APPRAISAL OF AUGMENTED REALITY TECHNOLOGIES FOR
SUPPORTING INDUSTRIAL DESIGN PRACTICES

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ABSTRACT

APPRAISAL OF AUGMENTED REALITY TECHNOLOGIES FOR SUPPORTING INDUSTRIAL DESIGN PRACTICES

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Augmented reality (AR) is a technology that enables the integration of computer generated data into real objects and environments. With the rapid advancements in technology, uses of AR have also become widespread. Nowadays, digitally created data including videos, images, sound, 3D models and text can be viewed superimposed on the real objects/environment through devices such as personal computers, tablets, smartphones, head mounted displays, and projection.

AR also offers potential uses for industrial designers, especially for design students. Some design stages, during which traditional tools and methods are used by designers, may not fully convey the total experience that a designed product offers, like audiovisual feedback and digital interfaces. AR can help by providing a digital layer in which designers can present information and make their presentation more interactive. Therefore, the present research aims to offer directions for industrial designers to use AR technology in design activities to enrich their workflow. A fieldwork with three progressive studies was conducted i) to create awareness of AR to imagine uses for AR in the design process; ii) to explore the potential of mobile AR apps in a design project in an educational setting; iii) and to offer solutions for the future uses of the technology by industrial designers. The fieldwork is undertaken in an educational setting to evade limitations of professional design setting such as time constrains, budget and marketing. The results show that AR can be utilized mainly in presentation and

prototyping stages of design process and with further development in the technology, AR might be useful for several other design activities such as scenario building, user tests, project research, material and mechanical considerations, product surface creation, and so on.

ÖZ

ARTIRILMIŞ GERÇEKLİK TEKNOLOJİLERİNİN ENDÜSTRİYEL TASARIM UYGULAMALARINI DESTEKLEMEYE YÖNELİK DEĞERLENDİRİLMESİ

Topal, Başak

Yüksek Lisans, Endüstri Ürünleri Tasarımı Bölümü

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Artırılmış gerçeklik, gerçek mekan ve nesneler ile bilgisayar ile üretilmiş içeriğin birleştirilmesini sağlayan bir teknolojidir. Hızla gelişen bu teknoloji sayesinde artırılmış gerçeklik teknolojilerinin kullanımı yaygın hale gelmiş olup, video, görüntü, ses, üç boyutlu model ve yazı benzeri dijital içerikler bilgisayarlar, tabletler, akıllı telefonlar, başa takılan ekranlar ve projeksiyon cihazları ile gerçek mekanları zenginleştirmekte kullanılabilmektedir.

Artırılmış gerçeklik, endüstriyel tasarımcılar için de potansiyel kullanım alanları sunmaktadır. Tasarlanan ürünün kullanıcıya sunacağı tecrübenin aktarılmasında tasarımcıların halihazırda kullandığı yöntem ve araçların yetersiz kaldığı aşamalar olabilir. Ses ve görsel geribildirimler ve dijital arayüzler aktarımında sorun yaşanan detaylardan bazılarıdır. Artırılmış gerçeklik, tasarımcıların sunumlarının üzerine dijital bir katman ekleyerek etkileşimi arttırabileceği için bu tür problemlere bir çözüm olarak önerilebilir. Dolayısıyla, bu çalışmanın amacı endüstriyel tasarımcıların tasarım süreçlerinde artırılmış gerçeklik kullanarak çalışmalarını zenginleştirmelerini sağlamak için önerilerde bulunmaktır. i)Artırılmış gerçeklik hakkında farkındalık yaratıp tasarım sürecinde kullanılabileceği aktiviteleri incelemek, ii) eğitim tabanlı bir tasarım projesinde mobil artırılmış gerçeklik uygulamalarının potansiyelini araştırmak, ve iii)gelecekte bu teknolojinin tasarımcılar tarafından kullanımına dair önerilerde

bulunmak için üç saha çalışması yapılmıştır. Saha çalışması profesyonel tasarım ortamında bulunan zaman, bütçe ve pazarlama sınırlandırmalarına tabi olmamak için eğitim ortamında gerçekleştirilmiştir. Çalışmanın sonucunda artırılmış gerçekliğin tasarım sürecinde sunum ve prototipleme aşamalarında kullanılabileceği, gelecekte teknolojinin gelişmesi sonucunda da senaryo geliştirilmesi, kullanıcı testleri, proje araştırmaları, malzeme seçimi ve mekanik detayların geliştirilmesi, yüzey yaratılması gibi tasarım aktivitelerinde kullanım potansiyeli olduğu ortaya çıkmıştır.

Anahtar Kelimeler: artırılmış gerçeklik, endüstriyel tasarım eğitimi, tasarım süreci, tasarım aktiviteleri

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

1.1   Background and Problem Definition

Industrial design is a profession in which educational and professional life involves a lot of hands on experience. In their design projects, typically the students are initially given briefs which explain the problem statement and set some criteria for design. After the distribution of the brief, the students move on to conducting research about the project, and generate initial ideas. In the development stage, they continue developing their ideas according to the data they gather from user testing sessions, material and production method selection, and constant feedback from the instructors. They are expected to communicate and present their ideas in many occasions during the process, up until the final presentation. This iterative process in educational design setting is arguably similar to the professional design setting.

In order to communicate their considerations in the product, one of the main responsibilities of the designer is to represent the visuals of the product concept [1]. Designers are encouraged to present their ideas mainly through the visualization of their ideas, speech and text being supplementary tools. The tools for visual presentation have their uses in different stages of the design process, and they have their advantages and disadvantages. Visualization tools such as hand sketches, digital 2D sketches, 3D computer models, physical mock-ups are employed to convey ideas. Hand sketches are handy for coming up with several ideas in a short time for further consideration. However, the result is often relatively unstructured and ambiguous [2]. While their ease and quickness is an advantage for initial idea creation, they can often be unsuit-

able for further development of ideas, and their time efficiency is questionable when higher quality visuals are needed. The biggest limitation of sketches is that it remains two-dimensional, and a two dimensional image of an object that is intended to have three dimensions is not an accurate or adequate visualization [1].

Another representation method is 3D computer models, which have certain advantages over 2D sketches, as well as downfalls. The presentation technique used for 3D computer generated data, which are renderings, still remain two dimensional, and it is difficult to put the model of the product into context. In final presentation boards, these renderings need to be carefully schematized to show multiple angles and states of the object both in a studio environment and in its intended environment of usage. An additional representation method is physical mock ups and prototypes. Physical mock ups are prepared to supplement the hand sketches and renderings. For the final presentation, a high quality prototype that is as close as possible to the intended design is produced. The difficulty is, it can be hard to build full scale prototypes, showcase moving parts and digital components, not to mention building physical models is a time consuming process. Industrial designers should keep a close watch on technological advancements, both for keeping track of the industry and to help them find ways to improve their efficiency as designers. Designers are not limited to traditional visualization tools and are able to use many innovative technologies, drawing tablets are an example. Industrial design profession is the perfect setting to sample innovative technologies that have the potential of helping the design process, such as AR, which is a newly developed and popularized tool. AR is described as a vessel to incorporate computer-generated data with real space, combining real and virtual objects with each other in real time. The technology has uses in a wide array of commercial and research fields. Over the years, AR has become as accessible as free apps that everyone can install to their mobile devices. At the current state of the technology, there are several design activities that AR could supplement. However, there has not been any recent research of the potential uses of AR for industrial design purposes.

1.2   Aim and Scope of the Study

The aim of this study is evaluating the possibilities of AR technology for supporting industrial design practices. This way, propositions on how AR technology can supplement the design process in different stages will be made.

AR technology has existed and has been on development for decades. Nowadays, with the developments in technology, AR solutions have become very easy to access, and currently there are several applications that can be run on computers, tablets and smartphones that can display 3D models, animation, sound, 2D visuals, and text. Because the uses of AR are very widespread and constantly changing, the scope of the study is not to cover each and every use of technology, but suggesting solutions through the existing and commercially available AR technologies.

1.3   Research Questions

According to the aim of the study, the research is subjected to the following research questions. Some of the questions are to be answered with the help of literature research, and some of them will be answered by the field study. The main research question will be investigated with the following research questions.

Main research question: What are the potentials of AR technologies to be used for design practices?

- How do industrial design projects typically progress with regard to different tools and methods used (e.g. for visualization, presentation etc.)

- What are the commercial and academic uses of AR and related technologies?

- What are the uses of AR in current design practices?

- Can AR technologies be reasonably beneficial to industrial designers?

- What AR systems can be recommended based on their suitability for industrial design and industrial design education practices?

1.4   Structure of the Thesis

The thesis is comprised of five chapters as follows. Chapter 1 – 'Introduction', sets the background information for the problem statement, and presents the aim of the study, research questions and the structure of the thesis.

Chapter 2 – 'Overview of AR technologies with their relevance to industrial design' includes an overview to introduce the product development process, and AR with a definition, brief history, components of the technology, and examples of current commercial and research applications.

Chapter 3 – 'Planning of fieldwork for evaluating AR technologies for industrial designers' introduces the structure and methods of analysis for the three-stage fieldwork.

Chapter 4 – 'Analysis of fieldwork for evaluating AR technologies for industrial designers' illustrates the results and analysis of the three studies carried out within the fieldwork, and discusses the results interrelated with each study.

Chapter 5 – 'Conclusion' puts forward the conclusions in relation to research questions and contributions for future studies.

CHAPTER 2

OVERVIEW OF AUGMENTED REALITY TECHNOLOGIES WITH THEIR RELEVANCE TO INDUSTRIAL DESIGN

2.1 Introduction

This chapter presents an overview of AR technologies to provide a basis of knowledge for evaluating their potential for the product design process. First, an overview of industrial design practice will be presented with references to literature about design stages, as well as the tools and methods used by industrial designers. Secondly, background information on AR technologies will be provided together with definition of terms, and a brief chronology of the milestone events in AR development. Finally, application areas will be discussed. Therefore, the chapter will consist of two parts, first part will focus on industrial design practice, and the second will introduce the AR technologies.

2.2 Product Development Process

In the contemporary understanding, definition for industrial design practice today as put by Industrial Designers Society of America is "the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer" [3]. Industrial design as it is today deals with several factors that contribute to what a good product is, and the designed product goes through many steps to become ideal. As explained by Cross, design is a unique process that consists of problem solv-

ing that takes place in three stages: defining the problem, coming up with solutions, and strategizing the process [4]. The stages that a product goes through during design are explained by Krishnan and Ulrich as "transformation of a market opportunity into a product available for sale" [5].

Each company may follow a different approach to product development processes. These approaches may also vary in complexity and focus depending on for example, type of product, user group, manufacturing capacity, and so on. However, if we were to look at the design stages in relation to the whole production process of a company in more detail, other business functions such as marketing, manufacturing, research, finance and management might come into the picture, making the process multidisciplinary. Product development stages will be categorized into three for following where industrial design will fit into the process: product development philosophies, new product development stages, and concept generation stages.
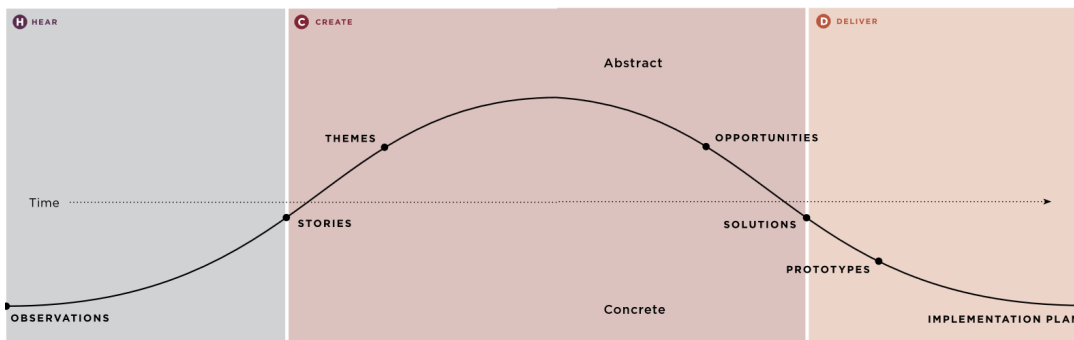
Figure 2.1: IDEO's Human Centered Design Process

Product development philosophies are individual companies' approaches to how development of new products should be planned, and they give insight into the companies' priorities on a conceptual level. This information usually communicates the vision of the company to the general public (Figures 2.1 and 2.2).

Ulrich and Eppinger have developed a new product development process to answer the question of what sequence of steps that go into the workflow of a company for effectively creating new products, from conception through design and commercialization. As seen in Figure 2.3, the generic product development process is on an organizational and multidisciplinary level and consists of six phases, of which each company might have their own interpretation. The *planning phase* is the approval and
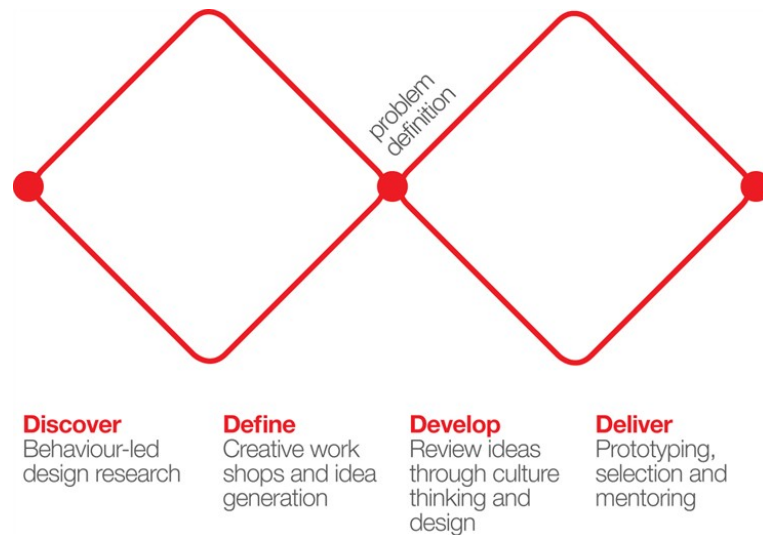
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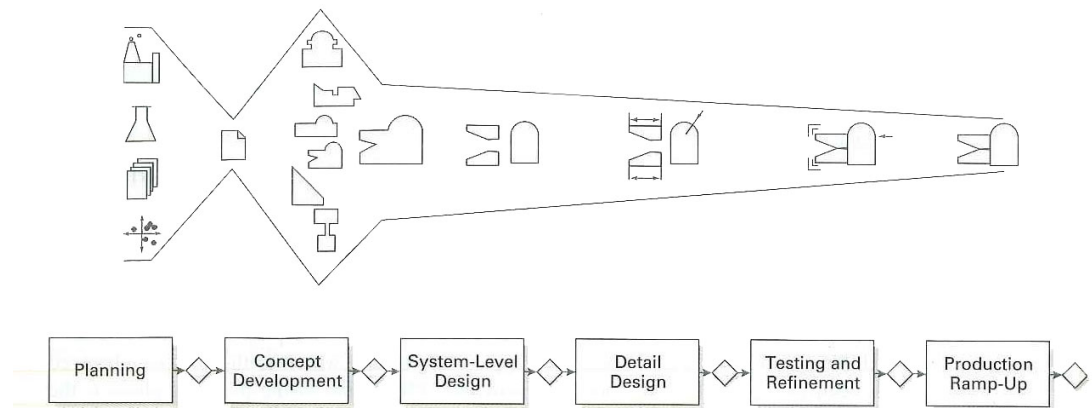
Figure 2.3: The generic product development process [6]

launch of the product development, and aims at generating the mission statement. The *concept development phase* is where the product starts taking shape. *System-level design phase* breaks down the product into parts for production and assembly, which follows in *detail design phase* as solving the material selection, costs and performance problems. The later stages are *testing and refinement*, and *production ramp-up* [6, p. 12-15].

The authors then concentrated on the concept development phase among the aforementioned phases to develop a process tree which goes into detail on concept generation. They suggest seven steps to concept development, which they have coined as the front-end process (Figure 2.4). According to the authors, these steps start with iden-

tification of customer needs and establishing target specifications. In concept generation, the identified needs and specifications act as a guide to explore several concepts with the help of activities such as (but not limited to) creative problem solving methods and sketching of iterations. Later on, they move on to the concept selection stage, during which these initially generated ideas are sifted through design criteria to be analyzed, eliminated and refined to come up with the most promising concept. In concept testing, user tests are conducted to gain insight on how the realized product will fit the needs of the market, which is followed by setting the final specifications of the product. Throughout these stages, there is constant revision and refining, and each company might have differences in their workflow [6, p. 16-17].

After moving from *new product development* to *concept development* to put the focus on the conceptual progress of a product in professional setting, the similarities in student design projects carried out in educational context should be analyzed to further specialize on the design activities. Focusing on design activities in design projects carried out in educational context brings the benefit of isolating an industrial designer's role in product development, which would normally involve collaborating with non-design related departments in a firm. The following educational design project workflow example is adapted from graduation design projects of Middle East Technical University Industrial Design Departments in the years 2012-2013 and 2013-2014. It can be argued that graduation projects are similar in nature to professional projects because they are developed in collaboration with companies. Throughout the projects, the students go through feedback cycles and official screenings in which they are expected to present the outcome of their design activities to the instructors. Table 2.1 shows the design activities and deliverables expected from students, and the correlating medium of presentation. Firstly, a *project statement*
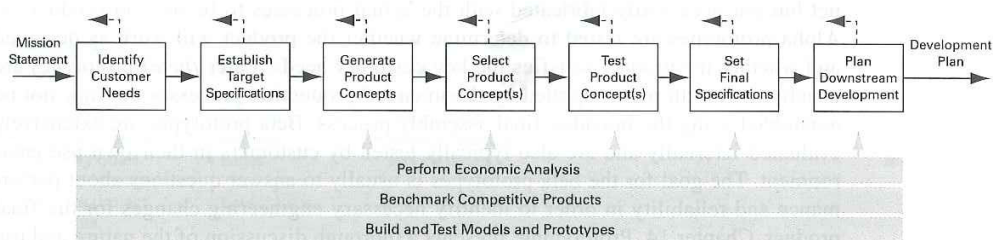
Figure 2.4: Front-end activities for concept development [6]

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Table 2.1: Deliverables expected from design students and the medium of presentation

Design activities and deliverables	Medium of presentation
• project statement • analysis of similar products • user group review • problem definition map • initial ideas workshop	• text • 2D images • diagrams, charts • sketches
• prototypes	• 3D mock ups
• presentation boards	• CAD renderings, drawings

that describes the area in which they will make a design contribution, to come up with a problem definition is presented. This project statement includes the user group, the context of usage, and the essential requirements that the product proposal should fulfill. The project statement is followed by a *user group review* in which the needs and characteristics of the user group are elaborated, and a user study is conducted to set some criteria for design. A field research of similar products is done for the *product analysis* deliverable, during which five products that are relevant to the project statement are analyzed to find strong and weak points concerning function, usability, aesthetics, usage context, interactions, cost, material, and so on. The *problem definition map* is developed by underlining existing keywords in the project statement that set criteria for design, and adding words and phrases that require further research in the field and among potential users. In the *initial ideas workshop*, the deliverables expected of the students are radical ideas that have innovative and adventurous qualities, which the needs of the users and potential product solutions are considered. The students are encouraged to push boundaries regarding technology, form, ergonomics, interaction, and functionality to have diversity in idea generation.

The students are expected to continue developing their ideas and present some deliverables for the preliminary jury. The project statement and the problem definition map are constantly revised and re-written based on results of research and feedback

from the firm and instructors. By this stage, students are expected to have chosen to develop two of their design proposals that they prefer. These two proposals are evaluated based on how well the usage scenario is planned and whether user research and field research has been incorporated. The design proposals are to be presented using *mock ups* and *presentation boards*. These presentation boards can have target group visualization, moodboards, storyboards, CAD product renders, exploded views, interface ideas, technical drawings, section views, and so on. Up until the final jury, the students are expected to develop their design proposals. The specifications for the presentation boards are very specific: a CAD product rendering of current design proposal, a CAD exploded view showing the individual components, product detailing such as user-product interaction, interfaces, selection of materials and manufacturing processes, mechanisms, assembly, anthropometric assessment, etc. For the final submission that follows the final screening, students are expected to provide a *project report* and submit their *sketchbook*, along with the finalized versions of their *final model* and *presentation boards*.

While this process and deliverables are from educational design projects, the activities are very similar to a professional designer's practice. Designers and design students use several physical tools and digital methods to produce the outcome that they are expected to deliver. In time, and especially with the popularity of digital design tools such as 3D CAD modelling and 2D sketching nowadays, it can be inferred that designers are open to the integration of new technology into the design process. The effectivity of the current tools and methods used by industrial designers in providing these deliverables in the standards that they are expected to reach is open to discussion. From this information to use as a basis for further exploration, propositions on how AR technology could be supplementary to the design process can be made.

2.3 Augmented Reality Technologies

2.3.1 Introduction

AR, founded as a concept in the 60s and officially coined in 1992 by Tom Caudell, has been on the focus of many researchers, and consequentially has been gaining the

attention of the general public. Now, with the advancements in technology in both software and hardware, the futuristic and awe-inspiring examples of AR are starting to become true. It is possible to alter the user's view of reality with superimposing the real environment with computer generated imagery. This review will consist of the definition of AR and related terms, a brief history of AR, current research and development applications, applications designed and used specifically for product design, and a review of mobile applications with their relevance to industrial design. This information about AR will provide a background for the studies that have been conducted to assess the possible advantages of the technology in industrial design process.

2.3.2 Related terminology

AR technologies are a way of embedding computer generated information into physical environments with the aim of enhancing human perception [8]. In other words, it is a combination of virtual objects and real world objects that coexist in the same real environment [9]. In order to define AR in more concrete terms, but without restricting the definition to a subcategory of the technology, one must look at the mixed reality continuum as defined by Milgram et al. [7].

According to this continuum, as presented in Figure 2.5, we have the **'Real Environment'**, which humans sense directly, physically through their sensory abilities on one end. On the other end, we have the **'Virtual Environment'**, which is completely made up of synthetic computer generated elements that are not bound by the laws of physics like time, material, gravity. In **'Virtual Environment'**, the user is not able to see the real world around them, because it is completely replaced by computer generated data. In the in-between stage, **'Augmented Reality'**, which can be defined as computer generated information embedded in real environment, and **'Augmented virtuality'** which can be defined as real environment artifacts embedded in a virtually generated setting. In other words, it is computer generated environment superimposed onto the real environment, so the users experience and perceive both at the same time. This continuum represents the **'Mixed Reality'**, and the difference between each stage is partly caused by the medium to view the computer generated
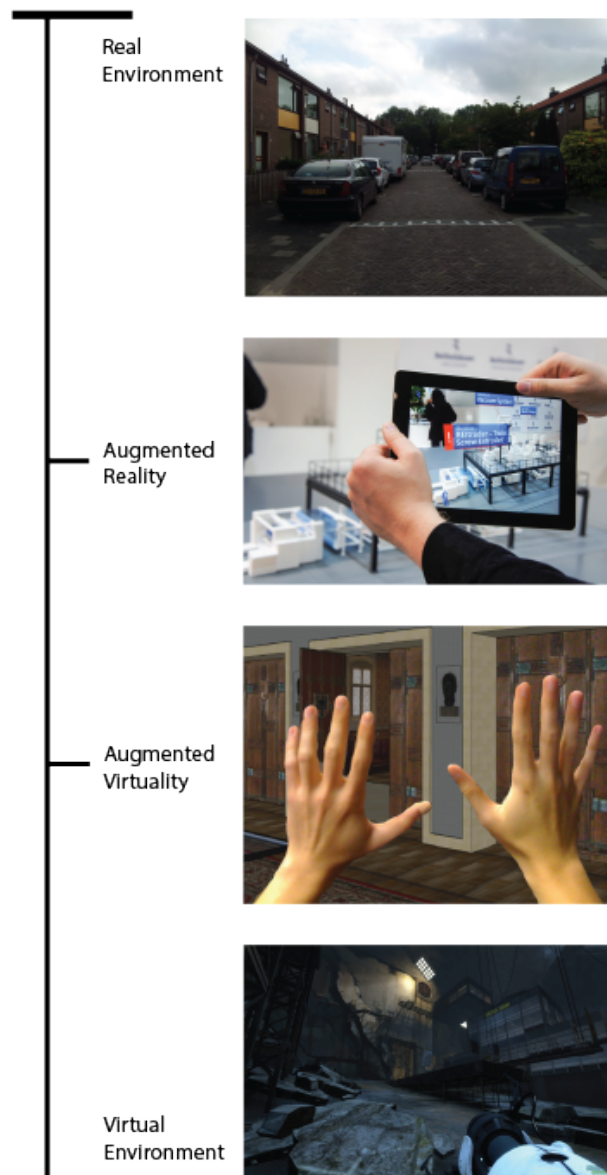
Figure 2.5: Mixed reality spectrum, adapted from Milgram et al. [7]

content. AR includes computer generated data in the real world through a layer. Synthetic elements are superimposed upon real environment with the aid of related hardware like monitors, head set displays or projectors.

To not limit AR to these physical solutions, Azuma defines AR with the following three factors [10], accordingly, AR is:

- a combination of real and virtual,

- interactive in real time,

- observed and/or experienced in three dimensions(3D).

By this definition, AR does not include 2D alterations on images, or digital enhancements of non-interactive media such as film and television.

2.3.3 Brief History of Augmented Reality

The history of AR as we know it today dates back to the 1960's with examples like simulators and head mounted displays. However, research has taken speed in the 1990's after the term has been coined by Caudell and Mizell [11]. Currently the technology is more widespread than ever. This section, compiled from [12], [13] and [14]; outlines and briefly explains the chronology of people that have worked with AR.

