MIXED REALITY TECHNOLOGIES FOR ENRICHING PRESENTATIONS IN INDUSTRIAL DESIGN EDUCATION

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ABSTRACT

MIXED REALITY TECHNOLOGIES FOR ENRICHING PRESENTATIONS IN INDUSTRIAL DESIGN EDUCATION

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Mixed Reality (MR) has developed rapidly in recent years, causing the technology to move out of the preserve of large budgets and significant infrastructure, into an accessible and affordable visualization tool capable of running on a smart phone. However, the usage of this technology for superimposing digital content such as 3D models and images onto the real world, has not been sufficiently explored in industrial design for presentation purposes. The first part of this study is an assessment of final presentation materials of industrial design students to find out the shortcomings of traditional presentation tools and methods in regards to visual communication. An analysis framework has been developed based on the communication needs of industrial design students in projects of large scale and complex interactivity and the benefits of immersion brought on by MR technologies to assess the final submissions of the students based on the representations of usage context, audiovisual feedback and 3D fidelity. The second part is a participant observation study where an elective course structure was devised towards incorporating MR technology to design projects to address the problems of representation in the aforementioned aspects of the design. The thesis concludes with strategies on how to integrate MR to final educational industrial design project presentations.

Keywords: Industrial Design Education, Design Representation, Mixed Reality, Virtual Reality, Augmented Reality

ÖZ

ENDÜSTRİYEL TASARIM EĞİTİMİNDE SUNUMLARIN ZENGİNLEŞTİRİLMESİ İÇİN KARMA GERÇEKLİK TEKNOLOJİSİNİN KULLANIMI

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Karma gerçeklik yakın tarihte hızla gelişmiş, dolayısıyla büyük bütçeli ve geniş altyapılı organizasyonların tekelinden çıkıp, bir akıllı telefonda bile çalışabilecek kadar ulaşılabilir ve makul fiyatlı bir görselleştirme yöntemi haline gelmiştir. Fakat, bu teknolojinin örneğin üç boyutlu modellerin ve imajların gerçek dünya üzerinde görselleştirilmesi gibi fonksiyonlarının endüstriyel tasarım çalışma alanındaki potansiyelleri henüz araştırılmamıştır. Çalışmanın ilk kısmı geleneksel sunum yöntem ve araçlarının görsel sunum açısından eksiklerini belirlemek için endüstriyel tasarım öğrencilerinin final jüri sunum malzemelerinin değerlendirilmesini içermektedir. Bu değerlendirme için tasarım öğrencilerinin büyük ölçekli ve karmaşık etkileşimler içeren projelerdeki görsel iletişim ihtiyaçları ve karma gerçeklik teknolojisinin getirdiği orada olma hissinin avantajları göz önünde bulundurularak sunumlarda kullanım bağlamının, görsel ve işitsel geribildirimin ve üç boyutlu aslına uygunluğun değerlendirildiği bir analiz çerçevesi geliştirilmiştir. İkinci kısım, tasarımın yukarıda belirtilen temsil problemlerini ele almak için MR teknolojisini tasarım projelerine dahil etmeye yönelik bir seçmeli ders yapısının

tasarlandığı bir çalışma içermektedir. Tezin sonucunda MR teknolojisinin endüstriyel tasarım eğitim projelerinin sunumlarında nasıl kullanılabileceğine dair stratejiler sunulmuştur.

Anahtar Kelimeler: Endüstriyel Tasarım Eğitimi, Tasarım Temsilleri, Karma Gerçeklik, Sanal Gerçeklik, Artırılmış Gerçeklik

to my family

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Throughout the turmoil me and my family has gone through in the past few years, seeing my tenacity prevail and being at the stage of writing these closing words presents me with a renewed rigor for research and life. I am grateful for my late father for teaching me that tenacity will prevail.

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I am grateful for having been a part of a METU Department of Industrial Design family, as much as an introvert can be. From the wisdom and friendly support of my seniors to the friends who I have been lucky to work alongside with; from late night dinners celebrating busy work days in my mezzanine office next to the big arched wooden door to the scuttle to finish work to enjoy fresh air in the canteen with familiar faces; from the warm glow of setting evening sun through the blooms of the apple tree behind the library to the joy of solitary summer strolls to collect wildflowers; it has been a dream come true. I am also thankful for my new family in ESTÜ Department of Industrial design for welcoming me and helping me find confidence by giving me initiative.

