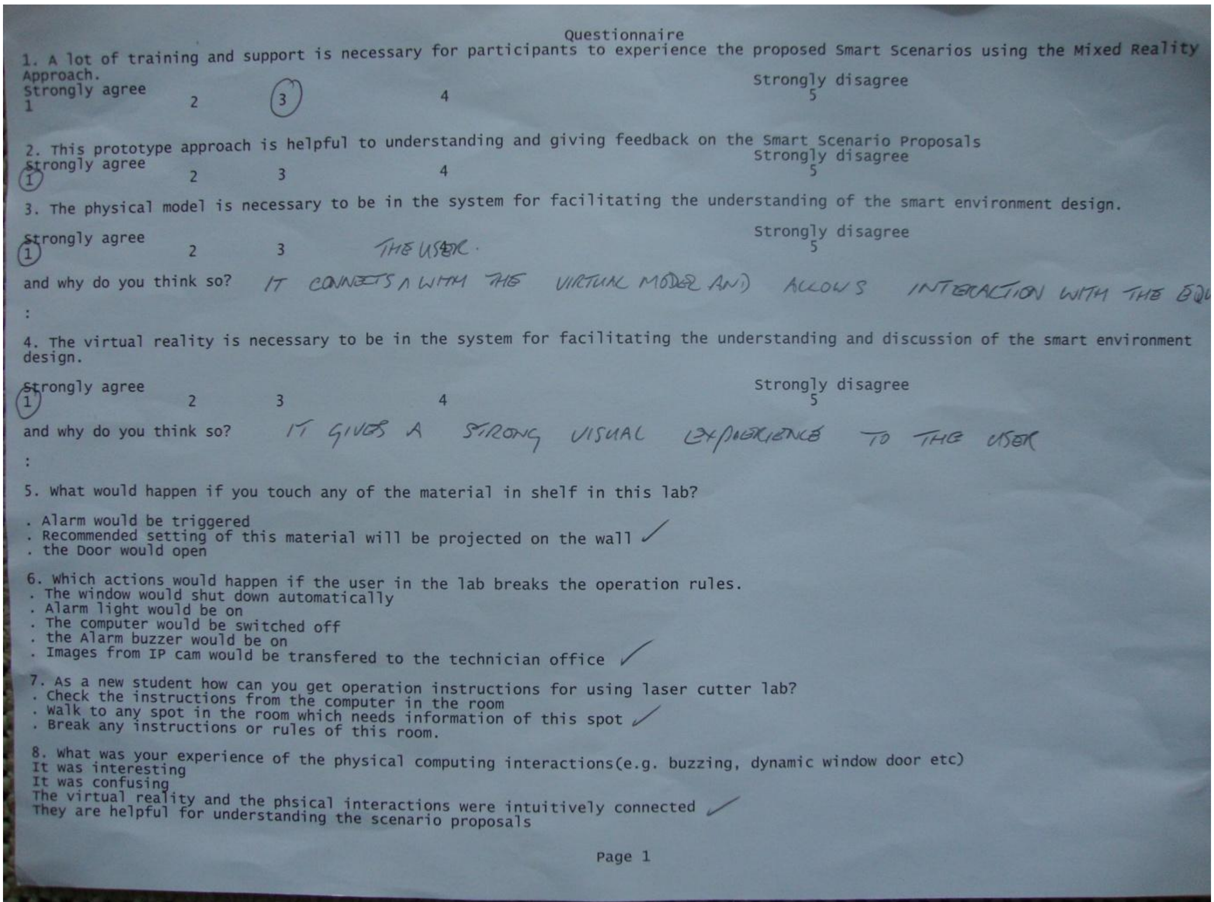
It was interesting
It was confusing
The virtual reality and the phsical interactions were intuitively connected ✓
They are helpful for understanding the scenario proposals ✓

Page 1

Questionnaire

9.Any other comments: MORE INSTRUCTION FOR SCENARIO 1 REQUIRED

Page 2



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Strongly agree 1 — 2 — (3) — 4 — 5 Strongly disagree

2. This prototype approach is helpful to understanding and giving feedback on the Smart Scenario Proposals

Strongly agree (1) — 2 — 3 — 4 — 5 Strongly disagree

3. The physical model is necessary to be in the system for facilitating the understanding of the smart environment design.

Strongly agree (1) — 2 — 3 — THE USER. — 5 Strongly disagree

and why do you think so? IT CONNECTS A WITH THE VIRTUAL MODEL AND ALLOWS INTERACTION WITH THE EQU

:

4. The virtual reality is necessary to be in the system for facilitating the understanding and discussion of the smart environment design.