1962

Sensorama, built by Morton Heilig is maybe the first example of multisensory immersion technology that has been built. It is a simulator which incorporates visuals,

Figure 2.6: Sensorama by Morton Heilig, 1962

sound, vibration and smell. This project did not gain financial support to be used for any specific purpose, but it was a milestone in the history of virtual reality, and as can be seen in Figure 2.6, is a rather large device.

1968

The Sword of Damocles, built by Ivan Sutherland (Figure 2.7), is a head mounted display system built for virtual reality and AR. It was one of the first examples of head mounted displays.

1975

Videoplace, built by Myron Krueger (Figure 2.8), was the first platform in which users interacted with virtual objects projectors, video cameras, special purpose hardware, and on-screen silhouettes of the users.

1992

The term "Augmented Reality" is coined by Tom Caudell and David Mizell as Boeing's Computer Services' Adaptive Neural Systems Research and Development project. The project aimed at finding an easier way to guide Boeing's engineers to manufacture the hardware. It was software that overlaid correct cable positions to Boeing aircraft.

1996

NaviCam, developed by Jun Rekimoto, is an AR prototype that uses one of the first
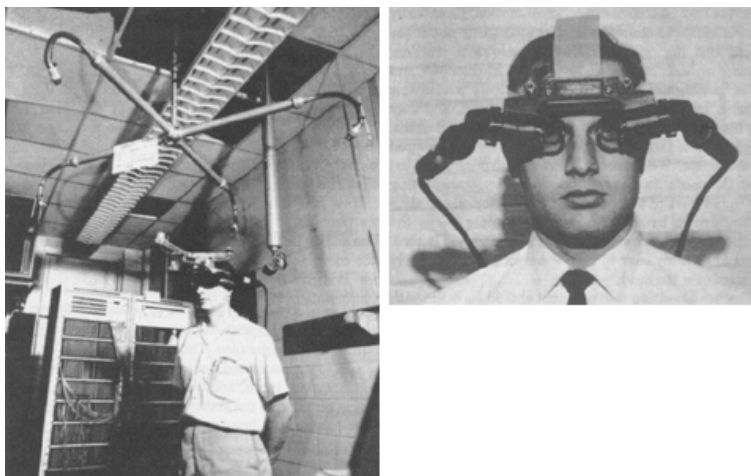
Figure 2.7: Sword of Damocles by Ivan Sutherland, 1968

Figure 2.8: Videoplace by Krueger, 1975

examples of 2D matrix markers (Figure 2.9). 2D matrix markers are square barcodes which are still being used for location tracking purposes for applications today.

1997

Researcher Ronald Azuma defines the three characteristics of AR mentioned above.

1999

The company Total Immersion launched D'Fusion, an AR development tool that can work in multiple platforms. Total Immersion became the market leader with their research and development of AR products. This was a big step in allowing development of AR applications to become widespread.

ARToolKit, an open source software for AR developed by Hirokazu Kato (Figure 2.10), is released. This toolkit offered an array of tools for capturing video to include
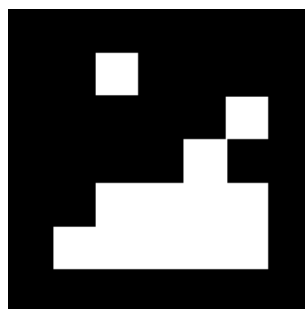
Figure 2.9: Example of a 2D matrix marker for AR by Rekimoto, 1996
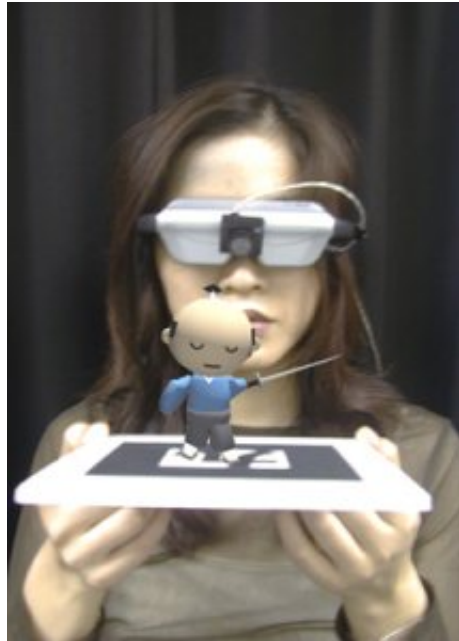
Figure 2.10: An example from ARToolkit application [15]

virtual objects and 3D graphics to be displayed on any operating system. ARToolkit has been very successful and examples of applications built with it can still be found widely today.

In the same year, also the first example of an AR browser was built by Hollerer, Feiner and Pavlik in the form of a wearable AR system that lets the user scan outdoor locations to find out information about interest points (e.g. location of library in the campus) for navigation [16].

2000

An AR version of the video game Quake, AR-Quake was built by Bruce Thomas et al.(Figure 2.11). It incorporated a tracking system, GPS and a digital compass to play the first person shooter video game in the real world. The user can see their health status bar and virtual enemies overlaid in the real environment. Usage of AR in the videogame industry is a big milestone in increasing the popularity of technology.

Battlefield AR system has been built by Julier et al. to assist the soldiers by providing

Figure 2.11: A screenshot from ARQuake [17]

information using a wireless network, a computer and a head mounted display.

2001

A mobile AR system for multiple users was developed by Reitmayr and Schmalstieg. This project explored the merits of collaborative qualities of the technology through navigation and information browsing activities in an urban environment. This was an important milestone in the technology because it allowed more than one person to reach the digital content overlaid on the real environment in real time.

Kooper and MacIntyre developed the Real-World Wide Web, which is the first AR browser that enables the viewer to combine the physical world with digitally created data through channels that are hosted on the internet. Development of AR browsers has sped up the evolution of the technology to reach the general public from development centers.

A navigation system for historical sites in Greece, Archeoguide, was built by Vlahakis et al. It included 3D models of temples and statues with people walking in the streets (Figure 2.12).

2004

Mathias Möhring created a 3D tracking system for mobile devices. This was the first time a transparent layer of computer generated data was viewed on a cell phone. The motivation for creating this system was fulfilling the potential of built in cameras in

Figure 2.12: Archeoguide, navigational system for historical sites by Vlahakis et al., 2001 [18]

cell phones as more and more people started owning cell phones with cameras[19].

2006

The Mobile Augmented Reality Applications project was founded by Nokia. This project explored the multi-sensor functionality of mobile phones to implement on an AR system that guides the user with text and graphics (Figure 2.13).

2008

Wikitude World internet browser, developed by Mobilizy, was launched. This smart-phone application overlays Wikipedia information on what is seen through the camera. Wikitude uses mobile devices like smartphones and tablets and gathers the digitally created information from the internet (Figure 2.14), meaning that there is very little effort needed on the user's end to experience AR.

2009

SPRXmobile developed Layar, which is an AR browser, and is now considered as one of the pioneers in the market.

2013

Google launched Google Glass, a head mounted display that enables the user to see the real world and the digitally produced data at the same time through a state of the art transparent screen (Figure 2.15). The display is controlled by voice recognition and touch activation. The launch of Google Glass created a viral effect of AR
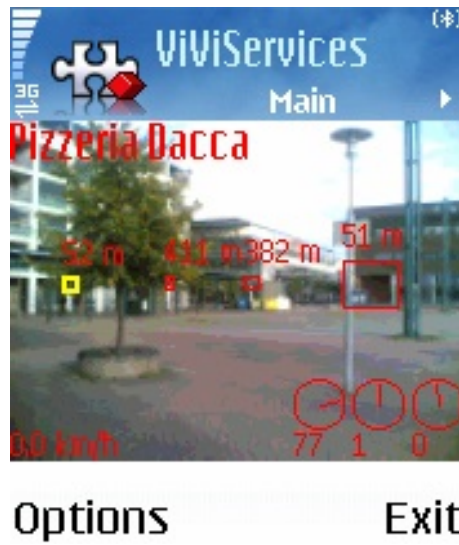
Figure 2.13: A screenshot from 'The Mobile Augmented Reality Applications' project by Nokia[20]
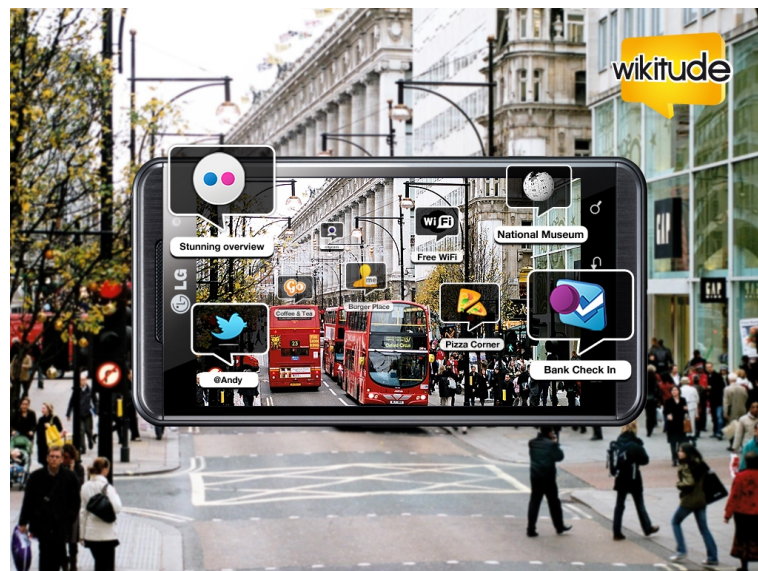
Figure 2.14: Wikitude world internet browser[21]
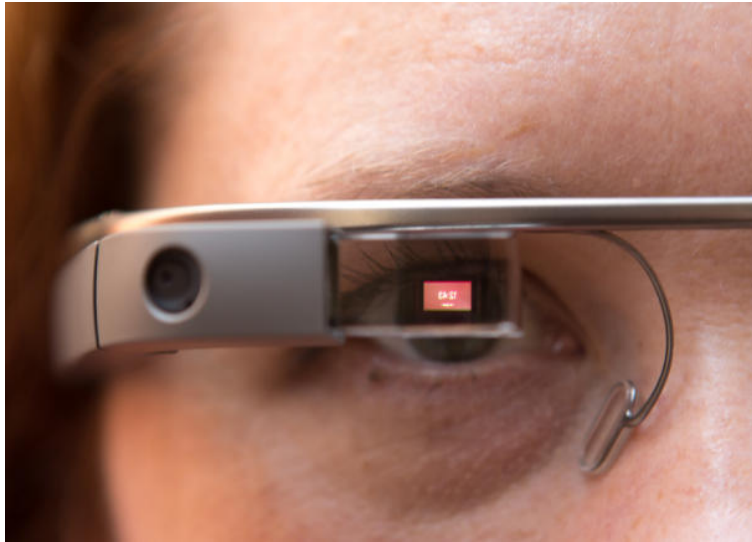
Figure 2.15: Google Glass[22]

technology, making it one of the most attention-grabbing technology items.

Throughout the years, the technology that started with large hardware components and very specialized and limiting software has turned into a science fiction dream come true. The experience of AR depends on the hardware and software components, which can create combinations that are suitable for diverse commercial applications. The following section will present the AR components to show the possible uses with today's technology.

2.3.4 Components of Augmented Reality

The core components of a typical AR system consist of the following *hardware* and *software* combinations [12]. As can be seen on Figure 2.16, these components come together to create an AR scene on a mobile device:

- *Hardware components:* a computer or a mobile device, a monitor or a projector, a camera, tracking components, a network system, a marker that is detected by the sensors and acts as a location pin for the digitally produced data.

- *Software components:* an application or a program that runs locally, web ser-

vices, a content server.

Some of the current hardware platforms that are used to showcase the AR technologies to users are computers with webcams, kiosks and window displays, mobile devices such as smartphones and tablets, head mounted displays and spatial projection. Each of these hardware platforms for displaying AR has different uses of the technology. For instance, room-sized projection/projection mapping/spatial AR is used by artists and advertisers that want to add optical illusions or extra dimension to large objects, or buildings. Kiosks are used in stores or museums to display more information on what's being sold or exhibited. In contrast to these, AR applications for smartphones and PCs are personal to the owner of the device, which means they can choose which AR application to use for their specific needs. This creates endless possibilities for the mobile AR application developer to specialize in any context, which can be proven by the numerous examples of mobile AR applications. Figures 2.17 to 2.20 present examples for different uses of AR.

In the following sections, current commercial uses of AR, research and development, and more specialized AR applications will be covered.
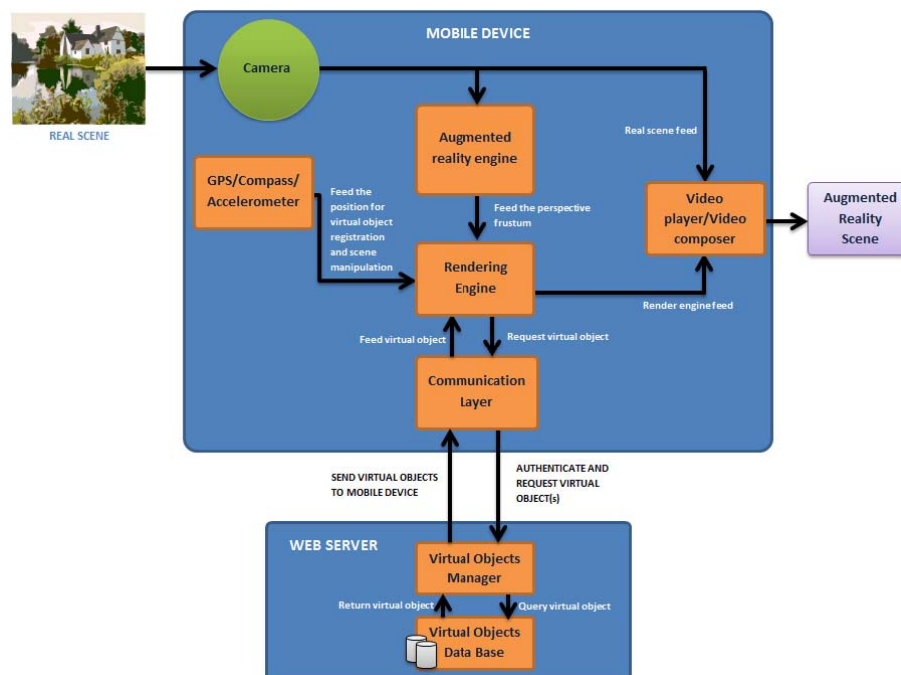
Figure 2.16: AR mobile platform architecture [23]

21

Figure 2.17: An example of AR use on a PC [24]

Figure 2.18: An example of AR use in a kiosk [25]

Figure 2.19: An example of an AR application on a mobile device [26]

Figure 2.20: An example of room-sized AR application [27]

2.3.5 Commercial Augmented Reality Uses

Ever since AR has gained public recognition and became a trend in technology, various applications have been developed in diverse commercial fields. Commercial AR applications are those that are available to use by the general public, and they can be divided into two categories: i) content creation and application building services, and, ii) end user applications.

Content creation and application building services, provide a base for companies to create their own applications, specialized for the purpose that they specify. These applications are marketed towards professionals in the industry and are not used by end customers apart from demo or trial versions the companies may provide. Some of the most popular AR content creation and application builders include Layar, Metaio, Wikitude and BuildAR. Because they are base programs for customization of AR content according to purpose, some of them consist of more than one product, such as content management tools and browsers to view AR channels. In these applications, people create their own AR content and publish them for the end users to interact with.

End user AR applications, are the ones that are specialized within their own sector and content, and are only available for the end users to interact with. These applications take up a majority of the examples that can be seen in the examples from different commercial fields including advertisement, architecture and construction, museums and tourism, medical, mechanics and repair, social networking, entertainment, military and navigation.

This range of examples is not a representation of the current technology in commercial applications as a whole, but has been refined to show a diverse selection of up to date, unique and attention worthy applications of the technology. Some of these examples will have AR as the main focus in large scale hardware components, and some of them are as simple as a mobile app. The scale in which AR is utilized in each example depends on the content and aim of the application.

To prevent confusion about terminology, some definitions should be presented. The term **app** is going to be used as the term for mobile applications, whereas the term

software application refers to software that is developed for AR without a reference for hardware. **Application of AR** is a more general term that deals with the utilization of the technology in the broad sense.

2.3.5.1   Advertisement

AR is most commonly used in advertising. Marketers use the technology to combine digital world with the physical world to give the users and the brands the ability to connect in a more interactive and attention grabbing way. Because it provides a multi-sensory platform to showcase the product, AR commercials have become a trend among advertisers.

For example, to promote the Beetle car, Volkswagen launched a billboard that had AR content. The billboard encouraged the viewers to download the VWJuicedUp app onto their smart devices to make the car on the billboard come to life. When the smart device is pointed on to the marker placed on the billboard, the car either performs flips and jumps on a ramp in 3D animation, breaks through the billboard and drives away, or slides through a tunnel (see Figure 2.21).

National Geographic was another organization which took advantage of AR technology by placing a large screen at the entrance floor of a mall, placing an AR marker on the floor, and letting the visitors see and interact with the animals that appear on their reflection on the screen (Figure 2.22). This big scale application of AR had the advantage of not being bound to an individual's mobile device; the computing and the presentation is done in a central workstation and all the visitors were able to see the interaction with the digital content on the screen.

A similar advertisement campaign was launched by Disney in the Times Square of New York. In this installation, a large screen in the form of a digital billboard was set up, and in the road across the billboard there was a circular marker that activated the AR content when a person stood on it. The content was Disney characters and they interacted with the viewer standing in the circle (Figure 2.23).

Hyundai promoted their 2011 model Accent Sedan with a projection placed on the side of a building (Figure 2.24). They mounted the actual vehicle on a building and

had a man climb down the facade to get in the car, and drive it in the AR content. This very large scale installation created a very attention grabbing effect.

Figure 2.21: VWJuicedUp application pointed on to the marker on a billboard by Red Urban Canada, 2011 [28]

Figure 2.22: National Geographic advertisement in a mall by Appshaker, 2011 [29]

Figure 2.23: Disney AR application in Times Square by Disney Parks, 2011 [30]

Figure 2.24: Hyundai Accent Sedan promotion in Kuala Lumpur by Hyundai, 2011
[31]

The last of such kind of examples is Starbucks' red cups for the festive season. The
AR app, called Starbucks Cup Magic, embeds holiday themed character animations
in the markers on their cups (Figure 2.25). The characters include a fox playing with
snow, an ice skater, a squirrel, and a boy sledding with his dog.

Figure 2.25: Starbucks holiday cups come to life with AR content by Blast Radius, 2011 [32]

2.3.5.2   Architecture and Construction

There are various AR apps for achieving immersive experience in architecture. These can be used for example, to make 3D models pop up from 2D plans; to show how a construction is going to look like when it is finalized; or to showcase city landscapes for urban planning.

ARki is an AR system that visualizes architectural prototypes in real time. The company aims to add layers of interactivity to existing presentation methods (Figure 2.26).

Urbasee is an app that aims to support architects and contractors by allowing them to see all sides of the designed building in its intended landscape. This way, the app allows imagining the finished building well before the construction starts (Figure 2.27).

Figure 2.26: ARki by Darf Design, 2014 [33]

Figure 2.27: Viewing of the construction site with Urbasee [34]

2.3.5.3   Museums and Tourism

AR offers a great opportunity to enhance the story telling of the exhibited artifacts within museums and historical sites. Museums nowadays have already integrated technologies, such as audio guides and QR codes that are linked to websites containing more information about the exhibited artifacts. Moreover, some museums are

already taking the advantage of AR technologies to bring the artifacts to come to life.

The CHESS (Cultural Heritage Experiences through Socio-Personal Interactions and Storytelling) organization, for example, partners with universities and virtual reality software developers to add AR content to the artifacts of the New Acropolis Museum of Greece and Cité de l'Espace of France. As an example, an iPad hovered over a sculpture to see its original colors can be seen in Figure 2.28.

Figure 2.28: Viewing a sculpture to find out its original colors [35]

In the city of Seville, an app called Past View combined with a HUD display offers tourists a-walk-in-time- tour with the city as if you were living in it decades ago (Figure 2.29).

Figure 2.29: Past View in the streets of Seville [36]

AR has also been used to gamify traveling. The app called The Game is essentially a treasure hunt where tourists are encouraged to find out facts about the city, sparking their interest in the location and creating appeal for the location. Yelp (Figure 2.30) and Wikitude can also be given as good examples of AR apps used for tourism purposes. When the users point their mobile devices to a location in the city, they can reach information about for example travel hotspots, landmarks, hotspots on their screen.
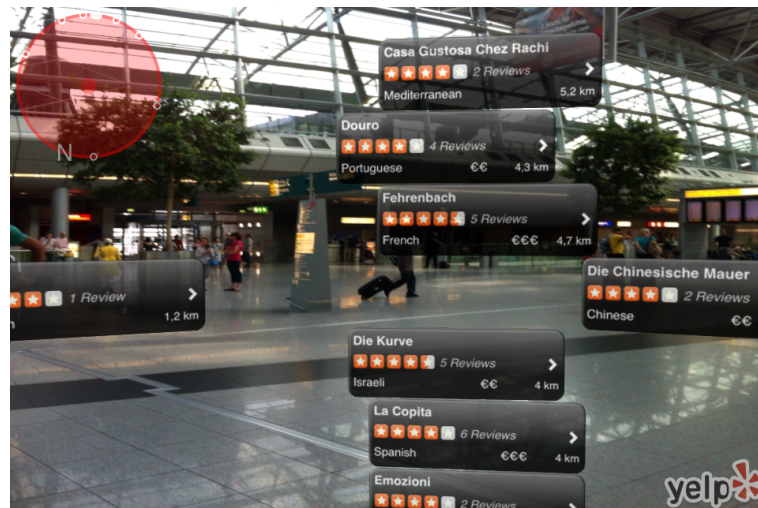
Figure 2.30: Reviews of restaurants through Yelp [37]

2.3.5.4 Medical

Medical AR is a wide and popular area of research that aims to bring the technology into medicine in the fields such as education, pre-planning and operation. However, medical applications present some challenges. In the cases, where the goal is to assist a surgeon, the hardware solution should not be obstructing the view or reducing the mobility. In addition, accuracy of tracking becomes crucial. As an example in medical use, Avinent Glass, the Google Glass app for dental implantology, superimposes instructions into the surgeon's view for performing surgery for dental implant placement (Figure 2.31).

Figure 2.31: Superimposed instructions appearing on Google Glass screen during a dental surgery [38]

2.3.5.5 Mechanics and Repair

AR apps are also being used in mechanics and repair to give further information about the part that the mechanic is working on. The content of the information presented may range from part-specific instructions on assembly with 3D models, to help the mechanic notice and repair the fault. As an example, when the driver of the car hovers her/his smart device over a certain part of the car, the I-Mechanic app gives information about that part – in a way, empowers the driver as a mechanic (Figure 2.32).

Figure 2.32: I-Mechanic application for car repair and maintenance [39]

2.3.5.6 Social Networking

AR also offers great potential for social networking and social media. In social media, people create profiles for themselves and share personal information online with their friends.

Recognizr, developed by TAT, uses face recognition and head tracking technologies to overlay social network profile links to a person (Figure 2.33). The app is designed as a platform that people can sign up and customize the information they want to share with their friends or colleagues. It is possible to link the user's face to Facebook, Twitter, Flickr, Last.fm, or SlideShare accounts, and people can reach this profile by scanning that person's face with their smart device.

Twitter 360, app for the iPhone, uses GPS functionality with the phone's built-in camera to show the location of the user's Twitter friends based on their recent tweets (Figure 2.34). With this information, it can be seen where the person you follow is located when they post a tweet.

Figure 2.33: Recognizr displaying online profiles of person by The Astonishing Tribe, 2010 [40]

Figure 2.34: Tweet 360 promotional image showing location of Twitter followers [41]

2.3.5.7 Entertainment

Using AR for bringing games into life in 3D is a dream to come true for many gaming enthusiasts. Instead of interacting with an unintuitive computer mouse and keyboard, players can interact with 3D game elements directly.

PulzAR, developed by Playstation for the handheld device PS Vita, with the help of its built-in camera that allows the user to create interactive desktop puzzles and play cards with printed markers (Figure 2.35). The puzzles have laser beams around the obstacles and reflective boards. The aim is to hit certain spots to gather points.

Ingress is a geo-location based game that incorporates real world locations with portals. The goal is to use the game as a guide to explore the vicinity and find as many portals as possible to win among other people who are playing. When the user is near a portal, the app notifies the user by overlaying the options on the image captured by the camera in real time. There are two teams who are in control of the portals and they have a variety of tools to take over them.

More conceptual examples of AR have been displayed in numerous Hollywood movies mainly of the science fiction genre. The AR examples from the movies presented here are used by the main characters in the movies.

Figure 2.35: PulzAR for PS Vita [42]

Figure 2.36: AR view as seen through Iron Man's suit [43]

In the trilogy of Iron Man movies, the main character Tony Stark is an engineer/product designer who creates the Iron Man (2008) suit using a holographic AR work bench. The suit itself also acts like a HUD display that shows information about the items on the field of vision as well as the status of the suit itself by the operating system that powers the suit (Figure 2.36). In the movie Avatar (2009), the holographic table is used to view the natural landscape of the planet the scientists are working on (Figure 2.37). Maybe one of the most widely known example of AR in science fiction movies is in Terminator, in the form of a HUD that is capable of facial recognition displays information about suspects(Figure 2.38)

Figure 2.37: AR holo-deck appearing in Avatar [44]

Figure 2.38: AR view as seen through Terminator's HUD in Terminator 2 [45]

Although these examples are fictional, they are worth paying attention, since movies are good sources for catching the hints for early concepts for future vision. It can be seen that transparent displays of different kinds are some improvements in the technology that might be expected from the future.