I would like to thank my mother for all the sacrifices she has made to help me become the person I am today. To me, she is the hardest worker. Every success I owe to her. I will never stop trying to make her and my dear brother proud.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

2D **:** Two Dimensional

3D **:** Three Dimensional

AR **:** Augmented Reality

CAD **:** Computer Aided Design

GUI **:** Graphical User Interface

HUD **:** Head Up Display

MR **:** Mixed Reality

VR **:** Virtual Reality

WOZ **:** Wizard of Oz

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Industrial design education typically takes place in a studio, a format popularized for design related professions for the past few decades (Cuff, 1991; Dutton, 1987; Schön, 1985; Webster, 2008), and that typifies the hands-on nature of the profession in a setting where instructors take on the role of the client for the designer-to-be. The main pedagogical activities during design studios are desk critiques, where the instructor and the student discuss design choices and imagine their consequences (Mewburn, 2012), and juries, which are used for criticism and evaluation (Peterson, 1979; Anthony, 1987, 1991; Frederickson, 1990; Attoe & Mugerauer, 1991; Ilozor, 2006). For their critique sessions and juries, industrial design students are expected to submit outputs of design activities such as research on the project and the user profile, idea generation exercises and initial sketches, iteration of ideas, 3D mockup creation, development and refinement of ideas, prototype building and user testing. Industrial design students use a variety of tools and methods to create models and representations of their ideas. These models and representations serve two purposes: to support communication to other people and to support their designing process (Wormald, 1997). Being able to communicate their ideas with instructors is vital for industrial design students' progress as designers. However, there are points in the development of an educational industrial design project where the students have difficulties in the representation of their ideas, especially in complex projects developed as teams.

The main communication language of the designer is visuals (Tovey, 1997; Purcell, 1998). The visual communication of an educational design project, depending on the stages of design, can be hand sketches, digital 2D sketches and 3D model renderings, physical mockups and prototypes. Each of these presentation methods has its own place in the design process. For instance, hand sketches are used in the initial stages of design, when the design student is expected to produce a high number of ideas to be put down in paper in a short amount of time. With sketches, design students generate concepts, externalize and visualize problems, organize cognitive activity, facilitate problem solving and creative effort, facilitate perception and translation of ideas (Do et al., 2000), express nonverbal thinking and provide a transition between vision and artifact (Ferguson, 1992), store the geometric form of the design (Ullman et al., 1990), and store ideas to revisit them in the later stages of design (Van der Lugt, 2005). The use of sketchbooks in the creative process has been documented (Tabard et al., 2008; Brereton, 2009). However, quick hand sketches are unstructured and ambiguous (Tang, Lee & Gero, 2011), which means they are not acceptable past the initial stages of design when more detail is expected from the visual representation of the idea. Moreover, the ability of working in a digital medium to undo, redo, distribute, network and access from more than one device (O'Neill, 2011) can be more feasible than hand sketching. More detailed drawings or even 3D computer model renderings can be used in the finalized versions of the design project. Unfortunately, however detailed the drawing or rendering might be, a 2D image of a 3D object cannot be visualized accurately or adequately (Tovey, 1997). Humans experience the world in three dimensions (Israel Wiese, Mateescu, Zollner, & Stark, 2009; Cölln et al., 2012), and without the z-dimension it is not possible to get a true feeling of a product.

Another visual medium for a design project is physical mockups. While having the z-dimension and a greater extent of interaction possibilities, physical mockups often do not embody true material properties, or show audiovisual feedback or graphical user interfaces. A working prototype is arguably the best representation of a design project in its finalized form; nonetheless, it is not always feasible to build full-scale prototypes. It takes a lot of time and resources to build a working prototype to show full size, working digital components, moving parts, material and texture, and so on. While sketches, detailed drawings, 3D renderings and physical mockups are intended to create a simulation of the designed product, the prototype is the product itself. This problem is even more pronounced in projects with high complexity with regards to scale and interfaces. Highly complex educational design projects, such as products with graphical user interfaces and large-scale vehicle interiors, prepared by a team of design students are difficult to present and test with prototypes of low fidelity. The dynamics in team projects involving division of tasks open up possibilities of better quality prototyping which has not been sufficiently explored.