Strongly agree (1) — 2 — 3 — 4 — 5 Strongly disagree

and why do you think so? IT GIVES A STRONG VISUAL EXPERIENCE TO THE USER

:

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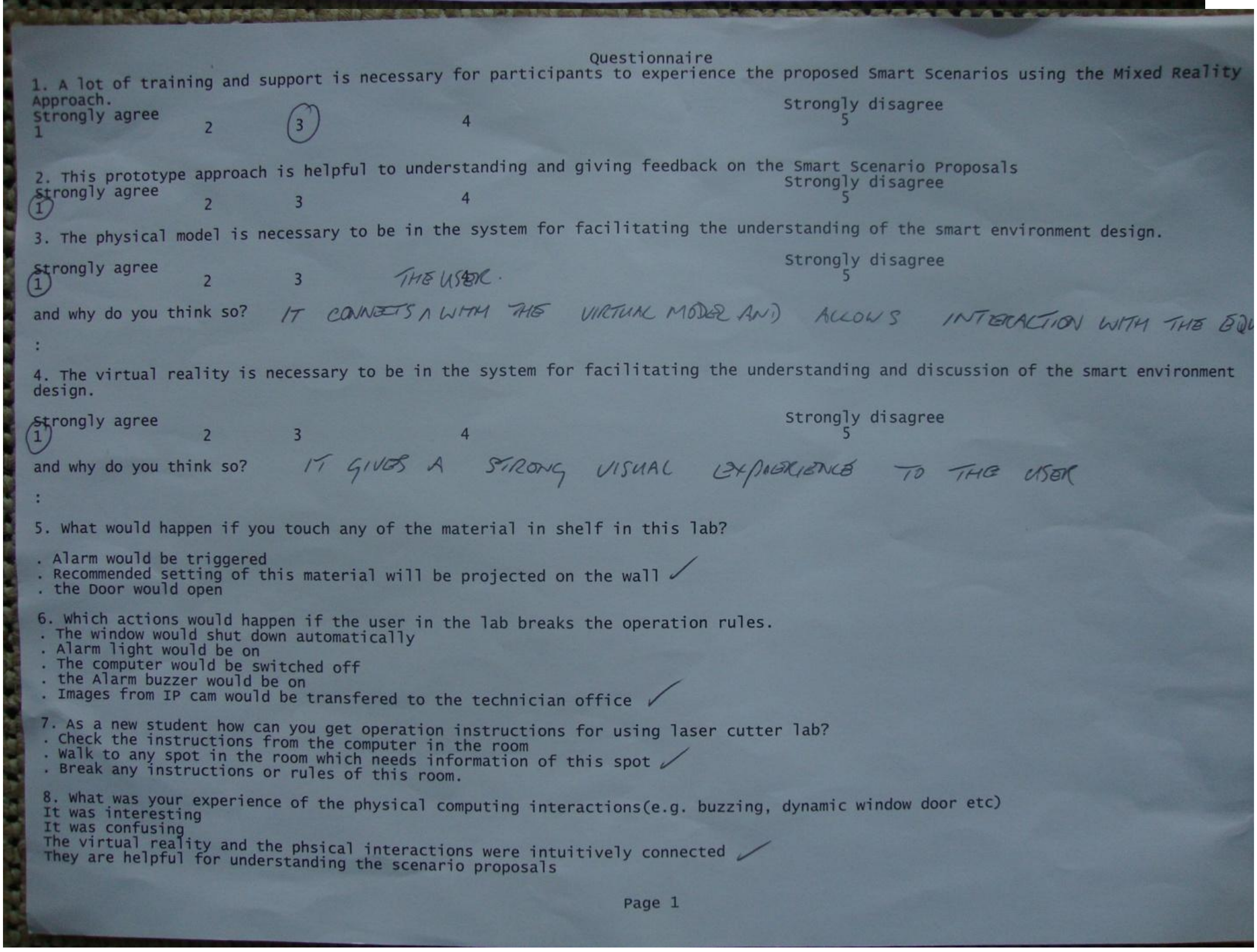
Page 1



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Strongly agree (1) — 2 — 3 — THE USER. — 5 Strongly disagree

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Strongly agree (1) — 2 — 3 — 4 — 5 Strongly disagree

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. The computer would be switched off
. the Alarm buzzer would be on
. Images from IP cam would be transfered to the technician office ✓

7. As a new student how can you get operation instructions for using laser cutter lab?
. Check the instructions from the computer in the room
. Walk to any spot in the room which needs information of this spot ✓
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8. What was your experience of the physical computing interactions(e.g. buzzing, dynamic window door etc)
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Page 1

Questionnaire

7. As a new student how can you get operation instructions for using laser cutter lab?

. Check the instructions from the computer in the room

. Walk to any spot in the room which needs information of this spot

. Break any instructions or rules of this room.