2.3.5.8 Military

Defense sector has always been one of the close followers of newly emerging technologies, and AR is no exception. HUD solutions can be used to train soldiers, or to show them enhanced information on the field. As mentioned in the history of AR, Battlefield Augmented Reality System was the first example of military related AR

reality applications. A more recent example is US military's smart helmet project. In this example, commanders can use their helmets as HUDs to send maps and other information to soldiers' HUDs (Figure 2.39).

Figure 2.39: ARC4 for the US military by Applied Research Associates, 2014 [46]

2.3.5.9 Navigation

AR can be used for navigation purposes to overlay maps and route information on the field of vision with the help of GPS and internet. ARnav Navigation app, launched by ARnav for Android users, makes outdoor navigation easier by overlaying hotspots from an open database and helping the user with step by step navigation shown as arrows on the road (Figure 2.40).

iOnRoad is a personal driving coach app that detects other cars on the road and gives real-time information in relation to the distance should be kept (with other cars) for safe driving; also offers notifications when the driver steers off the lane, while showing step-by-step navigation commands (Figure 2.41).
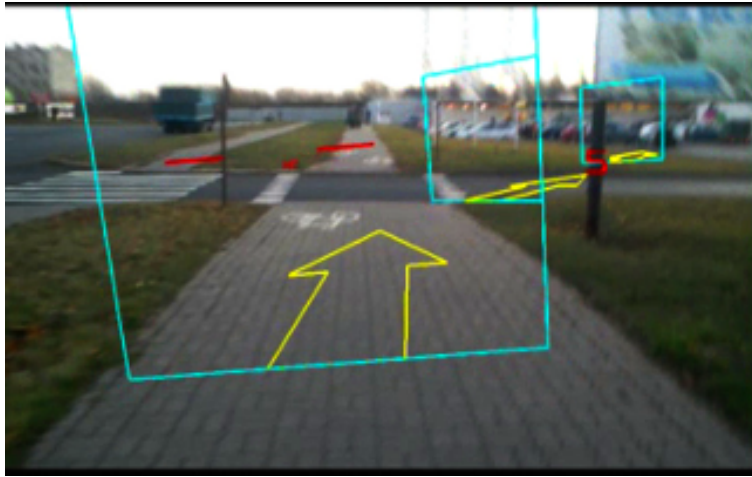
Figure 2.40: A view from ARnav app [47]

Figure 2.41: A view from iOnRoad navigation app [48]

2.3.6 Current R&D in Augmented Reality

As with any cutting edge technology, research and development (R&D) should be in close proximity to commercial applications. This section will outline some of the current AR projects that take place in (R&D) laboratories of academic institutions and companies. MIT Media Lab's Tangible Media Group and Fluid Interfaces Group are two of the pioneers in AR. Other institutions including New Zealand HCI Lab, Georgia Technical University, Graz University of Technology; automotive industry leaders such as BMW, GM, Land Rover; and hardware developers such as Google, Oculus Rift, Microsoft and CastAR have also released a number of noteworthy AR related applications. Some of these applications will now be presented to cover the range of (R&D), some of these offer very simple usage of AR whereas some opens

up wider visions.

Human Interface Technology Laboratory of New Zealand has been developing successful AR applications such as BuildAR, an application that allows the creation of AR scenes on a personal computer; colAR, a program for coloring the pages of a book and then turning them into 3D (augmented) objects.

Similarly, Georgia Technical University's Augmented Environments Lab has diverse research on technologies of AR and mixed reality. Their current project themes include using AR as a web browser, as a form of artistic and personal expression; building AR tools for specific needs, AR systems that allow for collaborative work environments, cultural heritage display systems, enabling technologies, and games.

Graz University of Technology has been working on various AR research applications in the Institute for Computer Graphics and Vision. Their projects include construction site monitoring and guidance, document inspection templates, a virtual dressing room, and applications for tourism and the medical field.

Munich Technical University of Germany has a research team that works with medical applications of AR. They develop innovative applications for guiding the surgeons while operating on their patients. Their work eliminates the need for the doctors to look at separate panels during surgery, and they use HUDs with high accuracy for safety.

- *inSide* (by MIT Media Lab) is a tangible interaction project that works by projecting information which the user can manipulate with their fingers on a 3D shape. It is possible to see transparency, animations, and section views on the physical object (Figure 2.42).

- *Sublimate* (by MIT Media Lab) is a 3D user interface that works with AR and a physical shape. The board with pins that have adjustable heights is manipulated by the user to create physical shapes that are tracked by the computer and presented on the optical see-through screen that follows the perspective of the user's head for accuracy(Figure 2.43).
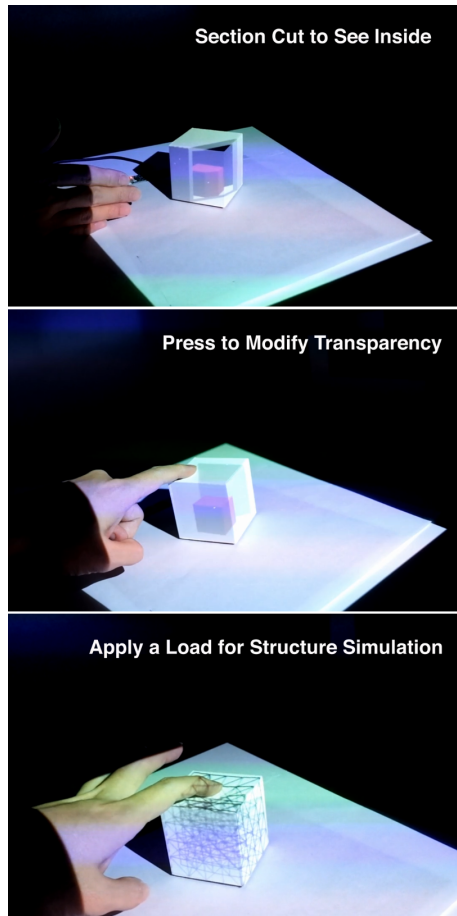
Figure 2.42: inSide, tangible interaction project [49]
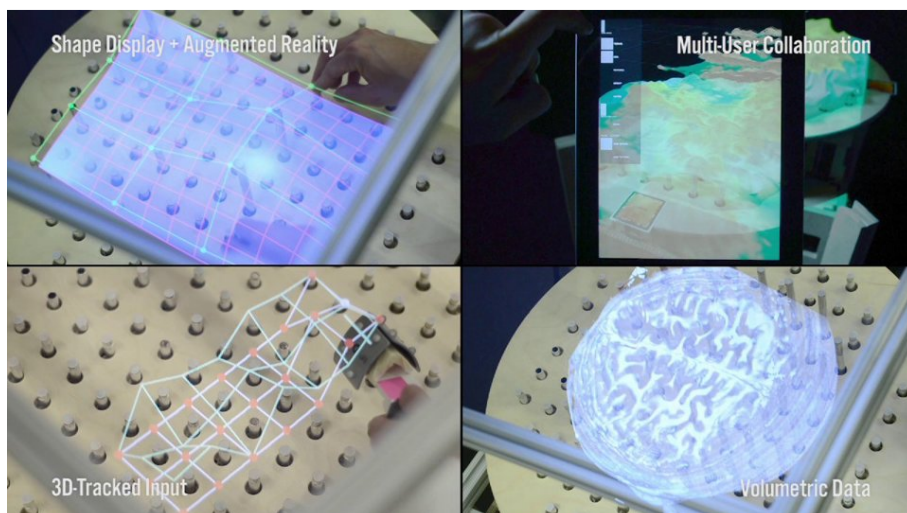
Figure 2.43: Sublimate, 3D user interface [50]
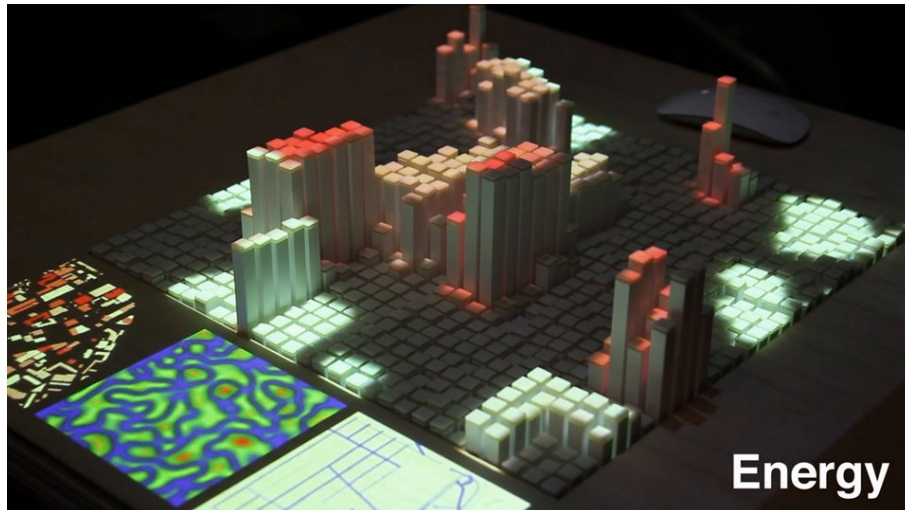
Figure 2.44: Tangible CityScape, tool for city planners [51]

- *Tangible CityScape* (by MIT Media Lab) is essentially a magnifying glass without a transparent display. It fuses virtual and optical magnification through an optical magnifier. It combines a magnifying functionality with information about the magnified object, such as scientific name, molecular level magnification, and so on (Figure 2.44).

- **Augmented Magnifier** (by MIT Media Lab) is essentially a magnifying glass without a transparent display. It combines a magnifying functionality with information about the magnified object, such as scientific name, molecular level magnification, and so on (Figure 2.45).
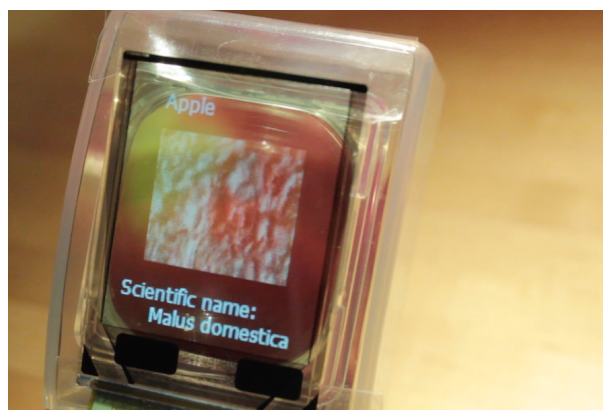
Figure 2.45: Augmented magnifier, magnifying AR application [52]

- *The Smarter Objects* (by MIT Media Lab) is a tool that enables interaction with everyday objects. A mobile device is pointed at the object, which shows interactive editing options through an AR application. Then, the object can be programmed to behave in a certain way, such as acting as a radio. Reality Editor is the software component that enables the user to set up the editing options (Figure 2.46).
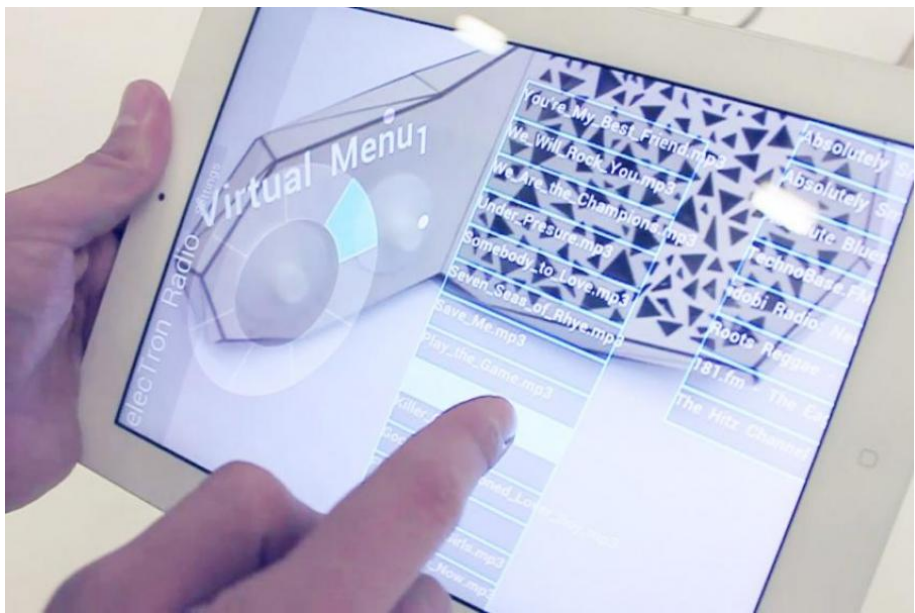
Figure 2.46: An object turning into a radio with Smarter Objects [53]

- *SixthSense* (by MIT Media Lab) is a wearable gestural interface that incorporates AR to provide information about the real world. It consists of a camera, colored markers on the finger tips, and a small projector worn as a pendant. The software tracks the location and movement of the hands and the arms, and projects the information onto the desired object with the projector (Figure 2.47).

- *Augmented Reality Product Counter* (by MIT Media Lab) is a product display surface that shows relevant information about products to be sold. The projection is made with LuminAR, which is another project that is a hardware solution for projection of augmented data. By this way, potential customers can see information on products such as price, technical specifications, etc (Figure 2.48).

42
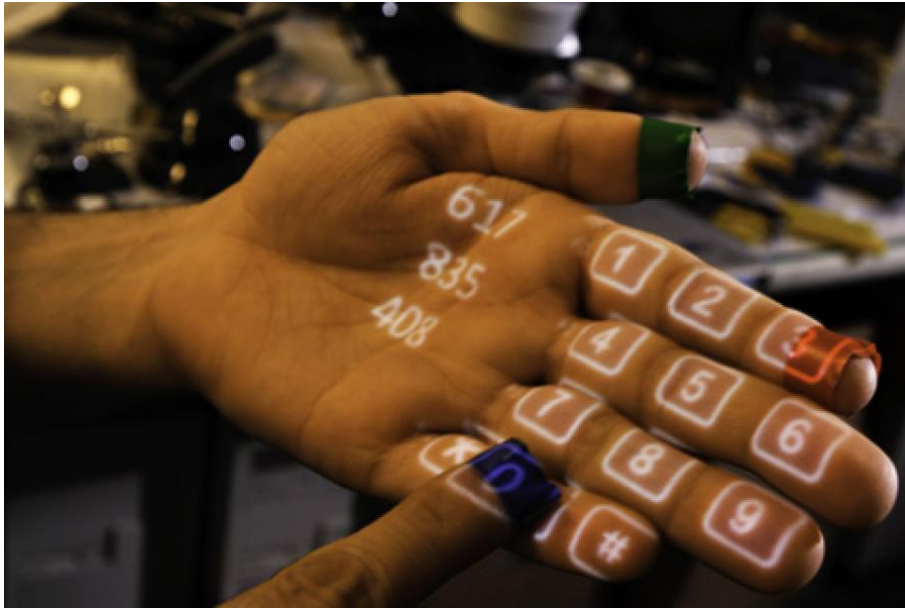
Figure 2.47: Interface of SixthSense [54]

Figure 2.48: AR product counter [55]

There are also companies with their research departments working on diverse AR uses. For example, IBM Research has been working on a mobile application that combines the merits of online shopping with inside the store hands-on experience. The app aims to offer shoppers with a personalized shopping experience and with immediate product comparisons and special offers as they move throughout the store (Figure 2.49).

Figure 2.49: Personalized shopping experience app by IBM Research [56]

Automotive industry is very inventive in their AR applications some of which we already started seeing in our cars. BMW, for example, has been working on a HUD project that shows information about parts of the car, and gives step-by-step instructions for repairing and maintenance tasks. General Motors is another company which has partnered with several academic institutions to use a HUD for superimposing informative graphics on the windshield of a car. Land Rover has been developing a type of a HUD that turns the body of the car as viewed by the driver transparent, so that the exact position of the wheels can be seen for ease of driving in off-road locations (Figure 2.50).

Figure 2.50: Land Rover AR off road guiding by Land Rover, 2014 [57]

Although they have been several years in the making, these hardware components have not been released for public consumption yet: Google Glass and Oculus Rift are two very popular HUD devices that are available for developers. Google Glass is a unique HUD that has a very small state of the art transparent monitor and is activated by voice recognition and a touchpad on the side of the frame (Figure 2.51). It allows the user to see the real environment as well as seeing the digitally produced information in the screen. Oculus Rift, in contrast, is a VR device that covers both eyes and shows a completely virtual environment to the user through LCD screens, allowing them to be immersed (Figure 2.52). Sony Computer Entertainment has been working on a headset that is similar to Oculus Rift in principle, called Project Morpheus, which they plan to integrate with the Sony Playstation 4 and Playstation Vita (Figure 2.53.

Figure 2.51: Google Glass [58]

Figure 2.52: Oculus Rift by Oculus VR [59]

Figure 2.53: Morpheus by Sony [60]

Figure 2.54: Microsoft's Illumiroom [27]

Microsoft Research is another company focusing on the technology. They have developed Illumiroom, a peripheral projection that helps the user be immersed in a virtual environment as it is projected into their living room (Figure 2.54). In the demos it is combined with first person shooter videogames. Another research project by the company is Wearable Multitouch Projection. This project combines depth-sensing with projection by turning everyday surfaces into multitouch interaction opportunities.

Another example by Microsoft is HoloLens, announced in 2015(Figure 2.55). HoloLens is a HUD that claims to start the era of holographic computing. To elaborate, it is a headset that lets the user see and interact with digital content through a transparent

screen to create an immersive AR experience(Figure 2.56). When the development of the device is completed, it is said that the users will be able to interact with the digital content with gesture recognition.

A HUD system that sets itself apart from other examples is CastAR glasses, which is made by the company Technical Illusions and is crowdsourced. Instead of having screens in front of the user's eyes, this pair of glasses has two small projectors on top that project the image to a special screen that reflects the light to the user's eyes (Figure 2.57). The glasses then pick up the images and turn them into 3D. The introductory video shows ideas of implementing this device into applications like tabletop gaming.

Figure 2.55: Microsoft's HoloLens

Figure 2.56: Immersive experience of using Microsoft's HoloLens [61]

Figure 2.57: CastAR head-up display by Technical Illusions, 2013 [62]

2.3.7 Augmented Reality Apps Relevant to Industrial Designers

Majority of the industrial design relevant AR apps are used in automotive industry, as exemplified in previous sections. Other examples of AR in industrial design have been limited to only a few commercial uses, and most of the effort has been done in research setting. However, there are several apps developed for mobile devices through which users can virtually 'try out' finalized products on themselves or within the intended environment for the product. Following are some examples.

The app developed by Botta Design helps its users to try on different watches to show exactly how the watch would look like if the users were wearing it (Figure 2.58).

Another example, Ultimaker, combines 3D printing with AR to see an image of the product being built on the printer before the printing has been completed (Figure 2.59).

Augment is an AR application that is specialized in marketing and sales of products (Figure 2.60). It is also intended to be used by industrial designers to enhance the production life cycle by enabling them to test their design virtually in the intended environment.

Ikea has recently started adding AR content in their product catalogues (Figure 2.61). In this way, customers can scan the pages that have extra content, such as downloadable 3D models of furniture, to test how they would look in their houses.

2.3.8 Research on Usage of Augmented Reality in Industrial Design Activities

2.3.8.1 Introduction

There has been research on implementing AR in industrial design activities. Visualization of products, simulation of usage and ergonomic analysis are some of the domains through which mixed reality can be applied to new product design [67]. There is a rich source of literature on which types of industrial design activities has been the spotlight of AR studies. These studies have focused on virtual design environments, hybrid/augmented prototyping, assembly in industrial design [68], and

Figure 2.58: AR visualization of watches [63]

Figure 2.59: Ultimaker, open source 3D printing and AR visualization [64]

other implementation areas in product development and realization such as design for collaboration, maintenance planning, factor planning, augmented training and augmented quality assurance [67]. It has been found out that AR is beneficial for collaboration in design discipline as well [69, 70]. The bulk of the studies that have been conducted in usage of AR in industrial design focused on augmented prototyping and virtual design environments.

Figure 2.60: Augment, AR content creation application [65]

Figure 2.61: Ikea AR application [66]

2.3.8.2 Augmented Prototyping

In the design process, designers go through stages that encourage them to build physical mock ups for testing purposes. However, these mock ups usually lack detail and can not provide an accurate representation of mechanical construction, material, assembly, etc. AR has been considered a valuable tool for bridging this gap. Verlinden et al. have defined augmented prototyping as incorporating AR with virtual and physical prototypes [71]. Verlinden, Suurmeijer and Horvath have worked on augmented prototyping systems and have summarized the domain of application in six categories of geometric modeling, interactive painting, layout design, information appliances, automotive design and augmented engineering; and have conducted multiple case studies on branches of industrial design such as information appliances, automotives and furniture [72]. An array of display technologies have been considered worthy of attention for augmented prototyping purposes of designers, such as see through displays, projection based displays and embedded displays combined with manual model making, automated creation and actuated surfaces [73].

Some experimental tools for augmented prototyping have been developed over the years. Park, Moon and Lee have proposed a system that consists of a pointer and an object for prototyping handheld products [74](Figure 2.62). Skin is an augmented prototyping tool that works by projecting materials, textures and colors as flat images onto surfaces of 3D mock ups (Figure 2.63) [75]. ARMO, short for augmented reality based reconfigurable mock up, combines rapid prototyping with AR based manipu-

lation of shapes, colors, textures and user interfaces [76]. Dynamic Shader Lamps, which consists of multiple projectors that render a virtual representation on top of a physical object, allows the user to paint on moveable objects [77](Figure 2.64).

2.3.8.3 Virtual Design Environments

Another application of AR into design process is virtual design environments that provide a tangible tool for three dimensional form-giving. According to Ran and Wang, this improved tangibility of design tools will result in more usable and interactive design processes [68]. There have been experimental tools that enable designers to engage in spatial design. ARCADE is a system for 3D solid modeling in an AR design space with a low learning curve and accessible equipment [78].

The aim for being able to interact with the designed object in a virtual world during design process has been explored by several researchers. Caruso and Re have developed an interactive AR system called 'Video See Through Head Mounted Display' for visualizing and interacting with virtual designed objects to be able to review and offer feedback to objects for further design improvement [79] (Figure 2.65). Dima et al. presented a display concept which uses AR with haptic feedback that allows designing of virtual geometry [80]. Santos et al. has proposed using digital tape in

Figure 2.62: Prototyping handheld products [74]

Figure 2.63: Skin augmented prototyping tool [75]

Figure 2.64: Dynamic Shader Lamps for interactive augmented prototyping [77]
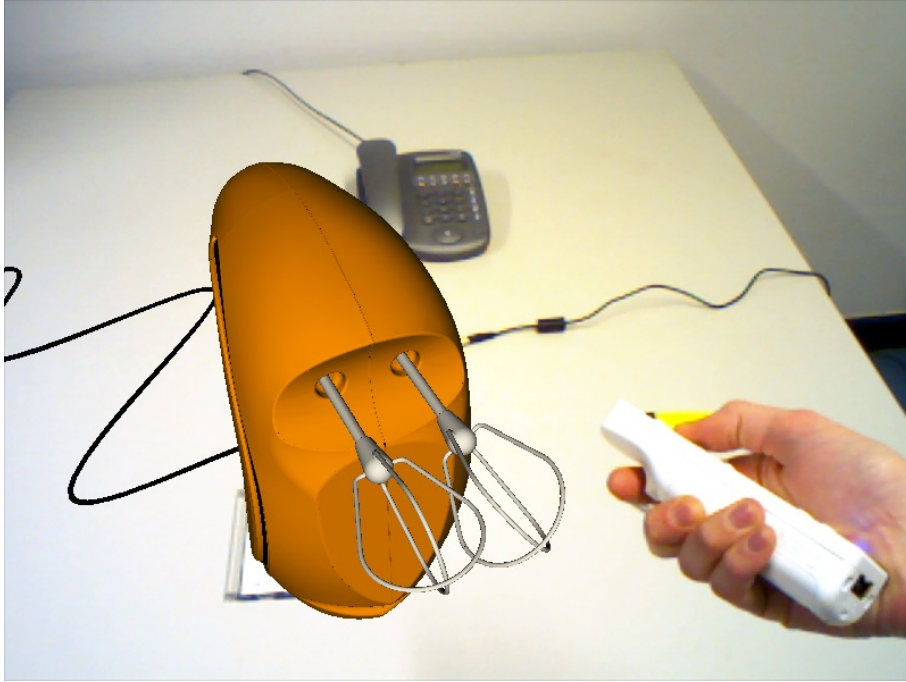
Figure 2.65: Video See Through Head Mounted Display [79]

an AR setting to aid freeform surface generation [81]. Another example of form-giving AR solution is Spacedesign, a free form modeling tool that has a virtual 3D workbench which designers can use for freehand sketching, surface creation and engineering visualization [82] (Figure 2.66). COVIRDS, short for Conceptual Virtual Design System, is a virtual reality environment for creating concept shape designs in a more relaxed setting than CAD software [83]. Responsive Workbench [84] and 3-Dimensional Immersive Virtual Sculpting systems are similar tools developed for creation of three dimensional shapes for product design.
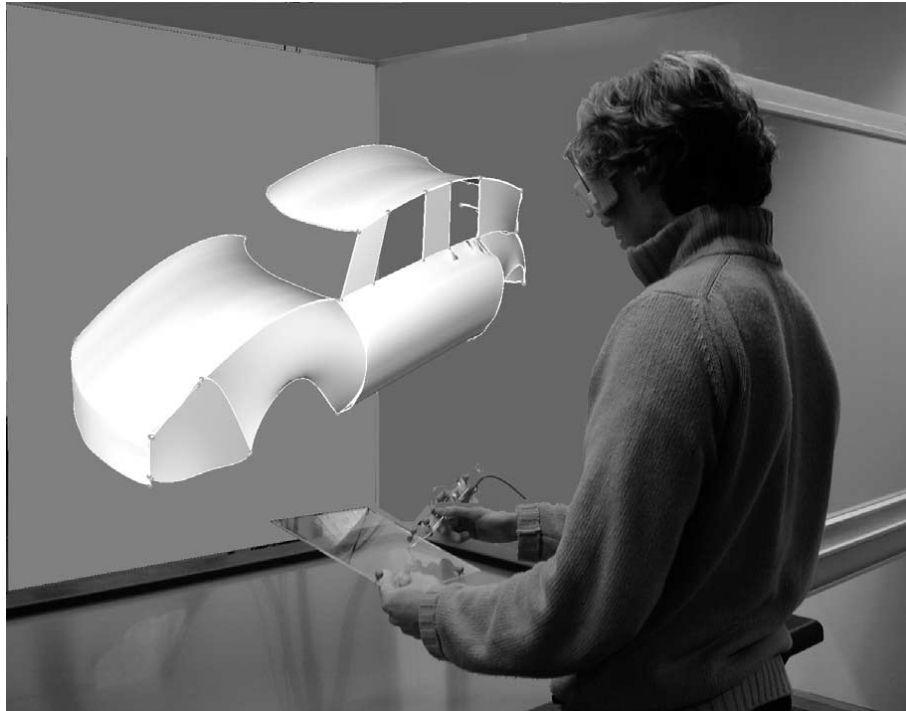
Figure 2.66: Spacedesign, AR freeform surface modeling [82]

2.3.9 Review of Mobile Augmented Reality Apps with Their Relevance to Industrial Design

Albeit not being directly marketed towards industrial designers, there are a selection of apps that are relevant to design activities. The apps shown in Table 2.2 are directly relevant with design activities, and can be used by industrial designers. Wooden Doll 3D is an app that places a jointed dummy in a scene in desired poses to provide a reference for drawing a scene. Augmented Drawing is useful for tracing digital images on paper by overlaying the image on the paper through the screen of the mobile device. The user looks at the paper from the camera of the mobile device and sees the image on the paper, and traces it easily. Colorify is an app that detects a certain color, and enables the user to change the selected color.

The apps shown in Table 2.3 on the other hand, are not directly relevant to design activities, and are not marketed as such. However, they can be used as a tool in some design activities. Pocket Snow Storm! enables the user to view the environment as if they were in a snow storm. This function could be useful for viewing outdoor usage of designed product in different weather conditions. Zooburst, described as a digital

storytelling tool for 3D pop-up books, could be used to present usage scenarios of a product. By using markers to show 3D models and animations as if the presentation board was a pop-up book, the usage scenario of a product can be displayed very easily. colAR Mix app can also be used for viewing 3D models of designed products, but the main purpose of the app is coloring in images in a coloring book and displaying the 3D model with the colors it has been painted in. This would be very useful in coloring and texturing the 2D drawing of the product and showing it directly on the 3D model.

Table 2.2: Mobile AR applications for design activities.
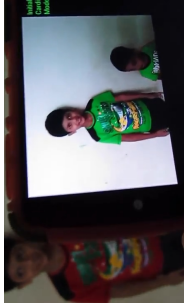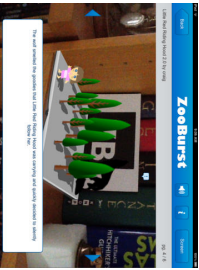
No.	Application Name	Developer	Representation	Description/Purpose
1	Wooden Doll 3d	Jeremie Daigle		Jointed dummy. *Drawing reference in a scene.*
2	Augmented Drawing	Iyen		AR tracing tool for drawing. *Ease of sketching by tracing a translucent digital image overlaid on paper.*
3	Colorify	Drona Systems		Changing colors of objects in real environment. *Being able to see different color options on the same object in real time.*

Table 2.3: Other mobile AR applications having potential uses for product/industrial designers

No.	Application Name	Developer	Representation	i) Description ii) Suggested uses for designers
1	Pocket Snow Storm!	Useless Creations Pty Ltd		Creation of virtual snowflakes. *Presentation – effect.* *Placing product in a winter scene.*
2	Zooburst	Zooburst LLC		Digital storytelling tool for making 3D pop-up books. *Presentation – usage scenario.* *Showing usage stages like a story in 3D.*
3	coIAR Mix	Puteko Ltd.		Displaying 3D models of colored-in characters in a coloring book. *Presentation – color and material on a 3D model.* *Sketching/coloring drawings of an object and showing how it would look like in 3D.*

2.3.10   Discussion

This chapter provided an overview of the product development process and introduced the concept of AR. Product development process is a subject open for discussion and development, and one needs to look at every step a new product goes through to be able to see the role of the industrial designer. Each product has a unique life story from conception of the idea to being manufactured, but the design activities in-between can be summarized, and the basic design activities that make up the whole process are arguably universal. AR is introduced later in the chapter by touching upon the definitions, related terminology and components, and the commercial and research applications of the technology. This technology has the advantage of being very eye-catching and popular among both developers and the general public, which means there is a vast resource of software & hardware combinations to be explored. Putting the focus on AR solutions for industrial design purposes starts building the bridge between the design process and the technology. As mentioned in the problem statement, there are activities in the design process that could be improved or enriched by AR, and even some new solutions can be made possible by the technology, and the motivation behind the fieldwork was to offer solutions to industrial designers to use AR in design process. The apps that were mentioned previously offer some suggestions on how the technology can be utilized. The fieldwork will be a continuation of these suggestions to help designers imagine and experience how AR can be used for design activities in different stages. The following section will introduce the structure of fieldwork for evaluating AR technology for industrial designers.

CHAPTER 3

PLANNING OF FIELDWORK FOR EVALUATING AUGMENTED REALITY TECHNOLOGIES FOR INDUSTRIAL DESIGNERS

3.1 Introduction

This chapter presents the structure and details of the field study for evaluating AR technologies for industrial designers. The three-stage fieldwork will be introduced along with the selection of AR tools, participant selection, and data collection methods relevant to each stage.

3.2 Components of the Fieldwork

As can be seen in the examples presented in the literature review, AR technology has been used in several design-related fields as an aid. Some examples of these uses are visualization of plans of buildings in architectural applications of AR, augmented prototyping of products which enhance physical mock-ups by overlaying material and texture properties real-time, and applications of AR in form-giving activities as reviewed by the term spatial design. AR has been implemented in several other fields that are not as related to industrial design, but might inspire potentials for designers. In commercials, AR has been implemented to improve the visual presentation of products; in museums, it has been used to provide additional information about artifacts; it is utilized as a tool to guide mechanics in assembly and repair tasks; all of which purposes might exist in a product's development stages. These examples are

the source of inspiration for the research, which aims at exploring the potentials of AR to enhance the design process.

The fieldwork consists of three studies: 1) Creating awareness of AR technologies; 2) Exploring the potential of mobile AR applications in a design project; and, 3) Self-reflection on the potential uses of AR technologies (Figure 3.1). Study 1 and Study 2 are undertaken in an educational setting, because design activities that students go through are similar to the stages of professional design setting; but without the limitations of time, budget and marketing.

Study 1 is aimed at creating awareness of AR technologies amongst designers and inspiring them about its implementation to industrial design to find out the conceptual possibilities a designer might think of with the inspiration from examples of AR integration in various fields.

Study 2 explores the potential of existing mobile AR applications in an educational
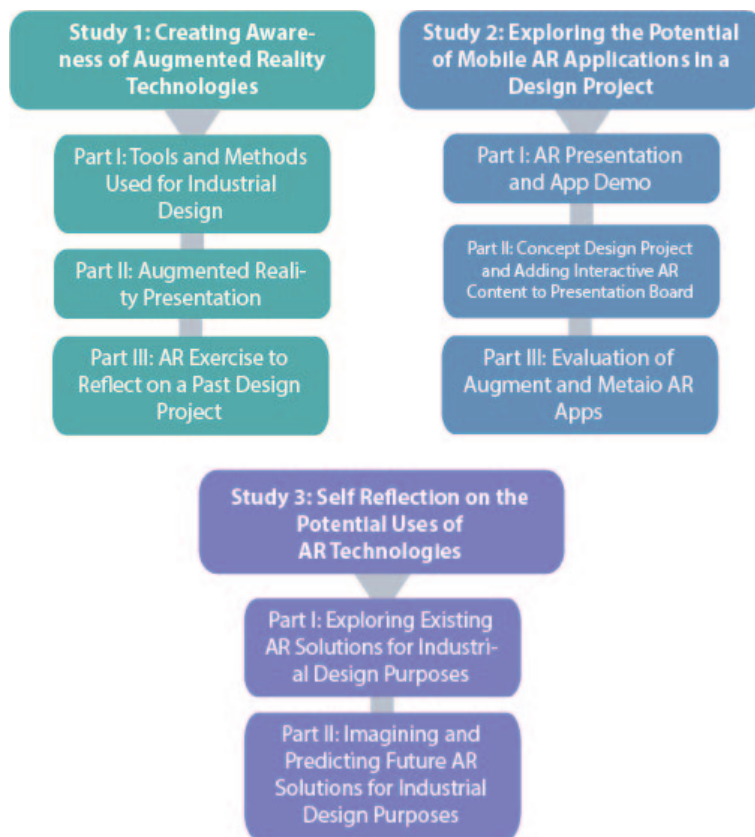
Figure 3.1: Components of the fieldwork

design project by setting a practical example of using a selection of AR apps for design activities, conducted by industrial design students.

Lastly, Study 3 is undertaken by the author to reflect on the potential uses of AR technologies, along with future predictions and suggestions. This study will provide a more in-depth review of the whole spectrum of current hardware and software combinations that are analyzed with their relevance and applicability to product design.

3.3 Study 1: Creating Awareness of Augmented Reality Technologies

3.3.1 Selection of Participants

Seven industrial design alumni with work experience as industrial designers participated in this study.

3.3.2 Part I: Tools and Methods Used for Industrial Design

The first step was a survey that aimed at finding out what stages design students go through in product development, matching these steps to the deliverables that they are expected to present, and evaluating the tools and methods they use in design activities. The participants were surveyed to provide a framework to briefly assess the design activities they go through, and the outcome of these activities. This was an online survey that each participant filled out prior to the presentation and the interview in the second and third steps of Study 1. The participants were asked to answer the following questions:

- What are the project stages that you go through from the briefing to the final presentation?

- What are you expected to document/present during these project stages?

- Do you feel you are able to satisfactorily present the intended interaction/interactivity of your products with users? If not, can you imagine ways to overcome this problem?

- Are you on the lookout for new tools and methods for designing products? Are you interested in new technologies for this purpose?

- Have you ever used AR (or similar applications) for presenting your projects?

3.3.3 Part II: Augmented Reality Presentation

In this step, all participants were given a one-to-one, 10 minute Powerpoint presentation that shows a wide range of AR applications, from mobile apps to room size projections. This information about AR and its application areas is aimed at inspiring the participants about enriching their industrial design process. After a brief definition of AR, the types of information that can be augmented into real environments with this technology are introduced (video, images, sound, text, interactivity, 3D models). Afterwards, a selection of interesting application areas of AR were shown including architecture, prototyping, museums, medical, mechanics and repair, construction, social networking, tourism, games, military, navigation and science fiction movies. While looking at these examples, they were encouraged to think about how they could apply the technology to the design process.

3.3.4 Part III: AR Exercise to Reflect on a Past Design Project

After the presentation, the participants were asked questions about how they could integrate AR in their design process in one or more of their previous design projects. It was a semi-structured interview that lasted between 10 to 20 minutes with each participant. Three of the participants were shown the presentation and interviewed at the same time. The questions they were supposed to answer in this interview were about how they could benefit from using a range of AR applications in one or more past design projects of their choosing, e.g. to enhance the presentation of their ideas, adding interactive content, improve presentation, etc., using specific examples to describe how AR could enrich their output. They were encouraged to think of this question considering the stages of their design projects. Because this is a study based on brainstorming, they were given no limitations as to what kind of AR technologies they could use, hardware and software-wise. They were also prompted to reflect on

what kinds of difficulties they might face when using AR applications in future design projects. The participants were asked the following questions:

- Choose one (or a collection) of your past design project(s) and think about where you would have benefited from using a range of Augmented Reality applications, e.g. to enhance the presentation of ideas, adding interactive content, improve presentation.

- Please give specific examples to describe the ways that AR could have supplemented the design process and enriched the output.

- What stages of your chosen design projects do you think would have benefited most from AR applications?

- What kinds of design activities might you have accomplished with Augmented Reality technologies if at the time you had access to the whole range of hardware and/or software and solutions?

- In future product design projects, what difficulties do you think you might face when using Augmented Reality applications?

- Would you be interested in exploring the possibilities of Augmented Reality technologies in a future design project?

3.4 Study 2: Exploring the Potential of Mobile AR Applications in a Design Project

3.4.1 Selection of Participants

Eight participants who were graduate level industrial design students taking the course ID535 Design for Interaction in METU in 2013-14 fall semester participated in Study 2. Their participation was during their design project for the course. They all had mobile devices (smartphones or tablets).

3.4.2   Part I: AR Presentation and App Demo

In the first stage of this study, the participants were given a more specialized Power-point presentation about AR mobile applications, which took place during class time and lasted for approximately 20 minutes. AR solutions have become very easy to access, and currently there are lots of software that can run even on computers, tablets and smartphones to display 3D models, animation, sound, 2D visuals and text. This makes the technology very easy to access, and the support from the websites and the community provides quick learning and implementation possibilities. In the demo, the participants were shown the basic structure and a mini tutorial of the selected software, and example uses showcasing the capabilities of each software as much as possible through projects in which the author implemented the usage of the software.

3.4.2.1   Selection of the AR Software

As this component of the overall research aims at gathering practical data about using AR in product design, accessibility and usability were the main criteria in selection of software. As outlined previously, AR software developed to be managed through personal computers and mobile devices are the most suitable choice. Among the two categories of AR software, namely content creation/app building services and end user AR apps, content creation software is selected. The reasoning of this choice is that this kind of software enables the user to create their own AR scenarios by overlaying their own content on physical surfaces such as markers, as opposed to end user apps that are specialized for displaying fixed content with very limited interactivity.

A number of software/apps that are developed for content creation and management have been tested by the author. These are Layar, Daqri, Metaio and Augment. Among these, Metaio and Augment were selected, because they are both applications that enable the users to create their own content and display it through channels they publish. They are both available for Android and iOS smartphones and tablets, and they have free of charge versions with much wider opportunities for creating and publishing content than the apps that have been eliminated.

3.4.2.2   Metaio Creator & Metaio Toolbox & Junaio Browser

Metaio software consists of three interconnected parts, each with a different purpose. *Metaio Creator* is used to upload digitally created content and link them to trackers, which at the end gets published into channels. Junaio Browser is an application to scan trackers to connect to the channels published with Metaio Creator to view AR content. Metaio Toolbox is a supplementary software that is used to make 3D point-cloud maps of objects to use for object tracking.

The types of data that can be augmented with Metaio Creator are (Figure 3.2);

- 3D content

- 2D image content

- Sound files

- In-page and full screen videos

- Youtube videos

- Buttons

- Web pages
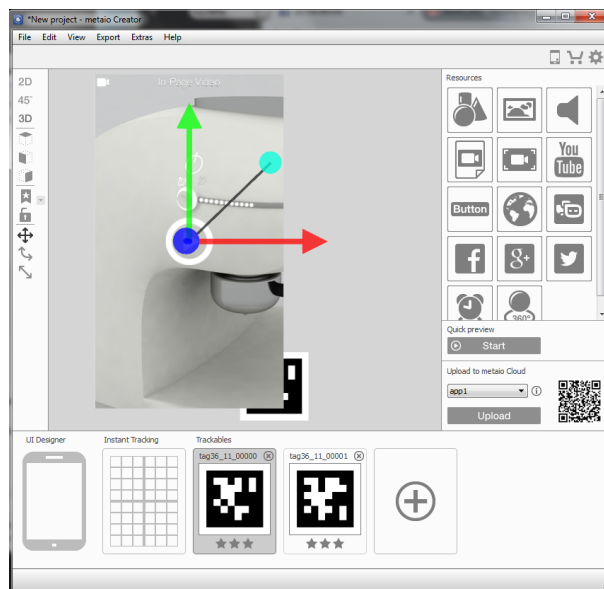
Figure 3.2: Example project shown in Metaio Creator

- Facebook, Twitter, Google+ links

There are two types of trackers that can be uploaded to Metaio Creator to augment with data: images and objects. Any image that can be easily recognized by the scanning software can be used as a tracker; however, the optimum results come from using a matrix marker. To use objects as tracker, Metaio Toolbox application is used to create a point cloud map of an object, or a CAD model can be uploaded.

Metaio Toolbox is a supplementary software to Metaio Creator that enables the user to scan a three dimensional object in real environment to be uploaded as a tracker(Figure 3.3). This is a mobile application, and the user is prompted to scan the object from different angles while the software takes pictures and saves them to create a 3D map (Figure 3.4). The more detail the object has on the surfaces; the better it can be recognized by the scanner.

Junaio Browser is the next step in the process after uploading a trackable and augmenting data on Metaio Creator. In Metaio Creator, the user is prompted to make an account and save their projects to Metaio Cloud by publishing them as channels. After a channel has been published, a QR code is generated for Junaio Browser to scan and reach the channel. These channels can be reached by using the search feature in the browser as well. When the user is connected to the channel, they can scan the trackable in the real environment to see the augmented data on top of it.
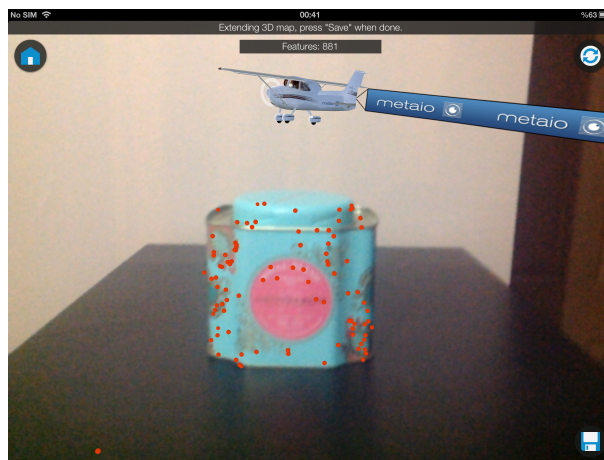
Figure 3.3: Using Metaio Toolbox to scan a tea box
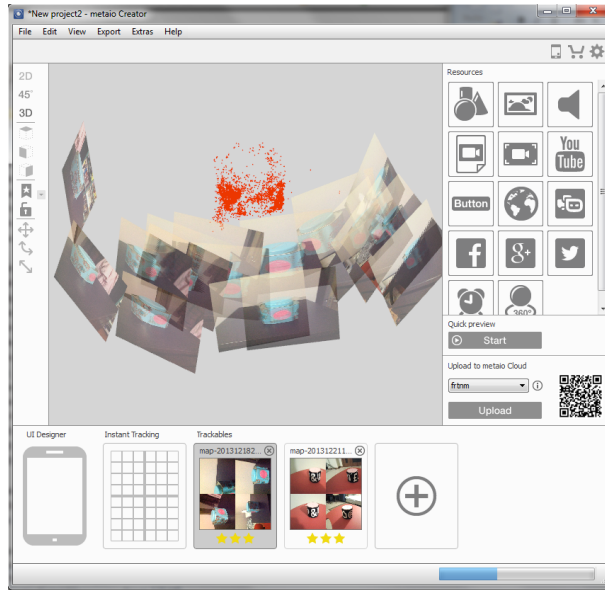
Figure 3.4: The scanned tea box uploaded as a trackable on Metaio Creator
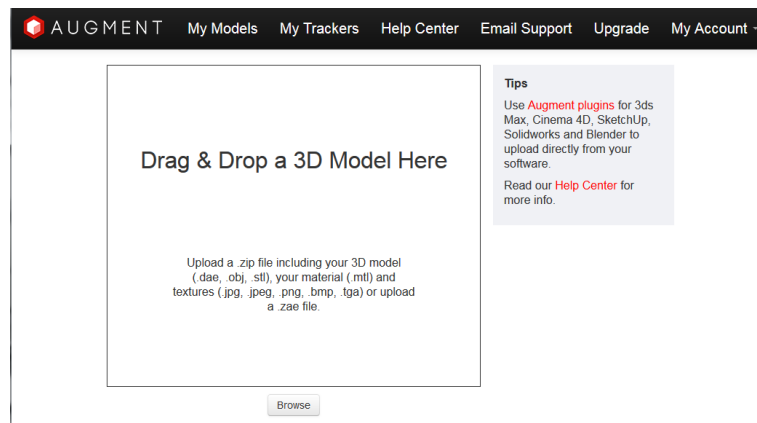
Figure 3.5: Augment website

3.4.2.3 Augment

Augment is a more straightforward application in comparison, but with fewer features. It has two sources of input from the user: the model and the tracker. The user simply uploads their model on the website (Figure 3.5). When they open and login on the application for their mobile device, they can take a picture of anything they want provided that it's optimal for tracking (or they can print and use the official Augment tracker image), and they can pin their model to the picture. When they scan the real environment with the application, their model appears upon the tracker. This model can easily be moved, rotated and scaled within the application itself.

3.4.3 Part II: Concept Design Project and Adding Interactive AR Content to the Presentation Board

The participants, who were graduate students taking the course ID535 Design for Interaction in METU, were asked to make use of Metaio Creator and Augment applications to add an interactive content layer to their final presentation boards of concept alarm clock project that they carried out. Between the briefing of the project and the final presentation, the students had five weeks to develop their projects and use the applications for their final presentation. During the development process of this project, the author was available in each feedback session as a guide to answer their questions and give them ideas about what they could do with the capabilities of the software. At the final presentation of their projects, they presented their interactive content on their presentation boards and 3D mock ups. The AR layer of each presentation was documented with photographs and screenshots.

3.4.4 Part III: Evaluation of Augment and Metaio AR Apps

Immediately after their presentation, the participants were handed a survey asking them to evaluate whichever applications they have used. The survey had questions for each software to gather information about how they used the software, how they thought it enhanced their presentation in ways that would not be possible with their usual workflow, their likes and dislikes about the applications. They were prompted to give their opinion on whether they think adding AR content to the final presentation boards were useful and why, the extra features that they would like to see which were not provided, and whether they would be willing to use the technology in a future design project.

3.5 Study 3: Self Reflection on the Potential Uses of AR Technologies

In this study, the researcher undertook an exercise to show the potentials of where AR can contribute in design projects.

3.5.1 Part I: Exploring Existing AR Solutions for Industrial Design Purposes

In this part of the study, the author used her past design projects Espresso-Based Coffee Machine and Wake Up Light as examples to reflect on potential contribution of AR within the design process. This exploration has been done both hands-on using easily accessible solutions to illustrate what the technology allows designers in the current state of the technology. The apps Metaio, Augment and Dynamapper were utilized to show previously unexplored benefits of AR in design activities.

3.5.2 Part II: Imagining and Predicting Future AR Solutions for Industrial Design Purposes

As a continuation of the literature research, Study 1 and Study 2, this section of the study proposed uses of AR that have not yet been developed for design purposes. All of the inspiration from existing examples, ideas from participants of Study 1 and Study 2 to make an AR solution just for designers, and predictions on what the future might bring are compiled to outline what kind of design activities might be good candidates for AR integration.

CHAPTER 4

ANALYSIS OF THE FIELDWORK EVALUATING AUGMENTED REALITY TECHNOLOGIES FOR INDUSTRIAL DESIGNERS

4.1 Introduction

As overlaid in Chapter 3, the fieldwork consists of three studies: 1) Creating aware-
ness of Augmented Reality (AR) technologies; 2) Exploring the potential of mobile
AR applications in a design project; and, 3) Self-reflection on the potential uses of
AR technologies. This chapter contains the relevant results and analysis of the three
studies.

4.2 Results and Analysis of Study 1: 'Creating Awareness of Augmented Real-
ity Technologies'

Study 1 consisted of three successive stages: i) Preliminary Study: Typical Design
Activities and Outcomes of Industrial Design Student Projects; ii) Augmented Re-
ality Presentation, and iii) Augmented Reality Exercise to Reflect on a Past Design
Project. Seven Middle East Technical University, Department of Industrial Design
alumni all with a degree of professional experience participated in the study. The first
stage involved the review of design activities and the outcomes that the participants
produced with relevance to various project calendars they followed in response to the
design brief and the requirements set by their instructors during their undergraduate
education. The second stage was a presentation given by the author to the participants

about the state-of-art AR technologies. This stage aimed at inspiring the participants about the potentials of AR technologies. To think about then reflect back about if they had the chance to use AR technologies at the time, how/and in which ways it could have helped them to improve various aspects of their project presentations. The third stage of Study 1 was a semi-structured interview about encouraging the participants to reflect back and imagine about if they had the chance to use AR technologies at the time, how/and in which ways it could have helped them to improve various aspects of their project presentations.