8. What was your experience of the physical computing interactions(e.g. buzzing, dynamic window door etc)

It was interesting

It was confusing

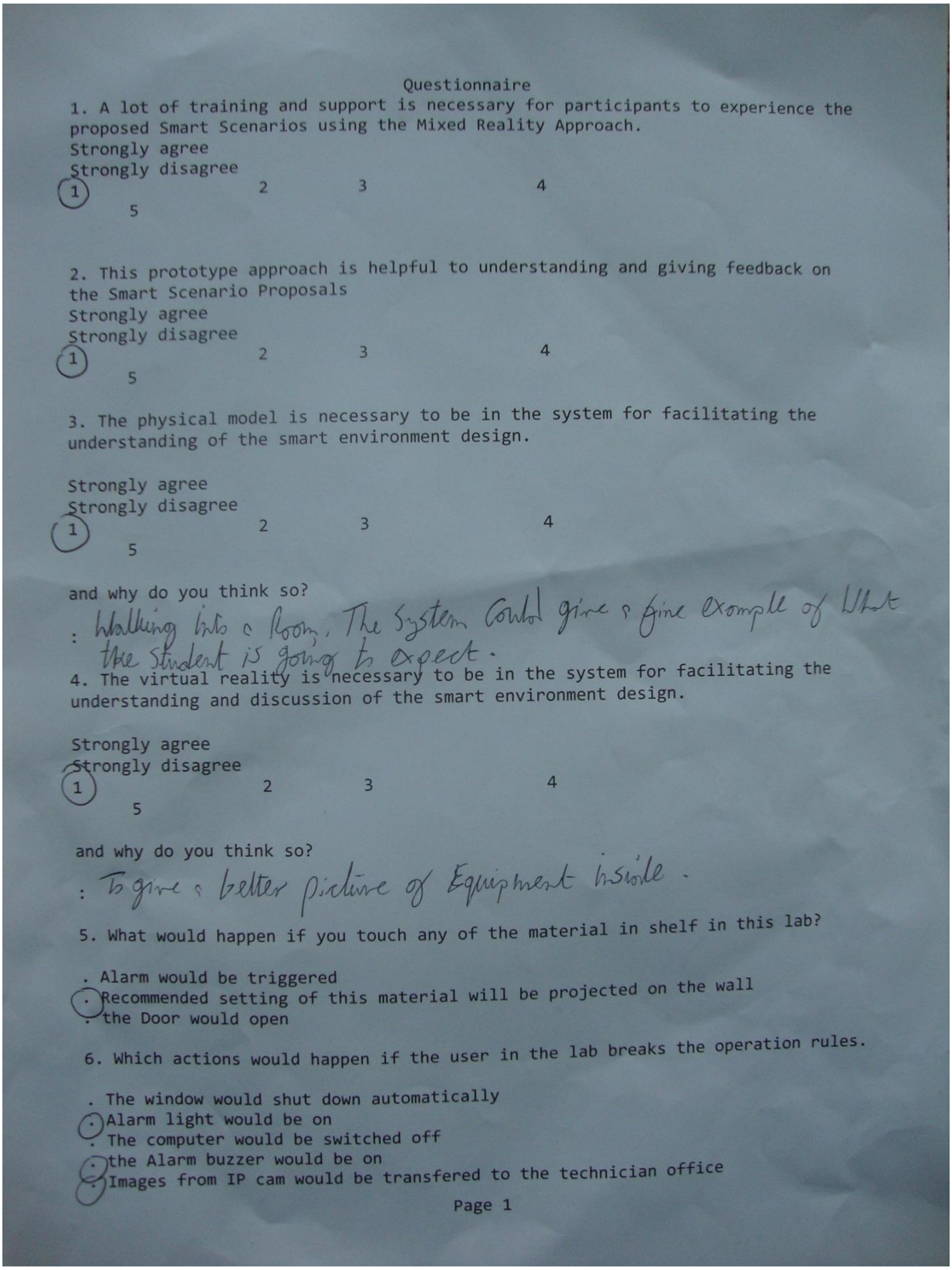
The virtual reality and the phsical interactions were intuitively connected

They are helpful for understanding the scenario proposals ✓

9.Any other comments:

Devices like this could go beyond the Classroom & probably be used in teaching Hospitals.

Also new Staff to the University would have a better Understanding of their new Work environment & What/How to operate the equipment they are about to work off/use.



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Strongly agree
Strongly disagree

(1) 2 3 4 5

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Strongly agree
Strongly disagree

(1) 2 3 4 5

3. The physical model is necessary to be in the system for facilitating the understanding of the smart environment design.

Strongly agree
Strongly disagree

(1) 2 3 4 5

and why do you think so?

: Walking into a Room, The System Control give a fine example of What the Student is going to expect.

4. The virtual reality is necessary to be in the system for facilitating the understanding and discussion of the smart environment design.

Strongly agree
Strongly disagree

(1) 2 3 4 5

and why do you think so?

: To give a better picture of Equipment inside.

5. What would happen if you touch any of the material in shelf in this lab?

. Alarm would be triggered
(.) Recommended setting of this material will be projected on the wall
. the Door would open

6. Which actions would happen if the user in the lab breaks the operation rules.

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Page 1

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