4.2.1   Part I: Preliminary Study: Typical Design Activities and Outcomes of Industrial Design Student Projects

4.2.1.1   Overview of Analysis and Results of Preliminary Study

In the preliminary study, the participants were asked five questions which were analyzed thematically. In the answers to the questions, the main goal was to figure out: a) the activities that industrial design students carry out, b) the deliverables expected at the end of each of these activities, and c) evaluation of physical materials and digital tools used in design projects.

a) Activities that industrial design students carry out

The participants were asked to recall their undergraduate design projects and think about the stages they followed based on their project calendar. The stages that they followed showed variations between the participants and between the projects, therefore the results will not be presented in a chronological order. However, it was still possible to reach a conclusion about the types of the design activities carried out, regardless of the consecutive design stages that they performed the activities in. Design students start with a *project briefing* that explains the criteria for design and define the problem statement. This briefing sets specifications for design proposal about the possible areas in which the new product will bring a design contribution. A *literature and field research* is conducted to gain insight on the context of the product. In this research, the students gather information about similar products on the market based on function, usability, aesthetics, usage context, interactions, cost, material, and so

on. A user group review is included in this research to set the criteria for the characteristics of the possible user such as age, gender, and occupation. The *initial idea generation* studies take place to explore possible solutions to the problem statement by pushing boundaries and generating as many innovative ideas as possible. The initial ideas are developed and presented through activities such as *sketching* and *model making/prototyping*. The students explore and present each step of the usage of their design proposal and present the usage scenario. The design proposal goes through *user testing* during which the student is expected to present the design proposal to a possible user to get feedback on the usage. In the later stages, *technical drawings* showing the details of the final design proposal are prepared. *Rendering of the 3D models* of the products are prepared for *final presentation*. In these activities, design students use a combination of physical and digital tools and methods.

b) Types of deliverables expected from design students

During these design activities, design students were reported to be expected to come up with and present some deliverables such as field research results, sketches, usage scenarios, moodboards, interview results, mock ups, CAD drawings and renderings, interface details, construction schemes and material selection, and videos. As outlined in Table 2.1 based on educational design projects, these deliverables are prepared using a variety of tools and methods.

c) Evaluation of physical materials and digital tools used in design projects

The participants of the preliminary study were asked to evaluate the current physical materials and digital tools they use in accordance with whether they are able to satisfactorily present the intended interaction/interactivity of their products with users.

A repeating comment was made about *representing interactive details* of the product. The tools and methods that the participants currently use, be it renders or physical mock ups, are not enough to convey enough details about interactivity. Videos were found to be a good way of showing interaction, but it is time consuming and requires a lot of effort. It was reported that it would be much better if there was a way products could be visualized in their own usage context, with opportunities to show the whole interaction scheme. Additionally, products with digital interfaces cannot be adequately represented with these methods. When presenting the stages of interac-

tion in the interface with posters, many steps are often skipped. It can be inferred that this is a result of the final medium of output even if it is created digitally: 2D posters. Even though digital content might have additional layers like three dimensionality, moving images, etc., the output is two dimensional, which limits the potentials of presentation.

Another issue is *scaling problems of CAD applications*. Because design students do not have a realistic representation of the interaction with the product they visualize, they have to do physical models in parallel to CAD drawings to overcome this problem. However, this is regarded as a time consuming solution, and the physical models do not always turn out to be exactly as it was intended.

In short, it was made clear that the participants thought there were weak points in the tools and methods they use for industrial design projects, especially when presenting interactivity and interfaces. After the survey about tools and methods in industrial design, the second and third part of the study took place.

4.2.2   Augmented Reality Presentation

In this stage of the study, the participants were given a presentation to inform them about AR technology covering a wide range of uses in different fields in order to inspire them about the third stage of the study.

4.2.3   Augmented Reality Exercise to Reflect on a Past Design Project

4.2.3.1   Overview of Analysis and Results of Augmented Reality Exercise to Reflect on a Past Design Project

The answers of the interview were organized thematically. Because the main reason for this part of the study was to find out which type of design activities the participants might enhance by using AR, the answers were categorized by each design activity.

The design activities that the participants came up with during the study are in relation to design activities such as a) presentation, b) scenario building, c) mock-ups, d) user

tests, e) research, f) idea generation, and g) getting feedback from instructors. These activities are listed not in chronological order in the calendar of a design project, but according to how suitable they are for implementation of AR. As the last category, h) the disadvantages should be discussed. The participants will be referred to as P01, P02... in the following section.

a) Presentation

The participants mentioned that in the final jury and presentation of the project, details such as interface, inner parts which they would not be able to show with the existing methods, can be shown using AR. Not only would this enable them to show more detail of the product, it would make the presentation impressive and attention-grabbing. P05 mentioned that the participant's graduation project had animated graphics, and with the help of AR, it would be possible to make this dynamic property of the product come to life and be more impressive in the presentation.

For presentation purposes, being able to see the product in usage context was found to be a major advantage of AR. It was found to be very useful to see the product in the environment it is meant to be used. Products are designed in a vacuum without any reference to the environment, and the only way to present the product within context is by Wizard-of-Oz techniques in rendering in artificial environments or using Photoshop to copy and paste the product in place. However, with AR designers have the chance of placing the product in its intended place to get a feel of how well the product fits in the context. It would be beneficial to see the product in many different places to know how it would look in different environment conditions like lighting. Tea set project of P04 was suggested as an example for seeing different contexts: in the cupboard for storage, in the kitchen counter for preparation, in the coffee table for usage. Another example was P01's table-top laundry machine. P01 commented that because the product was out of the norm of laundry machines that are self-standing, it would be good to see how it looks on top of a surface (Figure 4.1). P04 commented that it would be very useful when buying furniture to be able to see how it would look on one's home, to know whether it would fit, or it would make the room look cramped.

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Figure 4.1: P01's tabletop laundry machine design project

b) Scenario Building

In scenario building activities during which the interaction between the product and the user is drafted, AR can be used to make the process more efficient, as participants commented. It should be noted that usage of AR in this design activity is closely tied with presentation. The participants are disturbed by the fact that there is no way to show interfaces of products within the current presentation methods they use. Paper mock-ups are utilized to show interface details, however, this is not always found to be enough to portray the full range of interaction. It is impossible with presentation boards to show anything but 2D images and text, which the people viewing the board will not even pay full attention to. With AR, showing interaction details such as sound, texture, and animation is possible, which would normally be very difficult for the designer.

P07's espresso machine project is a good example for this implementation of AR (Figure 4.2). P07 said that in the project, a touch-activated textured surface started a process in the machine, and it would be beneficial to be able to show this not in a presentation board or a video, but on the product itself by zooming in on the textured surface to activate it to show the full range of interaction that takes place. P05 commented that in the lighting unit project, the back surface of the device was used as an
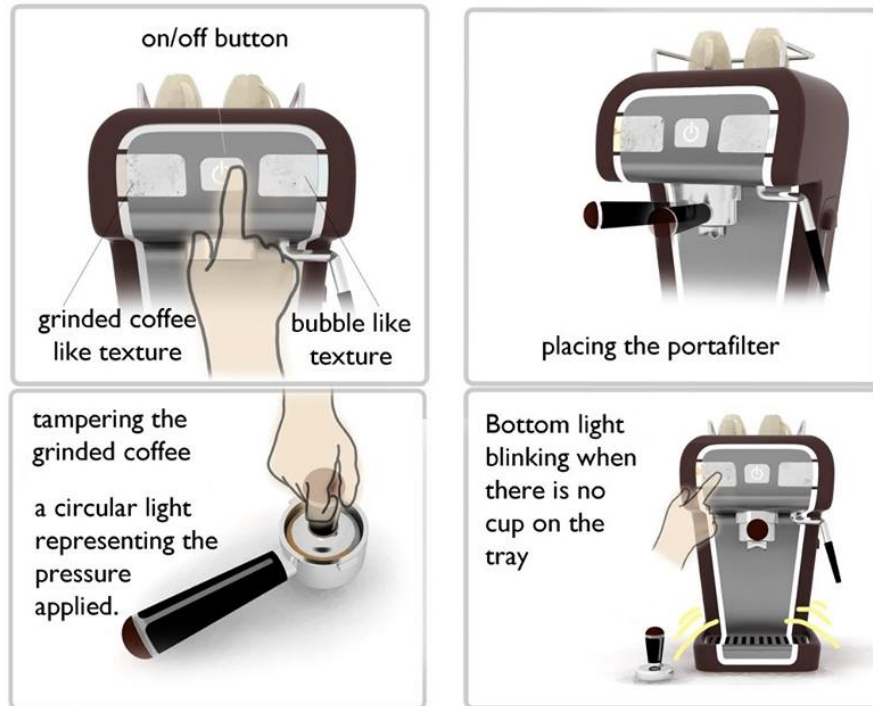
Figure 4.2: In P07's project, the touch-activated surface is not obvious in the presentation board

interface, and it was not possible to show this in the mock-up or presentation board. P05 thinks it was a waste of time and effort to make a video to show the interaction (Figure 4.3).

c) Prototyping

Many of the participants thought AR could be utilized in prototyping stages of design. Mock-ups are expected of designers, and most of the participants would rather spend their time on developing the usage details and preparing presentation boards that show the full range of the product than preparing mock-ups. This is because often it is impossible to show details such as color, material, texture and size as intended. It takes a lot of effort to produce professional looking mock-ups. The participants commented that AR could be used to enhance basic mock-ups. They would like to make a white mock-up without a texture and use projection mapping of AR to show selections of material, color and texture. This would prevent them from leaving the material selection to the last minute, as it would become very easy to look at many different options with projection on existing mock-ups. P02 commented that there was a very amor-

Figure 4.3: In P05's project, the 2D image is not sufficient to show the interactive surface behind the body of the lighting unit

phous form in a project, and the mock-up did not look satisfactory. If P02 had access to the necessary AR tools, it would be possible show texture quality in the prototype.

d) User tests and usage instructions

The participants reported that AR could be utilized in user tests, and for showing users how the product is meant to be assembled or operated. For user tests, AR was found to be very useful in showing the product in its intended context to give them an idea whether it would be suitable for them or not. In addition to user tests, assembly and usage details of complicated products could be showcased much more effectively than in presentation boards and user manuals if AR was utilized. Sometimes designers are discouraged from designing complex products because it is predicted that users will have problems with it, however if instructions could be overlaid on the product, it would open up many possibilities for the designer. Many participants commented that Ikea's example of placing AR content on their catalogues for assembly animations of their products was a brilliant idea that every designer could benefit from. The participants also commented that the presentation boards in exhibitions are not enough to give information on the product's usage details, and if with AR people can come and discover this kind of information from the product on their own when they are not there to explain, it would be a big advantage. P06 designed an air purifier complained

Figure 4.4: P06's air purifier design project

that nobody took the effort to read the presentation board and asked about information that was already given. P06 commented that if AR aid had been available, it would be possible to show how the filters work, how to change the filter, and so on. P06 would show the color of the filter changing from green to red to let the user know it needs to be changed, as this question was asked many times (Figure 4.4).

e) Research

In the research stage of design, AR was found to provide unreached potentials to designers. For instance, when the designers are doing field research before they start designing the product, they could search the existing products with an AR application to learn how they are made, who they are designed by, what components they are made out of, etc. This information is usually not provided by the sales people and seeing details about existing products would be very valuable. An AR app for building a material library was suggested by P05. P05 thought that out of all the materials and textures commonly seen in daily life, it would be good to be able to scan and learn what it is, and save it for using it later in a design project.

P04 thought that an AR app that gives information about the product in the design brief when the designer is introducing the product to potential users would be very useful, because sometimes they are required to design products that are not well-

known and not easy to imagine without any help.

f) Getting feedback

Another aspect in design process that AR can be utilized is presenting the progress in a project for evaluation to authorities or getting feedback. P02 came up with the idea of using AR to show how the product will perform in usage to be able to convince the stakeholders of the product that it will be suitable for production and durable for usage. P02 commented that it would be very useful if an AR app could show the load-bearing capacities of, for example, a load-bearing object with a pivot, or an object that is meant to be hanged on a wall to perform tasks upon. P07 thought it would be very useful in showing progress to the instructors on an educational industrial design project with the help of both physical and digital components, i.e. sketches and notes along with AR content. For practicality purposes, information augmented on the real environment viewed through a mobile device would be very beneficial, as opposed to showing this information on the screen of a PC, which lacks interactivity.

g) Idea generation

The participants commented that on the benefits of using AR in idea generation stages of product design, however they had difficulty in imagining possibilities. P04 thought that the implementation of technology in design process is very important, because even by seeing that the real environment can transform itself to another level by AR can inspire designers to push boundaries with using newly developed technologies in their projects. P03 declared that it would be really beneficial to use AR to visualize mindmaps for idea flow in idea generation stages.

4.2.4   Commentary

In the preliminary study, an overview of industrial design activities, the deliverables, and an evaluation of tools and methods used in design activities was presented. There are two main problems with these tools and methods: the interaction with the user can't be visualized adequately in the context of usage, and products with digital interfaces are oversimplified in presentation. Applying AR into design process can help eliminate these problems, as well as bring extra benefits. The main study, during which the participants imagined how AR could have been utilized in their past design

projects keeping in mind the problems in the tools and methods that they mentioned in the preliminary study, revealed that the stages that AR showed the most promise in integration with are *presentation*, *scenario building*, and *prototyping*. Apart from these three, the other design activities also mentioned are: *user testing*, *presenting usage instructions*, *conducting field research*, and *creating a material library*.

4.3   Results and Analysis of Study 2:   Exploring the Potential of Mobile AR Applications in a Design Project

This section reports on a study to explore the potential of AR technologies to beneficially provide an additional interactive digital layer of information onto 2D presentation models and 3D physical mock-ups, typical deliverables expected from an industrial designer. The study was carried out in an educational context, embedded in a design project called Bedside Alarm Clock which was a part of the Design for Interaction course in the 2013-14 fall semester in METU Industrial Design department. The Bedside Alarm Clock project had a duration of five weeks, and the students had 2-3 weeks for preparing the AR content for their projects, during which time the author had been available to assist them. This provided an ideal setting for experimentation and feedback, whilst being sufficiently close to professional practice to judge commercial applicability. Students were exposed to three project parts: i) AR presentation and software demonstrations; ii) concept design and creation of AR content; and iii) evaluation of utilized AR software.

4.3.1   Part 1: AR Presentation and App Demo

This step of the study consisted of a presentation that informed the participants briefly about AR technology, and introduced the two mobile AR apps Metaio and Augment. These two apps are available both for Android and iOs platforms, and they enable the user to upload the content they create and embed them on markers (i.e. 2D images that were recognized by the AR software to display the content on top of) and view the digitally created content in the real environment by scanning the market with a mobile device. The demo that followed the presentation showed step by step how to

use each app and exemplified their capabilities on a past design project of the author. The author's project called Ready-Set-Go Cappuccino is an espresso machine, which was completed for the same course the previous year. The 2D presentation board of the project was used along with markers to show interaction details in the project such as blinking lights, user-product interaction and sound, with the app Metaio.

4.3.2 Part 2: Concept Design Project and Adding Interactive AR Content to Presentation Board

The second step of the study started with the briefing of the Alarm Clock Project by the course instructors. The students were explained that they were expected to add AR content into the project presentation by making use of the two AR apps to enhance their final presentation, either on their 2D presentation boards or their 3D mock-ups. During the five weeks of the project development, they had guidance on what kind of data they can produce to enhance their presentation, and how to use the apps to suit their purpose.

4.3.3 Part 3: Evaluation of Augment and Metaio AR apps

The third and final step was the presentation of the participants' projects with the AR-enriched presentation boards and mock-ups.

4.3.3.1 Overview of Analysis of Usage and Evaluation of Augment and Metaio AR apps

The analysis of the usage and evaluation of Augment and Metaio AR apps of the study was done by examining each question of the survey. The screenshots and photographs of presentation boards and mock ups enhanced with AR content supplement the relevant questions. It should be noted that none of the participants used Augment, so all of the answers are gathered from their experience with Metaio. The participants will be referred to as P01, P02... in the following section.

Table 4.1: The additional content added to the presentations of participants.

File type	Usage	Participant	Medium of presentation
Sound	Sound of Alarm	P01, P02, P03, P04, P05, P06, P07, P08	Presentation board
Video	Video of alarm lights and movement	P01, P02, P04, P05, P06, P08	
	Video of interaction steps	P03, P05, P07	
	Video of alarm lights on mock up	P01	Mock up
	Video of interaction steps on mock up	P05	
3D Model	Texture on mock up	P02	

4.3.3.2 Results

Q1. What additional content did you add to your presentation by making use of Metaio?

The participants used Metaio app to enhance their presentation boards and mock ups with sound, video and 3D models. The sound of the alarm, the alarm light blinking or glowing, the interaction steps and the digital interface are things that the participants would normally have trouble showing in their presentation boards and mock ups.

As can be seen in Table 4.1, all of the participants had sound augmented in their presentation boards. The sound of the alarm was either embedded in a video that shows detailed interaction steps during usage, or separately to show the sound selection in the alarm clock. The videos that the participants prepared for presentation were augmented in the presentation boards and their mock ups. For their presentation boards, six of the participants showed the alarm lights and the movements in the product in their videos, whereas three of the participants showed the interaction steps, be it the screens in the digital interface, or the tangible interaction details. One of the participants chose to show the alarm light glowing, and another participant decided to present the interaction steps of the digital interface in the form of a video on top of the surfaces of the physical mock ups. One participant took it a step further by augmenting the mock up of the project with a 3D model that showed the true texture of the

material of the product. Figures 4.5 to 4.22 show a selection of these enhancements on the presentation boards and mock ups.

Figure 4.5: P01 scanning the markers on the presentation board to show the augmented animation showing the glowing lights of the alarm clock

Figure 4.6: P01's video of hand gesture to set the alarm clock, shown on the 2D presentation board

Figure 4.7: P01 scanning the marker on the mock up to reveal augmented video of blinking light
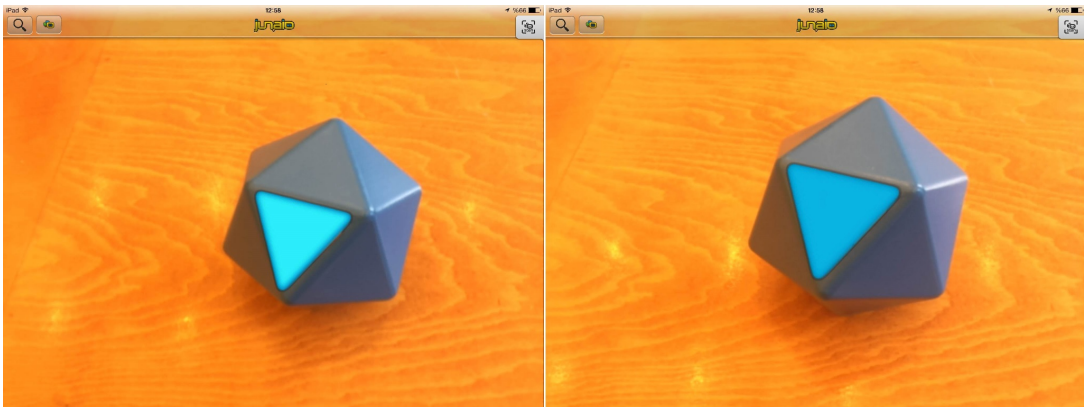
Figure 4.8: Two stages of the video showing the changing of the light in the surface of P01's mock up

Figure 4.9: P02 scanning the marker on the mock-up to show texture and animation of blinking lights
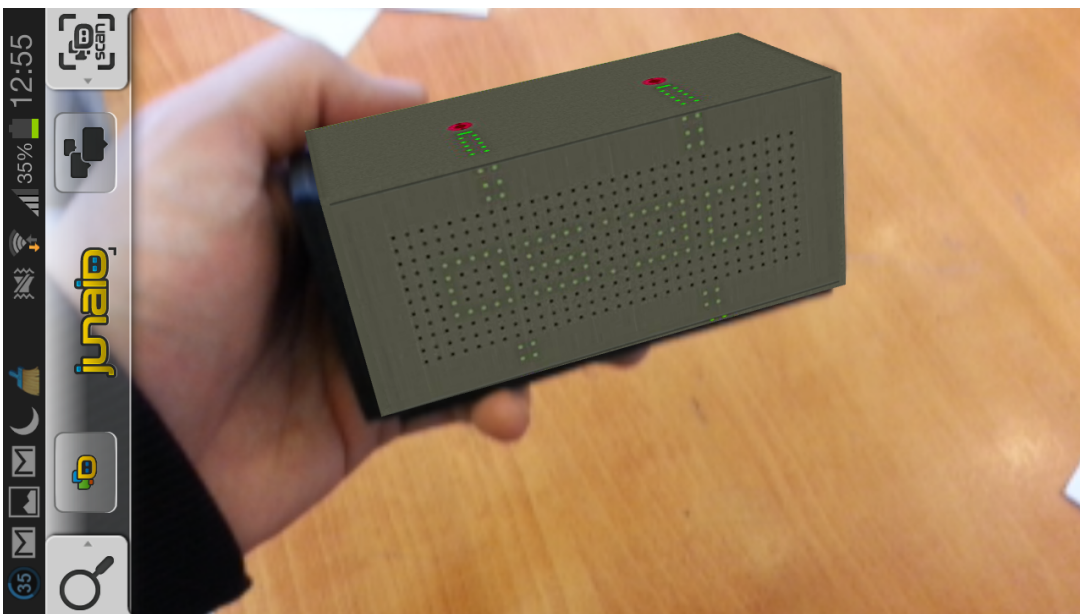
Figure 4.10: P02's mock up enhanced with AR to show material, lights and sound

Figure 4.11: P03 showing the usage video augmented on the presentation board

Figure 4.12: P04 showing a video showing interaction details augmented on the presentation board

Figure 4.13: P05 showing interaction steps in the interface of the alarm clock

Figure 4.14: P05 showing interaction details on a video on the mock up
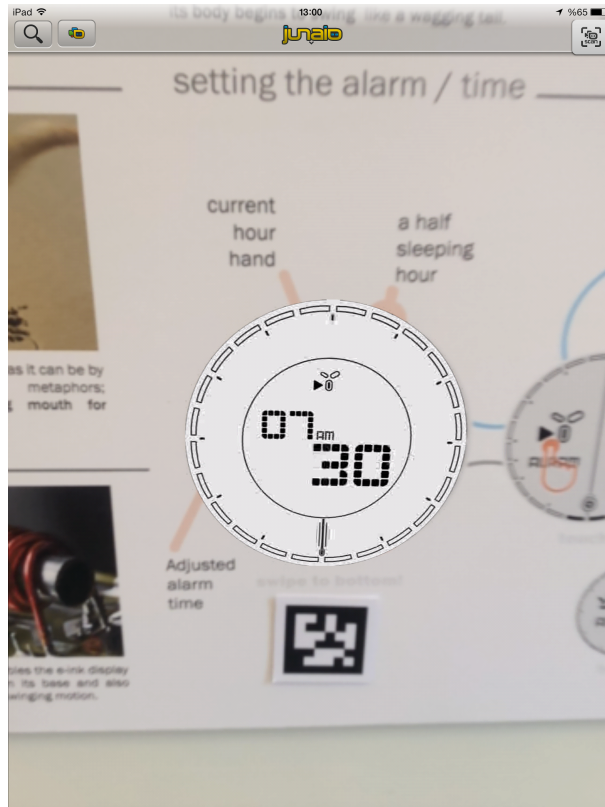
Figure 4.15: P05's screenshot of interaction steps of setting the alarm augmented on the presentation board

Figure 4.16: Screenshot from P05's video of movement and sound of the alarm clock augmented on the presentation board

Figure 4.17: Screenshot of P05's mock up with the augmented interface

Figure 4.18: P06 Showing the video of Mr Quiet overlaid on the presentation board
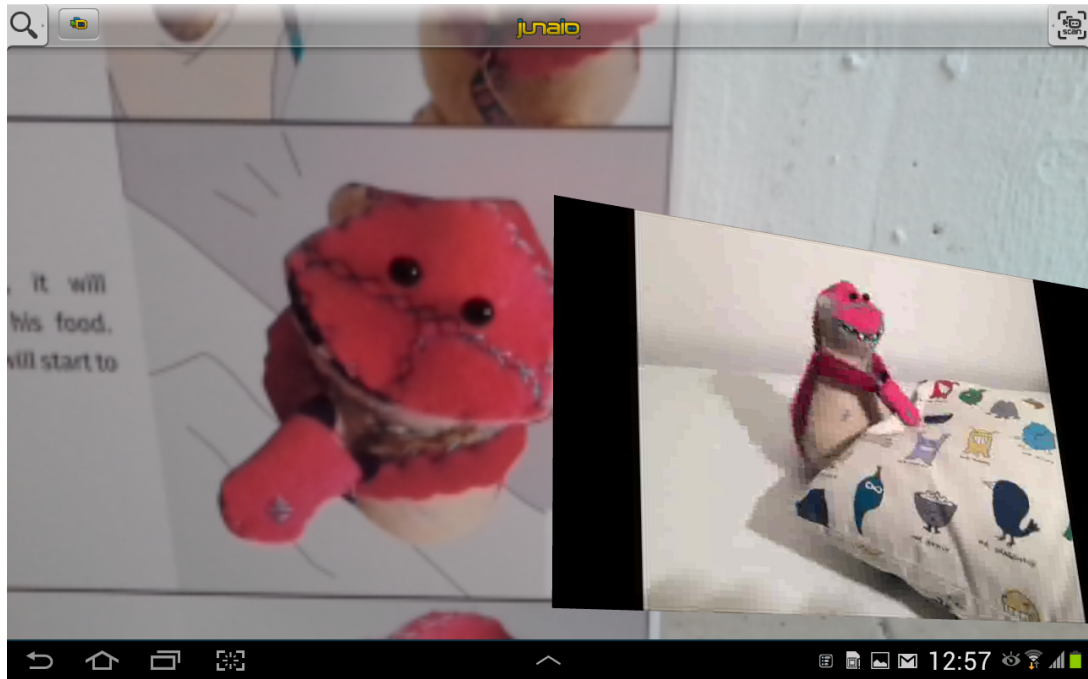
Figure 4.19: P06's screenshot of Mr Quiet in context of usage

Figure 4.20: P07 showing the hand gestures that activate the alarm clock on a video augmented on her presentation board
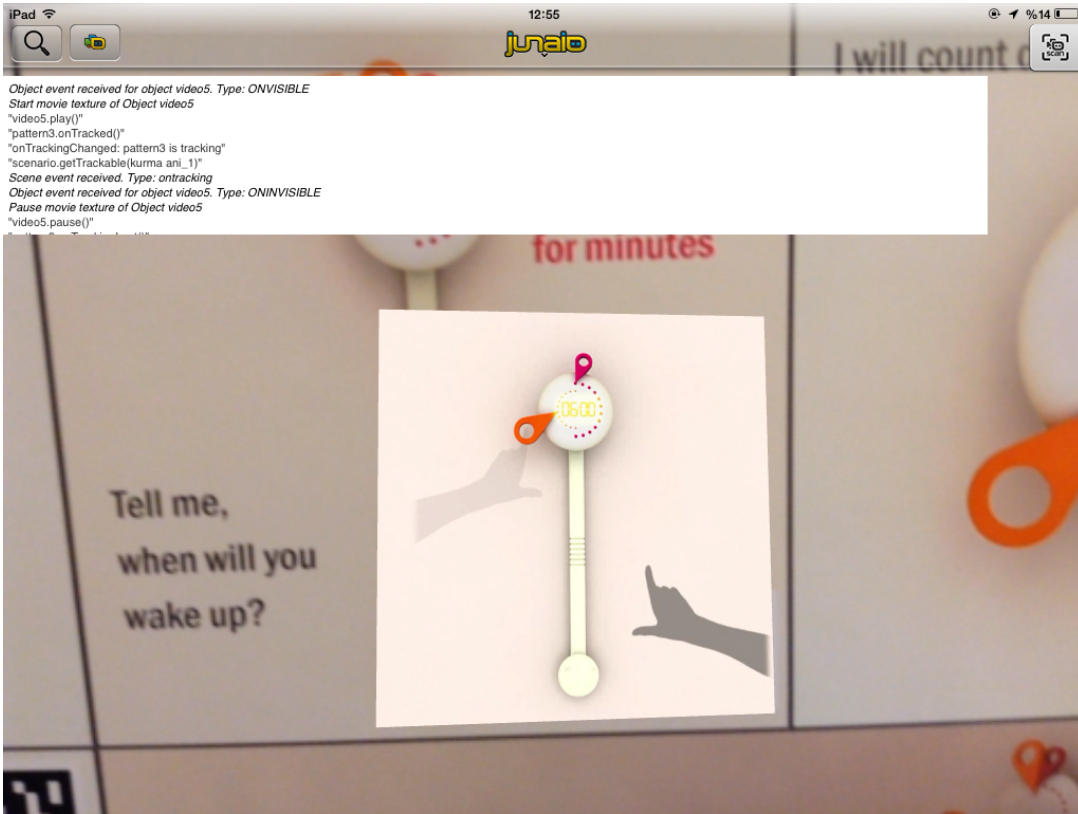
Figure 4.21: P07's screenshot from video of hand gestures shown on the presentation board

Figure 4.22: P08 showing the usage video augmented on the presentation board

Q2. How do you think the additional AR content enhanced your presentation? What do you think you achieved that you could not have done before?

Showing the stages of intended interaction with the product on the presentation board was a repeated comment about the advantages of AR. The participants reported that they could easily communicate the interaction steps of the product so as not to leave question in the minds of the jury. If it hadn't been for Metaio, they would have to orally describe or try to show the usage steps and interaction details only using static visuals. Because they were able to show video and sound, they were able to make it very clear to the observer how their product worked. To emphasize the importance of being able to show a video in such a setting without hassle, P07 made this comment:

> "If I hadn't used Metaio I would probably use an extra computer or tablet to present my videos. Videos are important for presenting moving parts and usage scenario of the designed products. In order to make people understand the exact usage scenario, designers are using images and words. They create a series of images and explain their scenarios step by step imitating the function of video. Metaio gives chance to express more with a small space." (Participant 07)

In short, the participants really appreciated being able to show video and auditory interaction, because the participants felt that only having presentation boards would not have been sufficient. To quote P08,

> "AR provides a new depth for the boring 2D presentation board. You can launch something with just a simple QR code. By using AR, I think I made it really clear how the alarm clock works, what sound does that plays and how the interaction takes place. It was much harder to make people imagine how your product works only with presentation board." (Participant 08)

Apart from augmenting presentation boards, some participants embedded video to their mock ups as well. In this way, the participants felt that they were able to illustrate the life-sized dimensions of the final product. In conjunction with the physical prototype, holding the physical object and the augmented projection of the final product onto it allow near tactile experience about the dimensions and general grasp of the

design intent.

Q3. What did you like about Metaio? What did you find easy?

All but one of the participants reported that they found the Metaio app easy to use, especially because it explained the process in two steps: adding trackers and adding media. Once they get the main logic, they could use the software so easily, especially with a 3D modeling background. P03 commented that the app was much easier than it looks, and all that was needed to do is place some QR codes or something else as triggers and put the materials that will launch. The participants thought that there were a lot of attributes of the software that could be helpful to them. For instance, being able to track 3D objects was found to be fascinating. P01 liked that the app augments the influence of traditional design poster on audience and gathers attention by offering eye-catching content such as showing the moving parts of the product, blinking LED lights or auditory results.

Q4. What did you dislike about Metaio? What did you find difficult?

A few difficulties were mentioned about the tracking functions of the app. For instance, the 3D object tracking functionality and the tracking of images was found to be problematic, because it took time for the app to recognize the object/tracker. One has to bring the camera close to the tracker for the app to recognize it, and then distance oneself from the tracker to show the whole content. This is also caused by lack of contrast and clarity when viewing the tracker. P05 commented that scanning of QR codes to enter the channel was an attention-breaker. Also, it was an annoyance that the app does not track more than one tracker at the same time, which would have been very beneficial for interaction augmentation with multiple objects, as P02 reported.

P01 commented that even though it was not difficult to use the software, placing the digital content on a poster by using QR codes was unnerving; because, the participant could not accomplish to make the intended effect at first trials. It would have been better if this process could have been made easier to carry out for first time users (designers). Although initial steps like inserting trackers and adding media to the trackers was found to be easy, the fine-tuning and adjustments took time for some participants.

Although it is less related to the usage of the application in industrial design process, it should be mentioned that some of these difficulties were problems like glitches in the program. It is found to be challenging to fit a resource to a 3D scanned model, because the software seemed to only have a perspective view to edit the model. It was a struggle for P08 to fit the resource on the desired place with the scale, move and rotate functions. Moreover, the software stopped updating data until the participant changed to a new channel, and some errors came up when the participant tried to view the content in the channel.

Q5. Would you use this application again? Why?

All of the participants said that they would use the application again. P01 commented,

> "I would definitely use this application again. Especially I am planning to use it in my printed portfolio. It is really an interesting and attractive way to show your work to people, especially for the parts that you wouldn't be able to show at all without this way." (Participant 01)

The participants reported that since the software is free, and there are lots of usage potentials such as adding animations, images and sounds to their presentation; it would justify the time it takes to create the intended content and apply it to convey their ideas in a more effective way and enhance their presentation. The presentation enriched with AR was found to be surprising, informing, and fun. P07 commented that it is nice to see something animated and moving on a piece of paper.

Q6. Where there other features or information you wanted to show with these applications that you couldn't show in the final presentation despite planning to? What was the reason you were unable to do everything you planned to do if this is the case?

Overall, most of the participants were able to show what they intended to show with Metaio, with some exceptions. P02 wanted to track more than one object, to be able to show separate parts of the alarm clock project interacting with each other in an AR setting. However, it was not possible to achieve this purpose, because Metaio is unable to track more than one object.

P02 commented that it would have been better to add more content. However, the

media to add to the presentation board took a long time to prepare, therefore it was not possible to add more. P01 said that it was possible to show everything the participant wanted to, but it took a whole day to master the software. The participant reported that he can do the same job now in thirty minutes maximum.

P08 commented about the limitation of using a mobile device. It would have been better to use an app through Google Glasss, which would allow people to touch, feel and interact with the product with AR. Similarly, the participant felt that it would be beneficial to use projection to augment data on presentation boards and mock ups.

Q7. Do you think adding extra AR content to final presentation boards was useful? Why?

All of the participants were in agreement that adding AR content was useful. They thought that it made it very easy for them to make everyone understand how their product worked by communicating the design intent and probable experiences with the product. They thought that it made the presentation more interesting to listen, and it even made it fun and magical. Because they could add more information to their presentation, they thought it provided a much deeper understanding of how the product works. They appreciated that the presentation board enhanced with AR would be useful in instances where they are absent, because the board would explain itself.

Q8. What additional features would you like to see, which were not provided by Augment and Metaio?

A number of possible improvements to what the apps provided were suggested. The main additional feature that the participants would like to see in an AR application for industrial design is being able to interact with the augmented content. As the apps are now, they offer only very basic interactivity with the content that is displayed on the mobile device when the user scans the tracker on the presentation board. Metaio can place a button on top of the marker that plays a sound when it is pressed. However, the participants commented that they would like to interact more with the content. This would also be beneficial to another participant's suggestion of enabling simultaneous multiple object tracking, which the user then can use to interact different parts of the objects with each other.

Another option that the participants would have liked to see was manipulating the content that is displayed. Instead of making revisions to the content, uploading it, publishing a channel and scanning the tracker again to reach the revised content, they would like to be able to make changes and get the results in real time. P04 had a detailed comment about a specialized AR app for designers to use. The participant said,

> "Maybe, there can be digital user interface elements such as buttons, knobs etc offered by these apps; and we as designers can add these interface elements on our non-working prototypes. After that, it may be possible to show several interaction outcomes just by using one scene and one QR code. For example, I am pressing a digital button that I located previously in the AR scene and see the outcomes as a blinking led. Then in the same AR scene, I am rotating a knob, and the blinking led changes its color. By this way, I don't have to use two separate scene and QR codes for interrelated interaction events." (Participant 04)

It was found to be a bit limiting to look through a tablet or a smart phone to view the augmented content. The participants thought that it would be great if there were a Google Glass or a similar product to wear see the content more effectively, and augmenting towards more of the senses besides seeing and hearing, like touch feedback, smell and maybe taste. p02 said that it would be beneficial to have a plugin in the app to use a high quality renderer to get better and more realistic lighting, texture and material visualizations.

Q8. Would you be interested in using Augmented Reality applications again in a future design project?

All of the participants said that they will be using AR apps in their future design projects. They thought that using a rough mock up to present final concepts and interfaces was an eye opening experience. They found the processes of both creating content and using it in presentation was useful and fun. They thought that it was more attractive to see things moving around the presentation board, instead of just static images. Provided that the apps suit their working style and they have time to dedicate to create the required content, they would be willing to use it.

4.3.4 Commentary

The main part of the study focused on the practice of using the mobile AR app Metaio in an alarm clock design project with interactive details such as sound, light and digital interface. The participant had success with the Metaio software package in presenting these details in their presentation boards and mock ups. They were able to show videos of alarm lights and movements, the interaction steps, the texture of the mock up as a 3D model overlay, and the sound of the alarm. By creating this additional layer of information on their presentation boards and mock ups, the participants were able to show details of their projects that they would not have been able to show with traditional presentation methods. It was promising that the quality of their presentation was heightened considerably and none of the participants had crucial difficulties during the process. Their ideas about improving the whole experience of using AR to enrich presentations will be useful for further studies on the subject.

4.4 Results and Analysis of Study 3: Self Reflection on the Potential Uses of AR Technologies

This section presents the study carried out by the author to reflect on the potential uses of AR technologies in design activities. The study includes two sections: i) exploring existing AR solutions for industrial design, ii) imagining and predicting future AR solutions for industrial designers. This study was aimed at covering existing AR solutions for industrial design purposes that had not been possible to cover in the previous studies. A review of the full range of AR examples from literature, and the solutions imagined by the participants of Study 1 and Study 2 was included in the completion of Study 3. In other words, instead of presenting the results of a stand-alone study; Study 3 is fed by the results of the literature review, and builds on to the results of Study 1 and Study 2. The structure of this study was built based on two factors: what are the unexplored potentials of the technology that can be applied to design process as of today, and what might be the future solutions for industrial designers that are yet to be developed and released.

4.4.1 Part I: Exploring Existing AR Solutions for Industrial Design Purposes

In this part of the study, the author chose a selection of previously completed design projects as examples, and tried to show the capabilities of AR in full potential. This part of the study was an exploration of what an industrial design student could achieve using AR technology with minimal effort, on realistic terms, with the current technology.

4.4.1.1 Past Design Project Enhanced with AR: Espresso-Based Coffee Machine

The 'espresso-based coffee machine' project was completed as part of a postgraduate course, Design for Interaction requirement, taken by the author in 2012/13 Fall semester at METU Department of Industrial Design. The project brief focused on a domestic kitchen appliance to empower householders to become baristas with the emphasis on designing for outstanding user-product interaction and experiences.

The author's project Ready-Set-Go Cappuccino (Figure 4.23) was a three-step espresso machine that guided the user to intuitively complete the tasks of grinding coffee beans, making espresso, and steaming milk for an optimum tasting cappuccino within time constraints. The three tasks are completed with the relevant buttons that give feedback with revolving light. The guidance is provided by a progressing LED light between the buttons that guide the users where they are in the process. The milk steaming nozzle has pressure sensors to regulate the steam intensity and is activated by pulling.

As the emphasis of the project was on creating a user-product interaction that empowered the user and made the process easy and time-efficient, it was crucial that the usage scenario could be presented without skipping any important details. Final design presentation was expected to be made on a single 2D board printout (60×110 cm) with foam back. Also, a realistic CAD rendering of the final design proposal placed in its use environment; and a step-by-step explanation of the interaction scenario should have been included in the board. However, feedback details such as blinking and revolving lights, and the sounds of the machine during operation were

Figure 4.23: 'Ready-Set-Go Cappuccino' the author's Design for Interaction project

impossible to show in a static 2D presentation board. The lack of interactivity in the presentation board was attempted to be compensated by explaining the details with text, which was not an optimum solution (Figure 4.24). In addition, a 3D physical sketch model or prototype was not an expectation for the final submission, which meant that the only way the product-environment interaction could be seen was with a CAD rendering in an artificial kitchen scene. This made the project very suitable for AR enhancement.

Following enhancements were made to the project's presentation board to show inter-action details by making use of Metaio software (Metaio Creator & Junaio Browser).

- The first enhancement was done to the first step of the usage scenario to show the blinking lights after the user presses the button to turn the machine on. A tracker was applied to the related image in Metaio Creator, then the tracker was then linked with a video file that showed the blinking lights. If the person viewing the presentation board scanned the tracker placed on it using Junaio Browser, the video attached to the tracker started to play.

- The second enhancement was done to the last step of the process to show that the user needs to pull on the steaming nozzle to activate it. Again, a tracker was added to the related image in the presentation board, which was then linked to a transparent video (i.e. having no background colour) of a hand silhouette

The user selects between enabling or disabling the steamer, then presses the button to turn the product on. The LED lights leading up to the grinder button start to light up, and the grinder button signals the user with a rotating light to use the grinder. In the meantime, the machine is heating up the water for later usage.

The user selects one or two shots with the switch, and presses the button to start grinding. The amount of beans to be ground for the selected number of shots is regulated by a microprocessor, as well as the tamping pressure after the grinding process is done. When the beans are ground into the portafilter and tampered, the light around the button turns off.

The lights leading up to the espresso button start to light up, and the espresso button signals the user with a rotating light to place the portafilter on the nozzle. The user places the portafilter on the nozzle, then selects one or two shots with the switch and presses the button to start the flow. The espresso button stays lit up during flow, and turns off after it is done. The flow time is controlled by a microprocessor.

While the espresso is flowing, and if the steamer option was selected at the start up, the lights leading up to the frothing nozzle start to light up and the light ring around the nozzle base starts signals the user with a rotating light to steam milk. The steam button stays lit up while steaming, and turns off after it is done. The nozzle has pressure sensors to regulate the steam intensity. The ribbed rubber detail guides the user to pull to start and adjust the flow.

Cappuccino is ready to drink.

The coffee bean container and the water tank caps have rotating lights that light up when there isn't enough for one shot.

Figure 4.24: Usage scenario of Ready-Set-Go Cappuccino explained with text and 2D images

pulling on the nozzle.

- The third enhancement was also added to the last step of the usage scenario. A sound file of steaming milk was embedded to a play symbol to let the user listen to the auditory feedback of the machine during this step. Figure 4.25 shows the trackers as placed on the images in the presentation board.

Additional AR enhancements were made to the project's presentation board by making use of Augment software (Figure 4.26). Augment was used to show the product in its intended usage environment to give a better impression of the context. In this case, the product is placed on a kitchen counter next to other appliances and objects. The 3D CAD model of the machine, which was prepared for the renders in the presentation board, was attached to a tracker which was placed on the kitchen counter. When this tracker was scanned with the Augment app, the 3D model of the machine showed up in real size. This model also had an animation that showed the portafilter of the coffee machine moving from the grinding section to the espresso nozzle.
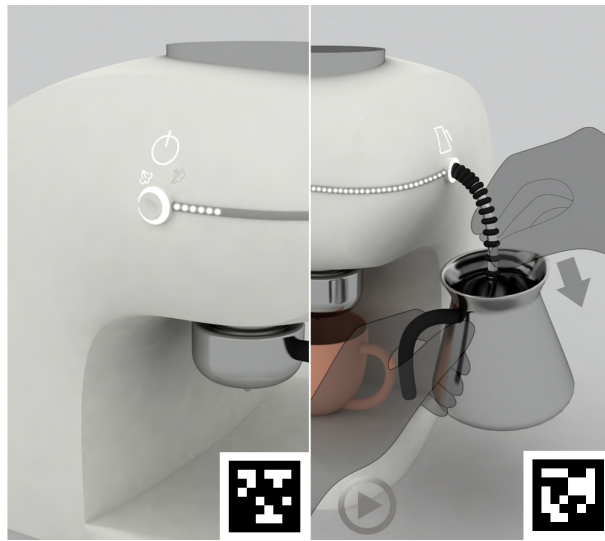
Figure 4.25: Images with the enhancement as shown with trackers on the presentation board

Figure 4.26: A model of the espresso machine in its usage environment

Details such as how the lights blinked, how the user needed to pull on the nozzle, and what kind of noise the device was supposed to make were some of the crucial interaction details of this project. Additionally, a physical mock up of the project was not developed. Therefore, a big part of what the designer was supposed to develop during the design process was not represented in the final form of presentation, a 2D presentation board.

What Metaio app helped the author to achieve was illustrate these details as an additional layer to the presentation board with video and sound files. The user interface was very easy to use, and the app was free, which made it a perfect solution to experiment with. The types of input that the user can upload to the software are very diverse, and settings such as transparency, placing a button on the AR scene to activate a command like playing a sound file, etc., makes the presentation not only informative, but eye-catching and inspiring. Because the emotional response to how a product is presented is also an important aspect of presentation, this process could be very fruitful for designers. One of the major disadvantages of the app is that the software is still in development, and there can be glitches sometimes. Other than the performance issues, the fact that the user needs to scan a QR code to find the AR channel, and then scan the markers for each augmented content can be a bit distracting and difficult to get used to for the third parties who want to view the content. However, the full version of the software package also has the feature to build an app that is independent, instead of being embedded in a channel that the user has to publish through Metaio.

Augment app helped to fill the need for a physical mock up by being able to see how the product would look in the intended usage environment. The animation also showed the moving part of the machine, as if the user was operating it. This representation of an important step in the usage scenario had not been possible with the presentation board. The 3D model, in the intended usage environment, showing how the part was supposed to be moved with an animation was the most that could have been done with the app, and it can be argued that it is the next best thing to having a physical prototype in place to demonstrate usage. The usage of the app is extremely simple, and it is not obligatory to use markers. The app has markerless tracking technology, the camera senses the environment and stabilizes the 3D model on its own. The only thing that the user needs to do is upload the content online, sign in to their

Figure 4.27: CAD rendered visual of the redesigned wake-up light

account on the app and place the content wherever they like. The limitation of the app on the other hand, is that the free version can only have two different AR content at a time.

Overall, the Metaio software package is the most sensible option for designers and design students at this time to do hands-on experiments with AR for presentation purposes. If a simpler, smoother app was needed, Augment is a good alternative.

4.4.1.2   Past design project enhanced with AR: Wake-Up Light

This design proposal was completed as a team project as the course requirement of Usability and User Experience Assessment in Design during the author's exchange studentship at Delft University of Technology, the Netherlands. In this project, a usability study was carried out on the Medisana WL 450 wake-up light to redesign an improved user experience (Figure 4.27). The principle of the product is letting people wake up in a more natural and relaxed way by imitating the sunrise and by making use of natural sounds. The sunrise is imitated by gradually increasing the intensity of the light along with increasing sound.

Figure 4.28: The physical prototype of the wake up light

The re-designed product improved upon the user experience with the changes in the digital interface, the physical interaction with the product, and the aesthetics of the form. To be able to present and do user-testing on these changes to the product, the design team prepared a prototype of the interface in Microsoft Powerpoint, and a vacuum-molded prototype of the body of the product (Figure 4.28). A problem that they had in doing the usability tests of the re-design was not being able to show the interface and the body of the product in the same place. Meaning, being able to test how the new interface worked with the changed form was not possible. The only solution to this was getting a print-out of one of the screens in the interface and sticking it on the surface of the physical model where the screen would be. Additionally, there was no convenient way of testing how the product might look like when the light was activated when it is in the sunrise mode.

Using AR at this stage would be feasible solution to these problems. The author has used Dynamapper app (developed by ReoTek) to project the user interface and the warm light that simulates the sunrise on the surface of the physical model. Dynamapper is a projection mapping app for iPad with which users can project still or moving images on surfaces (e.g. walls, objects, etc.) that they specify. The first step of using the app is connecting the iPad to a projector, and then placing maps on the desired surfaces using the app as mapping tool and previewing them on the surface with the
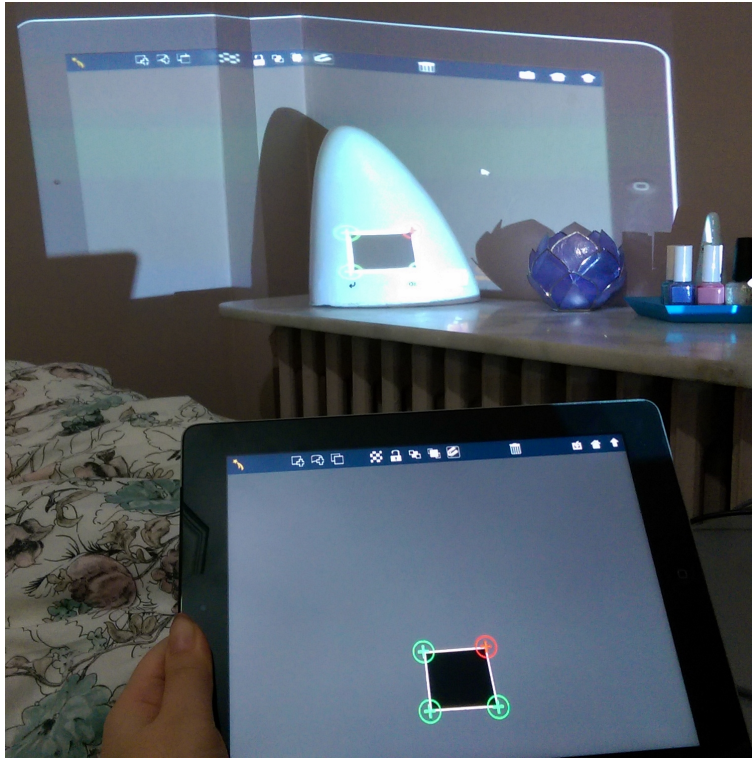
Figure 4.29: The process of placing maps on desired surfaces

projector, and placing images or videos on the mapped areas. In this example, the author has placed an image of the digital screen on the surface, and the warm glowing light when the alarm is activated (Figures 4.29 and 4.30). This way, a realistic representation of how the user might interact with the product in its intended environment of use, i.e. near the bed, is portrayed (Figure 4.31).

Dynamapper is an app that has unique qualities. There are other software options for projection mapping, however; Dynamapper is very user-friendly and easy to set up, making it very feasible for a designer to use. Projection mapping means that the designer does not have to urge the viewers to look through the screen of a device. Instead of having to hold up a device to view the augmented content, whatever that the designer wants the viewer to see is directly projected on the desired surface. This means not only will designers be able to show texture qualities on a simple physical model, and even illustrate the digital interface steps in the form of a video, they would also be able to present how a product that has an interaction with the environment of usage(such as a wake up light illuminating a room). This added layer of information in presenting in three dimensions can be considered as a revolution to traditional
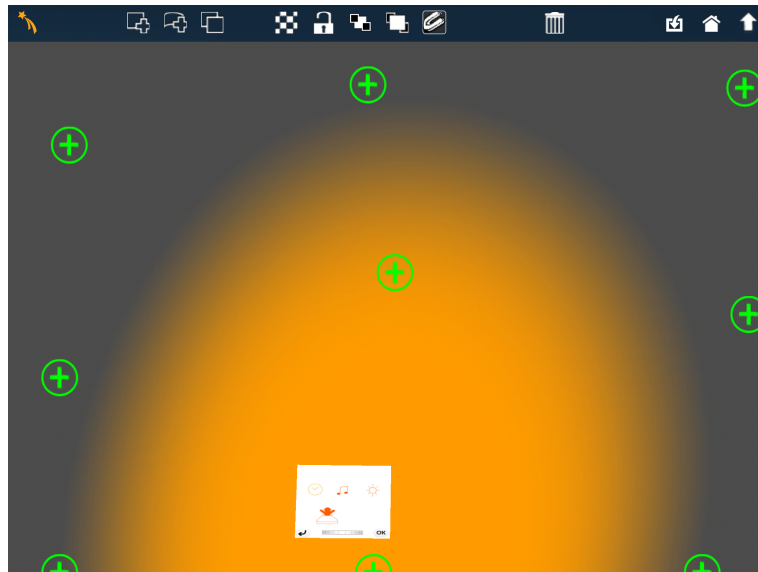
Figure 4.30: A screenshot from the app while the maps are being matched with images
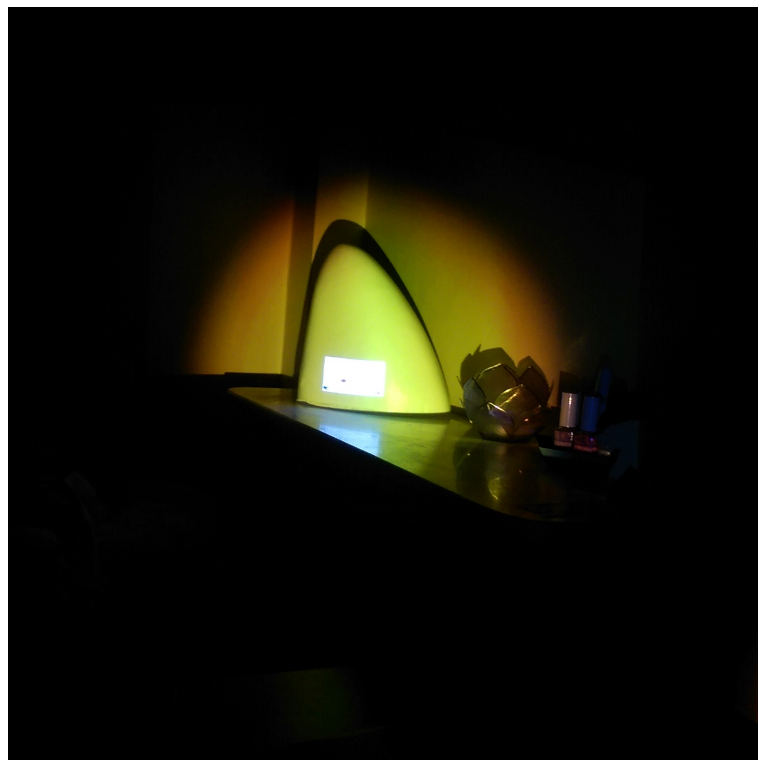
Figure 4.31: The projection showing the digital screen and how the light would look like

presentation methods for industrial designers.

4.4.2 Part II: Imagining and Predicting Future AR Solutions for Industrial Design Purposes

In this section, the author proposes the potential uses of AR – together with hardware and software combinations – in design without the boundaries of space, time and finance. The inspiration behind these AR ideas come from innovative hardware that has no specific software for an AR solution that could be used by industrial designers, and innovative software that has no easily accessible or yet-developed hardware component to run it with. In the results of Study 1 the participants came up with several ideas that could be developed further; and in Study 2, it has been proven that the existing AR solutions that can be used by industrial designers are also open for improvement. This part of the study can be considered as a collective brainstorm to inspire what the future of AR might look like for industrial designers.

4.4.2.1 Additional Interactivity in AR for Industrial Design Activities

If we look at the definition of AR, it is the visualization of digital media in the real environment. What about interactivity? Within any given AR system, the most common examples we see are digital content being displayed on a monitor or with projection, and the viewers simply observe, without being able to interact with the content. There are a number of commercial examples such as Augment in which elementary interactivity has been achieved by rotating, rescaling, and moving the object on the screen of the mobile device. There are some examples that have been completed as research that could be useful for industrial designers in certain design activities. The following examples have been introduced in Chapter 2. Here, they are reintroduced in Table 4.3 to match the description of the example to use suggestions for designers. These AR solutions would be beneficial for a specialized AR solution for industrial designers, as imagined by the participants of Study 1 and Study 2. It should be noted that these examples cover a wide range of hardware: projection, HUDs and mobile devices are included.

There first example of interactive AR systems is from MIT Media Lab: inSide, a tangible interaction project that enables the user to interact with projected AR content, Smarter Objects that enables the user to turn everyday objects into interconnected programmable devices such as a radio. Other examples are Spacedesign [**?**] for virtual surface modeling, Dynamic Shader Lamps [77] for real-time editing of material, texture and color properties of objects by projection AR, and Video See Through Head Mounted Display [79] enables the user to make changes to the design in a virtual environment.
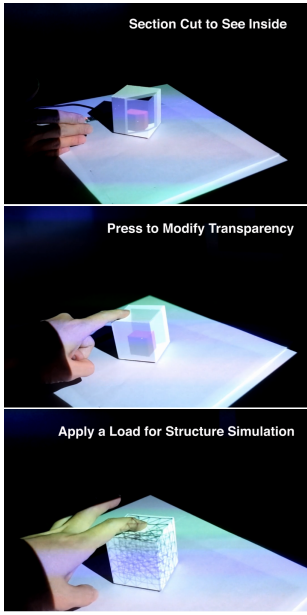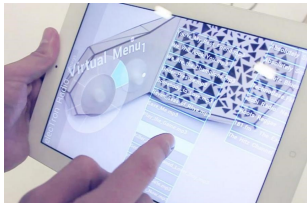
4.4.2.2   Additional Features for an AR Solution Just for Designers
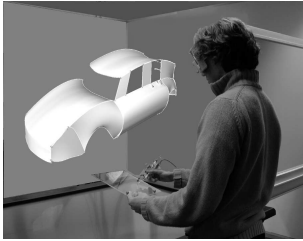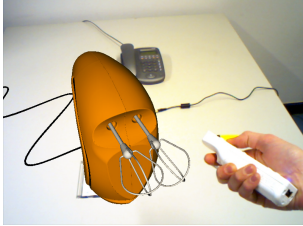
It has been made clear that AR would be a very fruitful tool to enhance the design process in various design activities. The possibilities for enriching design activities with AR has been imagined and explored in Study 1 and 2, and a consensus has been made on the necessity of an AR solution that is developed solely for the purpose of supplementing design activities. Study 2 showed that visualization of images, text, video, sound and 3D models are beneficial for presentation purposes. However, there are more design activities that AR could supplement. The following ideas for implementing AR into design process are not possible for the time being, either because the current technology has not been developed yet, or the related software has not been developed.

AR to support project research. A designer needs to conduct research on topics such as relevant products already on the market, manufacturing techniques and material selection for the product, etc. For these purposes, the capabilities of AR technology to scan markers or objects to get more information can be customized for designers to just show the information relevant for the research. For instance, when the designer is doing research on relevant products, they can scan the product to get information based on each part of the product what type of material it's made of, which manufacturing techniques have been used, how each of the parts have been assembled, and so on.

AR to support material considerations. When the designer is at the stage of selecting materials, it can be a problem to think of what kinds of materials that could be

Table 4.2: Examples of AR solutions with suggestions for usage in industrial design

Example	Developer	Representation	i) Description ii) Suggested uses for designers
inSide	MIT Media Lab		Tangible interaction project in which users can manipulate the AR content projected on a surface with their fingers *Finding out information about a product from its mock up: mechanical feedback such as structural integrity under pressure, detailed views of parts with transparency settings and section views.*
Smarter Objects	MIT Media Lab		Enables the user to turn everyday objects into interconnected programmable devices such as a radio *Being able to attach digital interfaces to physical mock-ups for presentation and user-testing.*

Example	Developer	Representation	i) Description ii) Suggested uses for designers
Spacedesign	Fiorentino et al.		Freeform 3D modeling tool with a virtual workbench *Digital real-time surface creation and editing.*
Dynamic Shader Lamps	Bandyopadhyay, Raskar & Fuchs		Interactive augmented prototyping *Painting on move-able objects to project a virtual representation of the product on a mock up.*
Video See Through Head Mounted Display	Caruso & Le		Visualizing and in-teracting with virtual objects for feedback and improvement *Making changes to the design in a virtual reality environment.*

suitable for the product. The materials used in a product can greatly affect what kind of experience the user is going to have when interacting with it. Therefore, a designer should always be aware of their surroundings to keep track of what kinds of materials that they would prefer their users to interact with. An AR app that enables the designer to create their own material library would come in handy for this need. Using this app, the designer can take pictures of different materials and textures to create their own material library. When paired with a projector and a plain physical mock up, trying on different textures for the product even just for visualization, can improve the design process by thinking about material selection as soon as the designer has a physical mock up.

AR to support mechanical and structural considerations. It is difficult to guess the mechanical response that the designed product will give when the designer does not have access to relevant testing software, which is typically used by mechanical engineers. An AR solution that shows mechanical information such as structural integrity under pressure during usage, load bearing capacities, surface distortion, etc. projected on the mock up and interacted with in real time would be a feasible solution for this problem. MIT Media Lab's project inSide is a project that sets an example to this kind of usage by enabling the user to press a finger on top of a physical mock-up to see the changing of a surface under pressure with projection.

AR to support display and feedback interfaces. What if we were able to combine AR with an interface prototyping tool? POP: Prototyping for Paper (Figure 4.32), is an app that transforms pen and paper ideas for digital interfaces into a real working prototypes. It has been commented that when designing interactive projects, designers have problems with building the interface stages, and testing them. This app is the perfect solution to this problem by providing a working prototype of the interface of the product that the designer is working on. By creating each screen of the interface by sketching them on paper, taking photographs and uploading them to the app, and linking the functions together with buttons on the screen, it becomes very easy to show interfaces. If we take this app however, and give it an AR interface, it would be even easier to imagine a working prototype of a digital interface on top of a physical mock-up. This would work by using the app like an AR browser, viewing the surface that is supposed to have the digital screen to make the interface prototype show up,

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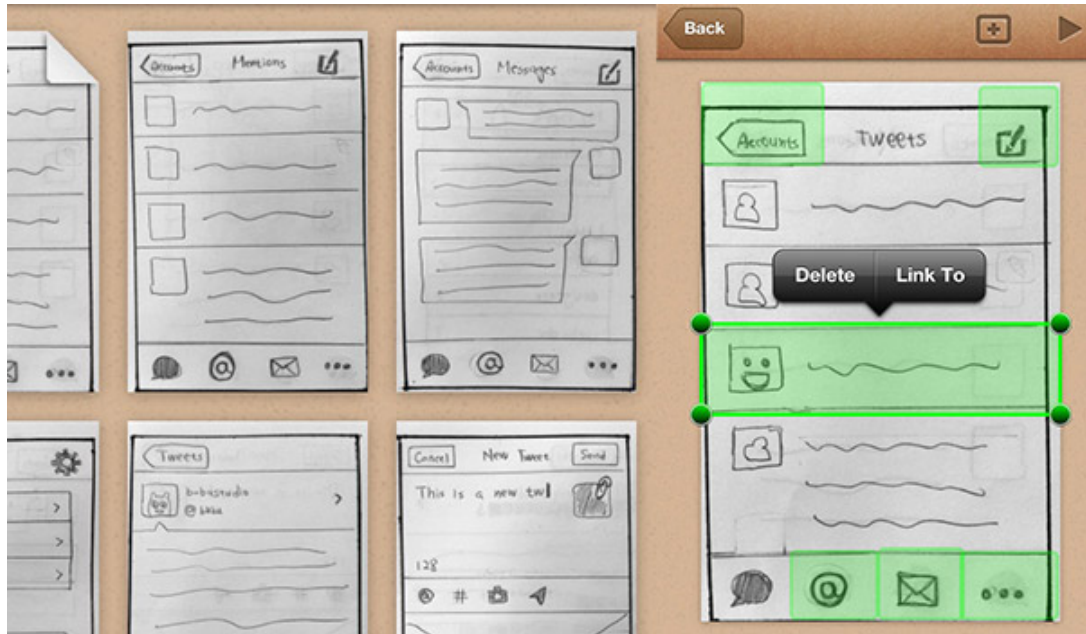
Figure 4.32: POP interface Prototyping app

and using the screen as if it's a touch screen on the surface of the physical prototype.

AR to support real-time virtual interaction. Development of technologies like AR depends a lot on developer communities working on both software and hardware. With open-sourced software development kits, integration of hardware for input and output of AR is rapidly increasing. Oculus Rift is an example of a crowdsourced head-up display that gained success within the developer community. The most noteworthy integration with this device, however, can be named as the Leap Motion. Leap Motion is a device that senses the movements of the fingers of the hand. The device maps out each finger and knuckle and lets the user interact with virtual objects with their own hands, in real time. The user simply connects the Leap Motion device to a personal computer, and places their hands on top of the device for recognition (Figure 4.33).

Several developers have experimented with mounting a Leap Motion device on the Oculus Rift headset to provide a source of input for the user to interact with virtual objects. This integration brought so much potential to both of the devices that Oculus Rift came up with a special Leap Motion mount that makes the assembly very easy. The wearer now has to use their hands in front of their head to view a virtual environment where they can use their hands in (Figure 4.34).

Figure 4.33: Leap Motion

Figure 4.34: A person wearing the Oculus Rift with Leap Motion mounted
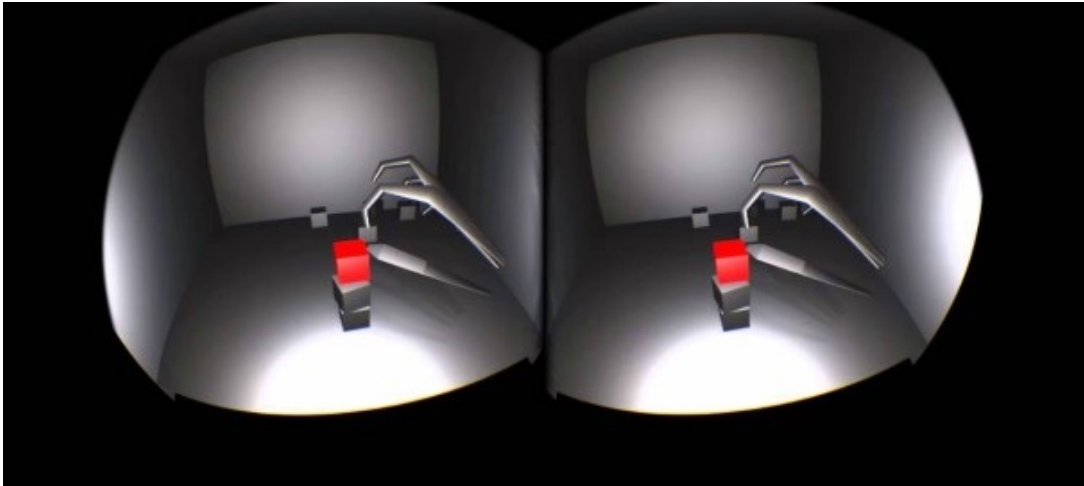
Figure 4.35: Picking up virtual objects with Oculus Rift+Leap Motion

Oculus Rift, normally being a device just for displaying a virtual environment to the wearer, can gain interactive qualities with the addition of recognition of hand movements. In the example in Figure 4.35, the wearer is doing simple tasks such as picking up virtual objects.

AR to support product surface creation. This hardware combination, with the right software to accompany it, can be used in 3D surface creation for industrial design. Much like manipulating a piece of clay, the designer can use their hands to shape and modify a virtual block of material. 3D surface creation is just an example. Because software possibilities are endless, an interface prototyping tool can also be implemented. The virtual hands of the user can be used for interacting with the digital interface of a designed product inside the virtual environment. If a webcam is integrated along with this system, the objects can be viewed in the real environment, making the whole setup an AR system instead of a VR system.

AR to support 3D visualization of 2D drawings. Another possible use of AR for design purposes would be for visualizing a 3D model from 2D drawings of products. Recognizing the dimensions and surface details of a technical drawing from the top, front, side and section views, the software would draw the model in 3D and display it when the technical drawing is scanned. There are no examples of such usage of AR with image recognition to build 3D models, but it can be considered to be a prediction for the future.

4.4.3 Commentary

This study was a combination of currently available but not yet explored AR solutions for industrial designers, and suggestions for designers with possible future advancements in the technology. The mobile apps Metaio, Augment and Dynamapper has been found out to have potential for designers as of today, as exemplified in the past design projects of the author. The main suggestion for future incorporation of AR in design practices is additional interactivity. This functionality has been studied before, and here they are matched with suggested uses for designers. To round off the suggestions for future, additional features of a possible AR solution to be developed just for designers are presented. As a result, there is a wide range of design activities that can be enhanced with AR when/if the technology advances to fit the needs of an industrial designer.

4.5 Discussions

4.5.1 Study 1 Results

Results of the preliminary study. It was found out that there are two main problems with the digital methods and physical tools designers use in product design. Firstly, the interaction with the user can't be visualized adequately, especially in the context of usage. This results in not being able to spot scaling problems, where the size of the product does not meet with user's needs. Secondly, products with digital interfaces are oversimplified in presentations because it is not possible to show all stages of interaction. Applying AR into design process can help eliminate these problems, as well as bring extra benefits. The participants reported that they do not use AR applications, but they are open to innovative methods for design and would be willing to apply them into their design process if they are easy to access and implement.

Imagining possible uses of AR in design stages. The stages that AR showed the most promise in integration with are presentation, scenario building, and prototyping.

It was already clear from the preliminary study that 2D presentation boards are lacking in showing the interactivity and interaction details of a design project. It was made

clear in this exercise through concrete examples of projects that AR can be used to show such details, be it being able to show animated graphics and interface details in a product, or being able to show the interaction of the product with the context of usage and the user.

This proposed functionality of AR to show interaction stages was proven to be useful for scenario building stage of design as well. The interactive quality of AR enables the stages of interaction to show in real time in design projects. Showing these interaction stages in a traditional presentation board would be possible by showing frame-by-frame what happens in each stage. However, interaction stages are not always linear, and showing interaction on a presentation board often oversimplifies the interface. An example of using AR to show interaction was prototyping the digital interface and augmenting it on the presentation board, so that viewers can see the whole interaction scheme on, for example, a mobile device.

Another design deliverable that AR can enrich is prototypes. Prototypes are found to be difficult and time consuming to produce, which results in oversimplification of the product's features, such as texture and materials. This problem can be overcome by generating a very simple mock-up of the product, and using AR to project texture and material on the mock-up. This way, several options can be shown as well.

Apart from these three, other design activities are also mentioned. For user testing, the product can be presented with AR in its intended environment of usage. Usage instructions can be augmented onto the packaging of the product to act as an interactive user manual. Field research can be conducted by scanning products to learn about how they are produced, scanning and saving unknown textures and materials to create a library for later usage. Presentation purposes of AR can be used to get feedback on the state of the design, and idea generation would ideally be supplemented by AR inspiring designers about emerging technologies.

The foreseen problems with using AR for design activities. The main possible problem was the learning curve. The participants commented that within the tight schedule of a design project, the priority would be generating new ideas for the project itself, and not learning how to use AR software. It is found to be crucial that whatever AR tool that they are using should be working smoothly, is easy to learn, is compatible

with whatever data generation software that they are used to using, and should be specialized for industrial design process to save time with irrelevant options. Apart from this problem, they would be concerned with the price and accessibility of the technology.

4.5.2 Study 2 Results

Using Metaio AR software package in a design project. The participants had success in their presentation by using the AR software package Metaio. They were able to show the usage scenario and digital interface details from start to finish with audio-visual feedback. Having easy access show to the digitally created content that explained the interaction steps in real time was a major advantage to having only 2D presentation boards with static images. The only other way that the users could show the videos explaining how the product is operated, and the sound feedback it provides if they did not use the AR app would be to set up a laptop next to the presentation board and manually showing the relevant data during the presentation. However, this would not have been possible in a setting where the designer was not present next to his/her presentation board, like in an exhibition. By placing markers on the presentation board, the designer allows every viewer with a mobile device to be able to see the extra content that will explain the interaction details of the product.

Another aspect that AR provided some of the participants with in their presentation was the enhancements they could apply to their mock ups. They were able to deliver a basic physical prototype, and create videos that show the digital interfaces, dynamic details and texture properties that would be either impossible or very time-consuming otherwise within the scope of an educational project. That they were able to scan trackers on their mock ups with their mobile devices and be able to see how a blinking light would signal to the user that they need to interact with the product, or to list the steps that the user is supposed to go through to set the alarm, or to visualize how the texture quality of the finalized product would look like; can be considered to be an improvement to the presentation of 3D prototypes.

Reaction to the AR app. The participants had very positive reactions. They found the Metaio software package easy to use, and the abundance of useful attributes and

the fact that it was free justified the learning curve. They thought that with AR, their presentation boards were much more fun and interesting, while presenting information about the product in much more depth. The adjectives that the participants used to describe using AR in their presentation were surprising, informing, fun, interesting, attractive, and even magical. They were able to present everything that they would've liked to present with the additional functionalities of AR, and this eye-opening experience would encourage them to use AR apps in their future design projects.

The participants had some negative comments about the AR implementation process as well. The technical problems that were related to the software seemed to be a setback, albeit a minor one. For instance, the size of the marker and the lighting conditions affect the smoothness of tracking. The glitches in the interface of the content creation software made it difficult at times for the participants to edit the contents within the program. Maybe the most noteworthy disadvantage of the software was that it was not specifically tailored to suit a designer's workflow. These disadvantages of the selected software package does not diminish the potential the participants thought implementation of AR in presentation of their projects has, but it would provide a basis of information to set criteria for an AR software or app to be used for industrial design purposes, which will be mentioned shortly.

Suggestions for improvements. The most noteworthy suggestion for improvement was being able to track more than one object, and being able to interact with multiple objects at the same time, object-to-object as well. This would mean that product concepts with more than one component that are linked together in some way could be prototyped.

The Metaio software package included both software to edit and publish AR content on a PC (Metaio Creator) and viewing the published content on a mobile device (Junaio browser app). This meant that the participants had to edit their content on their computer, upload it, and view it with their mobile device each time they had to make adjustments to their content. If basic editing options were available for the mobile device they used, they could do real-time editing of their content, and try on multiple selections in a short time.

Another suggestion was about the hardware limitation of working with the monitor

of a mobile device. It would be more intuitive to use projection to display the AR content on top of the presentation board or mock up, so that the viewer does not have to depend on a mobile device. Additionally, Google Glass integration is a hardware solution that would revolutionize the process by enabling the viewer to view the AR content without having to work through a monitor.

The perfect AR solution for designers. The best case scenario would be to develop an AR solution that included both hardware and software for industrial designers that would be specialized only for their needs. The previous comments about multiple object tracking, real-time content editing, and hands-free hardware options could be the beginnings of a new AR system that designers can use.

4.5.3   Study 3 Results

Exploring existing software & hardware combinations for AR in a design project. The software that has been used are Metaio, Augment and Dynamapper. The advantage of using Metaio, as a continuation from Study 2, was being able to present interaction details with video and sound, which would normally be explained only in text in the presentation board. The added value of Augment was showing the 3D CAD model of the product in its intended environment of use, and the movement of a part during usage as an animation. The 3D CAD model and animation took the place of a physical mock up in this presentation. The app Dynamapper on the other hand, was proved to be useful in enhancing the physical mock up of the product. Interaction details such as the digital interface and the glowing light of the product was projected on the plain white mock-up. All of these uses are additions to the traditional methods of presenting the details of a design project. These methods of presentation can be used in several stages of the design process: getting feedback from instructors, conducting user tests, and final presentation.

Possible future improvements to AR technology for design purposes. The main addition to what can currently be achieved was additional interactivity between the user and the augmented content. Being able to interact with the content in the AR interface would mean that the technology could be used not only in presentation, but for other design activities such as 3D surface creation and research. If we look at the

research and development applications of AR technology, there are many examples of increased interactivity between the user and the content. These examples present possibilities for designers to achieve tasks such as finding out information about a product from a mock up, being able to attach digital interfaces to mock ups, surface creation and editing, making design changes to the prototype in a virtual setting.

An AR solution developed for industrial designers. This part of the study included speculations about where the technology might progress towards for creating possibilities of implementation to industrial design process. In the research phase of a design project, the process would go faster and more efficiently if getting information about the material, production method, assembly of the product was as easy as scanning it with an AR browser. For the material selection phase, a material library that is built by the designer by saving pictures of materials and textures from real life to project them onto plain physical mock ups of the designed product would be a big improvement to the traditional method of just imagining that it would be made of a certain material. Similarly, the mechanical response of the designed product upon usage is also up to imagination in most cases. An AR solution that would do the necessary calculations to show a real-time simulation of usage including visualization of surface distortion, load bearing capacities, etc. would be a powerful tool for a designer. Another aspect of products that can't be portrayed and thus, tested in design projects is digital interfaces. Combining an interface prototyping tool such as the POP app with an AR interface would allow the designer to show the digital interface screen in the real context of the product would be invaluable for design projects with a focus on interactivity. And for surface creation, a set up such as the combination of head-up display with a device that tracks hand movements would be the ultimate tangible interface alternative.

The results of Study 3 can be summarized as in Table 4.3. The design process is comprised of the stages project briefing, research, initial idea generation, interim presentation, development of design concepts, user testing, and final presentation. The design activities that can be supported with AR technologies are listed in groups of whether the current state of the technology allows it, or the usage is a suggestion for future.

The Design Process	Project briefing	Research	Initial idea generation	Interim presentation	Development of design concepts	User testing	Final presentation
Currently available (S2, S3)							
Presentation					▪		▪
Physical mock up creation				▪			▪
Suggestions for future use (S1, S3, L)							
Scenario building activities							
User tests and usage instructions						▪	
Project research		▪				▪	
Material considerations					▪		
Mechanical and structural considerations					▪		
Display and feedback interfaces					▪	▪	▪
Real-time virtual interaction			▪	▪	▪	▪	▪
Product surface creation			▪	▪	▪		
3D visualization of 2D drawings			▪	▪	▪	▪	▪

Table 4.3: Design activities that can be supported with AR in correlation to design stages

CHAPTER 5

CONCLUSIONS

5.1 Introduction

The present research aimed at evaluating existing AR technologies for supporting industrial design activities at different stages. AR, even though being a technology on the rise for several years and now has become a trend among developers, is relatively slow to be picked up by the general public. There are a number of reasons why there are so many examples of AR in research setting, yet it is not as widely used as other technologies. AR is a technology that is comprised of a software component and a hardware component. Hardware components of AR such as HUDs and projection systems are being developed in research centers, however it takes a very long time before an AR hardware product is completed in the development stage, and has started being made available for the general public. Therefore, there is a mismatch between the development time for hardware components and software components. For this reason, the AR solutions that can be utilized by industrial designers have been limited to the hardware & software combinations that are available as of today.

The literature survey was conducted to introduce AR, to exemplify the commercial uses as well as R&D, and to provide a basis for introducing AR to the design process. In order to understand the potentials of AR technologies to be used by industrial designers, the fieldwork consisting of three studies was carried out. Study 1 started with a preliminary study that looked at the stages design students go through along with an evaluation of physical tools and digital tools used in design projects to produce deliverables such presentation boards, 3D mock ups, and so on. The results

of this preliminary study were linked to an exercise with industrial design alumni to brainstorm about how AR could be useful for their past design projects to produce the deliverables that they were expected to present. Study 2 was a hands-on survey about how mobile AR apps could supplement the final presentation stage of industrial design process, and was conducted with design students working on a project. The participants used the mobile AR app Metaio to enhance their presentation boards and mock ups with additional content. Study 3 carried out by the author was aimed at uncovering the full potential of existing AR solutions for industrial design, and offering solutions for designers to utilize AR in their activities by making predictions about the future development of the technology.

The results of the fieldwork indicated that AR technologies can offer promising support for industrial designers such as presenting details such as audiovisual feedback, interaction details and digital interfaces of their projects, and for enhancing the physical mock up creation/prototyping process by superimposing material, texture and interaction details on a plain physical model. Additionally, future developments will enable a number of design activities to be done with the addition of AR to make the design process richer and more interactive. The fieldwork was carried out in an educational setting; however, the results show that the design activities that AR could support might also exist in a professional design setting, which means both design students and design professionals can benefit from this study.

Accordingly, this chapter presents the research questions and their answers from the literature review and the field study. After that, the limitations of the study are discussed along with future notes for designers.

5.2 Revisiting the Research Questions

The main research question of this study was: *'What are the potentials of AR technologies to be used for design practices?'* Direct answers to specific research questions posed at the beginning of the study now will follow.

5.2.1 How Do Industrial Design Projects Typically Progress with Regard to Different Tools and Methods Used (e.g. for visualization, presentation etc.)?

In industrial design practice, the milestones in the development of a product depend on various factors such as marketing, manufacturing, budget, and time. These factors may have less bearing at student design projects although the stages being followed during the design process would have great similarities. In order not to be limited by the aforementioned factors in the development of a new product on the design activities that are involved in concept generation, industrial design projects that are carried out in educational setting are surveyed.

In order to be able to outline a typical student design project workflow the project calendars of the 'ID402 Graduation Projects' course carried out at the Department of Industrial Design of the Middle East Technical University in the years between 2012-2013 and 2013-2014 were studied. Graduation Project is a final-year studio-based course in which students work on their major product design projects in collaboration with commercial partners. Therefore, the project workflow was believed to have lot of similarities with the professional setting.

Accordingly, a design project typically starts with the project briefing, which contains the problem statement and the general design criteria for the project. A research about the potential user group, similar products in the market, and the usage context is conducted prior to the initial idea generation stage, which is when the students are expected to come up with as many innovative ideas as they can. After selecting the promising concepts, the students develop their ideas in parallel to activities such as usage scenario generation, material and production method selection, and so on. Students then may need to do user testing to for design evaluation, detailing, and to test the usability of their product proposal, and present the final outcome of their revisions and developments at the final presentation. Throughout this process, the students are expected to present deliverables such as 2D sketches and mindmaps, results of research and user tests, physical models and prototypes, and presentation boards that contain for example, CAD renderings and drawings.

The medium of presentation for activities in intermediary stages of design are usually text descriptions for project statements and problem definitions, 2D images for making collages about user group reviews and results of research about the project statements, diagrams and charts that explain the thought process behind the development of the problem definition with relation to the findings of research, and sketches for initial idea generation. For the interim presentation of design projects, the design students are expected to deliver the 2D sketches of their concepts and the physical mock ups that they have built. Lastly, for the final presentation, they are expected to present a high quality prototype that exemplifies the final product with as much detail as possible, and 2D presentation boards with CAD renderings and drawings that explain the concept thoroughly.

5.2.2 What are the Commercial and Academic Uses of Augmented Reality and Related Technologies?

AR, which is described as a way of visualizing computer generated data superimposed on physical objects/environments, has been on development for several years, and has become very widespread in commercial and academic fields. Commercial uses of AR can be divided into two categories: i) content creation and application building services; ii) end user AR applications. Content creation and application building services enable companies to create their own AR solutions based on the content they specify. Examples such as Metaio, Wikitude and BuildAR are some of the software development programs for content creation and application building. End user AR applications are specialized AR solutions with specific content in the relevant sectors. The majority of the AR examples in commercial settings belong to this category. These commercial fields that utilize AR the most are advertisement, architecture and construction, museums and tourism, medical, mechanics and repair, social networking, entertainment, military and navigation. Advertisement sector, being the most widespread field to utilize AR, uses the technology to create attention-grabbing and awe-worthy visualizations of products that are being marketed. In architecture and construction, AR is used to embed visualizations of finalized buildings can be embedded on 2D plans and unfinished construction sites. For museums and tourism purposes, AR is utilized to show historical information on artifacts and acts as a guide

to show travel hotspots. For medicine, mechanics and repair, AR can give on-site feedback to guide the professional about the tasks that they are about to perform. In social networking, AR is used to connect people's faces to their online profiles, and in entertainment sector the interactive qualities of AR can help bring video gaming come to life in the real environment, a quality of AR that can also be seen in science fiction movies. For military and navigation uses, AR is utilized to show real-time information about landscapes using additional technologies such as GPS.

In the academic field, research on AR and related technologies focus on development of hardware and software solutions. The hardware developers have come up with devices such as Oculus Rift, Google Glass, Microsoft Hololens, Morpheus, Illumiroom and castAR. These are devices that range from HUDs for complete immersion, HUDs with transparent displays and projector-based display solutions. MIT Media Lab uses AR in projects for tangible interactions and fluid interfaces every year, in projects such as inSide, Sublimate, Tangible CityScape, Augmented Magnifier, Smarter Objects, AR Product Counter, and SixthSense. These are examples of heightened interactivity within the physical world and the augmented content, and use hardware components like sensors for gestures etc. to be able to provide additional interaction. Sectors such as automotive industry and medicine also benefit from applications of AR technology and continue to develop purpose-specific solutions. These examples are explained in Chapter 2.

5.2.3 What are the Uses of Augmented Reality in Current Design Practices?

There are a number of commercial examples of AR for design purposes. These examples enable the users to view a product (such as furniture) in the desired environment prior to purchase, so that they can get to sample the product. This functionality is utilized by companies to better communicate their products to their potential customers, which is an aspect of product development that can be the role of an industrial designer depending on the company.

There has been research on using AR in industrial design activities. Some of the highlights in research for AR implementation in design are virtual design environments, augmented prototyping, assembly in industrial design, design for collaboration, and

other implementation possibilities in product development in a general sense. The main two research areas have been about augmented prototyping and virtual design environments.

Augmented prototyping studies aim at enhancing physical mock ups with AR to be able to present additional information. Experimental tools for combining physical mock ups with augmented details have been developed in research setting. These examples show virtual renders on top of physical objects and let the user interact with the content in real time.

In virtual design environments, three dimensional form-giving activities are carried out in real time. This way, designers are able to interact with the designed object in a virtual setting with the help of hardware solutions such as HUDs to increase the tangibility of surface creation in design process.

There are a number of mobile AR apps that are not marketed towards designers, but have potentials for design activities. Some examples for these design activities that can be supplemented with mobile AR apps are drawing references. For instance, being able to pose a virtual mannequin while operating a design product can produce a high quality 2D image that shows how the product is meant to be operated. Additionally, designers can use an app to trace the silhouette of an image that is superimposed on paper to aid with their sketching activities in early stages of design. Additionally, the apps for seeing different color options on an object in real time can be used by designers to assign colors to different parts of their design either on their sketches or their mock ups to provide more options during presentation stage. Moreover, an app that enables the user to display weather conditions superimposed in the real environment can help a designer place their product in a specific weather setting for presentation. Lastly, a 3D storytelling app for making pop-up books can be used by designers to show usage stages like a story. These apps are outlined in detail in Chapter 2.

5.2.4 Can Augmented Reality Technologies be Reasonably Beneficial to Industrial Designers?

Answers to this question were surveyed with the combination of the results of the literature research and the fieldwork. These potential uses are divided into solutions that are currently available, and suggestions for future use when/if the technology is developed enough to be widely accessible by the public.

The currently available AR solutions that are accessible for any designer to use are useful for visualizing information about design projects for presentation purposes. These augmentations for presentation purposes can be used for design activities such as interim presentation, feedback and revision sessions for development of concepts, user testing and final presentations. Additionally, currently available AR systems can enrich physical mock ups to be used in design activities such as interim presentations, development of design concepts, user testing and final presentations. In these presentations, designers are able to convey details about the design project such as audiovisual feedback, digital interfaces, interaction details, material and texture qualities with the help of AR content in formats such as sound, video, image, 3D CAD model and animation. These uses have been explained and exemplified in detail in Chapter 4.

The future solutions for AR can be useful for a number of design activities in the design process. For instance, scenario building activities for development of design concepts can be done with using AR in developing and presenting each stage of the interaction process. In addition, user tests can be conducted to give the users a better idea about the audiovisual feedback and interaction details of the product, in addition to usage instructions. Project research can possibly be conducted by scanning related products to reach information about manufacturing, materials and assembly details. Moreover, material considerations for development of concepts can be done using AR apps if a solution for building a material library containing texture and color details that are collected by the designers from real life sources was possible. Visualization of mechanical and structural feedback the user gets from the product upon usage could be useful for user testing. Other design activities such as developing display and feedback interfaces for user testing and presentation of products, real-time vir-

tual reaction and product surface creation for generation of initial ideas and making concepts start to take shape in a virtual environment and making 2D drawings as a base for 3D visualization might be possible in the future of AR technology. All of these examples are explained in more detail in Chapter 4.

5.2.5 What Augmented Reality Systems can be Recommended Based on Their Suitability for Industrial Design and Industrial Design Education Practices?

To elaborate on the AR systems that can be utilized by industrial designers and industrial design students, it is necessary to look at the findings of Study 2 and Study 3, where practical implementation suggestions have been exemplified. These recommendations are mobile apps, because mobile devices are the only hardware AR components that have a wide range of software selection. The mobile AR apps Metaio, Augment and Dynamapper have been proven to be useful for presentation and prototyping purposes in industrial design. These apps have been selected because they enable the user to use their own content to superimpose on the environment of their choosing. This customizability of content makes these apps suitable for any design project. The free version of Metaio offers the most potential among other content-creation AR software, and the Augment app is free of charge, which makes these apps suitable for design students. The Dynamapper app is useful because it is a projection-mapping app with a very simple user interface.

- With Metaio, the user can overlay usage scenarios, digital interface details, audiovisual feedback on 2D presentation boards, and texture and color on mock ups in the form of sound, video and 3D model files that can be viewed through mobile devices. As exemplified in Study 2 with the Alarm Clock project and in Study 3 with the Espresso Based Coffee Machine project, these kinds of content enhance the presentation of the product and help the designer to convey ideas in ways that would not have been possible without the addition of digitally created content.

- With Augment, the user can upload 3D models and animation files of their products containing texture, material and color properties to present the prod-

uct on any environment that can be viewed through mobile devices. In the
Espresso Based Coffee Machine project shown in Study 3, being able to show
the realistic 3D model of the product in the intended environment of usage,
and being able to show the moving parts in the product brought a new level of
interactivity to the presentation of the project.

- With Dynamapper, the user can enhance a plain physical mock up with additional details of the product such as texture and surface details, material, lighting details, and digital interfaces. The advantage of Dynamapper is being operated on a mobile device, but displayed by projection. The user can overlay the desired AR content using the mobile app, and the projector will show the finished presentation. This way, the designer can turn an intermediate-level physical mock up into a vessel to show many aspects of the final design. This has been exemplified in the Wake-Up Light project in Study 3 by showing how the light would change the ambiance of a room, and how a digital screen would look like on the surface of the product.

5.3   General Comments on the Findings of the Fieldwork

As a result of the three studies, certain advantages of utilizing AR in the design process has been found. It was found out that creating a digital layer of information containing details such as audiovisual feedback and interaction steps in the format of videos and sound files was an improvement over orally describing or using only static visuals during presentation. In other words, utilizing AR in presentation of design projects filled a gap in the design process where traditional ways of showing interactive details of design projects would not have been sufficient. Videos and sound files can be prepared regardless of using AR or not, however; because AR gives the opportunity to show these files directly on top of objects in the real environment, the presentation quality is much higher than if the designer would show the video or play the sound file in a separate device external to the presentation material. Co-location aspect of AR (as opposed to calling information via webpages through QR codes) allows for smooth integration of the digital data with the presentation itself.

Another stage in the design process that AR was found to provide significant advantage was mock-up creation. To make realistic mock ups designers would have to spend a lot of time and effort to prepare texture, material and color by hand. By using AR, designers are able to create digital files containing the intended material qualities and project over plain mock ups to visualize a more realistic and professional prototype with much less effort. Furthermore, designers can create video files containing video and audio, even digital interfaces and project on their mock ups. This would be a much more practical solution over dealing with electronics and coding to make a prototype that shows every feature of the final product.

Because AR is an interactive and attention-grabbing way of presenting information, it can be used to create marketing appeal to products as well. Professional designers can benefit from the realistic, interactive visualizing properties of AR to convince consumers.

5.4 Limitations of the Study and a Note for Future Research

To complete an AR setup, an input, a processing unit, and an output are needed. The development for AR technology therefore highly depends on the content that is going to be displayed, and where this content is going to be placed on. This makes the process of developing AR solutions for specific purposes, like the activities for industrial design that are listed in Table 4.3, very slow. For this reason, mobile devices and AR apps make the perfect combination for testing AR in a design setting. However, the apps that have been tested are limited to the three that are mentioned in 5.2.5, because while the hardware components (mobile devices and projectors) are readily available and widely used, there are no other software options that are specific for designers that can be used. Nevertheless, even though it was limited by factors such as accessibility, the fieldwork that was carried out by the accessible and currently available AR technologies provided some very useful insight on how the technology can be used in industrial design projects in educational setting and the advantages it could bring to the industrial design process.

For further research, keeping in mind the results of the fieldwork, a mobile app that

is specialized for industrial designers can be developed. If we were to take this a few steps further and wait for their development to finish and their release for the public, a HUD with a transparent screen such as Microsoft HoloLens or Google Glass can be used as a hardware component base to build a software solution that is specifically aimed for design purposes.

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APPENDIX A

PRESENTATION OF STUDY 1

Augmented Reality
for Industrial Design

a study of ways industrial designers can benefit
from available AR applications

Başak Topal
MSc student @ METU ID
basaktpl@gmail.com

Aim of this study

General aim of my thesis study is to evaluate AR technologies to
support industrial design practices. This way, I will be able to
propose how existing AR technologies can supplement the design
process in different stages.

AR applications have become very easy to access, and currently
there are lots of applications that can run even on computers,
tablets and smartphones to display 3D models, animation, sound,
2D visuals, and text. The potential of this technology should be
explored in a design education setting.

Therefore, I will give you brief information about augmented
reality and its application areas to inspire you about enriching your
industrial design process. After this presentation, I will kindly ask
you to look back on your final project in ID535 course and think
about how augmented reality could be implemented.

What is Augmented Reality?

http://www.youtube.com/watch?v=09vxKN1zLNI

What is AR?

- Augmented reality technologies are a way of
  embedding computer-generated information
  into physical environments with the aim of
  enhancing human perception (Krevelen,
  Poelman, 2010).

Types of information that can be augmented into real environments

- Video
- Images
- Sound
- Text
- Interactivity
- 3D Models

Interesting Application Areas

Please keep in mind when looking at
these examples to apply the
technology to a design process.

Architecture

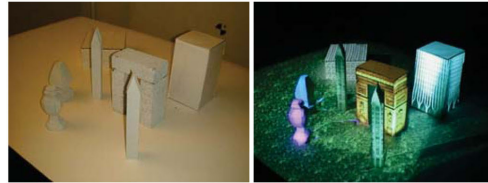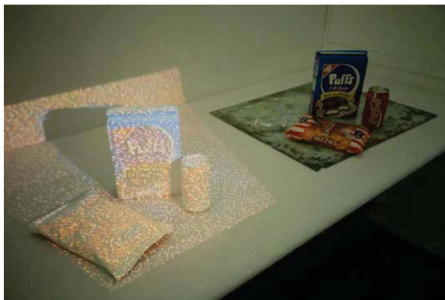Michael Naimark's Small projection Studies (1991)

Prototyping

Table-Top Spatially Augmented Reality

Museums

"Ultimate Dinosaurs" exhibition, Royal Ontario Museum

Medical

Mechanics and repair

ARmedia Augmented Reality 3D tracker

Construction

Social Networking
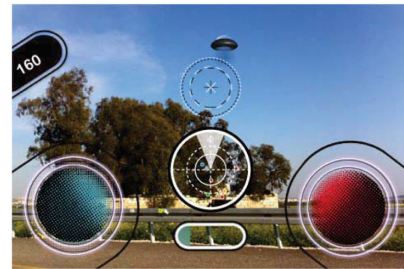
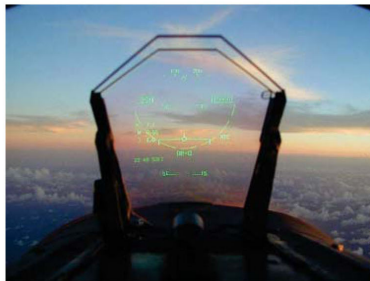## Tourism

Layar

Games

AR Invaders

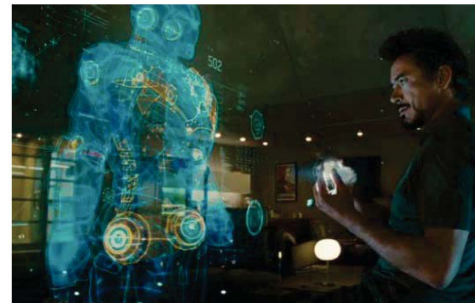## Military

Navigation

TapNav Augmented Reality Navigation App

Science Fiction Movies

Minority Report

Iron Man

Interview Questions

- Can you choose one (or a collection) of your past design project(s) and think about where you would have benefited from using a range of Augmented Reality applications, e.g. to enhance the presentation of ideas, adding interactive content, improve presentation, etc.
- Please give specific examples to describe the ways that AR could have supplemented the design process and enriched the output (You can describe by making use of sketches, annotations etc.)
- What stages of your chosen design projects do you think would have benefited most from AR applications?
- What kinds of design activities might you have accomplished with Augmented Reality technologies if at the time you had access to the whole range of hardware and/or software and solutions?
- In future product design projects, what difficulties do you think you might face when using Augmented Reality applications? (If you have already used any AR applications, please also reflect on your previous experiences.)
- Would you be interested in exploring the possibilities of Augmented Reality technologies in a future design project? (Please elaborate on your answers)

Other AR apps

- Content creation/management applications
  - Layar
  - Daqri
  - **Metaio Creator&Junaio Browser**

- End-to-End branded applications
  - **Augment**
  - Aurasma

- Inspirational applications
  - Zooburst
  - Wooden Doll 3d
  - Pocket Snow Storm
  - ColAR Mix

APPENDIX B

PRESENTATION OF STUDY 2

Augmented Reality
Mobile Applications

a study of ways industrial designers can benefit
from available AR applications

Başak Topal
MSc student @ METU ID

What is Augmented Reality?

Definition of the term, related concepts along with examples
are already covered in earlier weeks of ID535 course.

Aim of this study

General aim of my thesis study is to evaluate AR technologies to support industrial design practices. This way, I will be able to propose how existing AR technologies can supplement the design process in different stages.

AR applications have become very easy to access, and currently there are lots of applications that can run even on computers, tablets and smartphones to display 3D models, animation, sound, 2D visuals, and text. The potential of this technology should be explored in a design education setting.

Therefore, as part of your ID535 project, my specific aim will be to evaluate two mobile AR applications (i.e. Augment and Metaio) and understand to what degree you find these applications useful to support your final presentation.

Stages of Study

PART I – Augmented Reality Applications Demo.
Today, I will carry out a demo for two mobile AR applications: Augment and Metaio, available for iOS and Android.

Part II – Concept Design Project and Adding Interactive AR Content to Presentation Boards.
As the students of ID535 course this semester, you are asked to make use of Augment and Metaio applications to add interactive content to your final presentation boards of 'Concept Design Project' that you are carrying out.

Part III – Evaluation of Augment and Metaio AR Applications.
On the completion of your presentation boards, I will distribute a short questionnaire to better understand your experiences with the two applications.
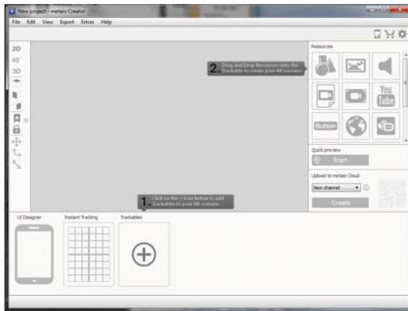
Introduction to selected AR apps

Now, I'd like to give you a half-hour demo to introduce the two mobile AR apps that we chose for this project, and hopefully give you initial inspirations about how they may support your final project presentation!

Metaio Creator&Metaio Toolbox&Junaio Browser

Metaio Creator: free software to upload trackables and AR content and publish them as channels

Metaio Toolbox: iPad application in addition to Metaio Creator to make 3D maps of objects you want to use for object tracking

Junaio Browser: iPad application to scan trackables to view AR content

Metaio Interface

Types of Data to Augment
with Metaio Creator

- 3D content(.obj, .md2, .fbx)
- 2D image content(.jpg, .png, .bmp)
- Sound files(.mp3)
- In-page and full screen video(.mp4, .avi, .mov, .mpg, .mpeg)
- Youtube video
- Buttons
- Web pages
- Facebook, Twitter, Google+ link

Metaio Creator

Metaio Creator developer portal has all the information you need.

http://dev.metaio.com/creator/tutorials/

I recommend going through the three tutorials initially, then browsing the other titles.

Our goal will be creating public Junaio channels.

Metaio Creator Demo

I will show you two examples with two trackables each. In the first one I used image tracking to augment information on my presentation board. In the second one, I used the object tracking feature to augment information on a physical mock up.
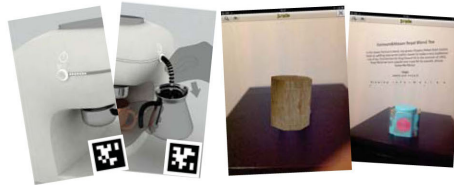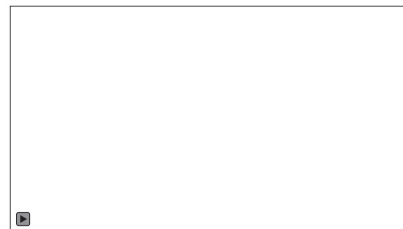

Metaio Creator Demo

Image tracking: uploading images to be tracked

- Video of flashing lights on the espresso machine: 8 individual frames as a stop motion animation in Adobe After Effects
- Animation of hand pulling on the steamer: a .png image of the hand assigned as a transparent texture on a plane in 3DS Max, then animated
- Interactive button which plays sound

Object tracking: scanning of a 3D object as a tracker with the Metaio Toolbox application, or uploading a CAD model

- Information text above tea box: transparent text animation prepared with Adobe After Effects presets
- Texture overlay on physical mock up

Augment

http://www.youtube.com/watch?v=EEstFtQbzow

augmentedev.com

Augment Demo

I will show you an example with my espresso machine project.

augmentedev.com/faq/

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