These potential problems in the presentation of an educational design project may lead to misunderstandings between industrial design students and their instructors. Students, or teams of students, may have difficulties in communicating their ideas to their instructors, which makes it hard for instructors to give feedback during desk critiques and juries. What could be a step between the current simulations of a product that cannot communicate either three dimensionality or detail, and a full working prototype? Moreover, in what ways can an intermediary simulation between the real product and the 2D representation of the product enhance communication between industrial design students and their instructors?

Industrial design profession deals with the advancements in technology and helps make people’s lives better in doing so. In this vein, it only makes sense that a newly popularized technology such as mixed reality (MR), an umbrella term for augmented reality (AR) and virtual reality (VR), is used to supplement the design process. Designers are not bound to use only traditional tools and methods, but can use the aid of technology to make their workflow and output richer, drawing tablets being the prime example. Starting in the late 2000s, a large number of studies can be noted for the development and appraisal of tablet-based sketching systems (Li et al., 2012; Wu et al., 2012; Wang & Karlström, 2012; Pao et al., 2012), and almost fully digital design systems (O’Neill, 2011; Al-Doy & Evans, 2011). Educational projects in industrial design studios are very suitable for the integration of new technologies into product development, because industrial design students are arguably more open for experimentation with technology. Additionally, it has been argued that novel information and communication technologies can greatly benefit design education. To quote Reffat (2007, p. 39), “New media and their forms of representation are challenging traditional skills of communication and representation. Changes in practice as well as design education should look to new media with the opportunity for further exploration of design ideas, creation of new forms, and new design vocabularies”.

Mixed reality is a spectrum that combines virtual elements with the real world (Milgram et al., 1995), most popular applications being augmented reality and virtual reality. There has been rapid development in these technologies over the past few years, and MR-enabled hardware has become more and more accessible and affordable, moving out of the preserve of large budgets and infrastructure. Several big electronics companies have released MR hardware systems and controllers for customer use. In a previous study, it has been found out that usage of AR has helped in the presentation and physical mockup creation stages of the design process, and was found to have potential in supplementing design activities such as scenario building, user tests and usage instructions, project research, material considerations, mechanical and structural considerations, display and feedback interfaces, real time virtual interaction, product surface creation and 3D visualization of 2D drawings (Topal, 2015). An educational setting where industrial design students can explore the possibilities of MR based on their needs would be ideal to pinpoint how they can enrich the process and the outcomes of their projects with MR, and to strategize a pedagogical approach.

1.2 Aim of the Research and Research Questions

MR technologies have been on development for many years. MR has become more and more widespread in non-design related fields, and it has yet to be sufficiently explored in design education. The aim of this research is to propose strategies to teach MR to industrial design students so that they can enrich the outcomes of their projects. It is necessary to strategize the scope and practicality of teaching a technology as innovative and diverse as MR to fulfill the specific needs that design students may have in the representation of their projects.

In order to pursue the aim of this research, the main research questions are posed as follows:

- What is the approach in teaching design and how does it relate to teaching MR to industrial design students?
- What kinds of educational strategies should be employed to teach MR to industrial design students based on their representation needs?

In relation to these questions, the study will address the following sub-questions.

- How do educational industrial design projects typically progress, and what kinds of prototypes are created in the design process?
- What are the shortcomings of traditional design representation tools in presenting complex educational industrial design projects?
- What are mixed reality technologies and what are their current uses and benefits?
- What are the uses of MR in current design practices?
- How can the benefits of immersion provided by MR systems strengthen the shortcomings of traditional representation tools in presenting complex educational industrial design projects?
- What methods and strategies should be employed while teaching MR to industrial design students so that they can enrich the process and outcomes of their projects?

1.3 Methodology of the Research

As a recognized strategy for facilitating changes in the execution and comprehension of practice, action research was thought to be particularly suited in accomplishing the study's aims, combined with the data from an initial study on the assessment of four educational industrial design projects as case studies. In evaluating the design process, case studies can be used as an approach to research (Moore, 1983, p.26) with the ability to "explain and understand the phenomenon" in depth" and "in the round" (completeness). Case studies are essential in this position since a more superficial survey can ignore many crucial topics (Birley and Moreland, 1998).

The process of action research was first conceptualized by Lewin (1952) and further developed by Kolb (1984), Carr, and Kemmis (1986) and others (cited in Ortrun Zuber-Skerritt, 1992). Ortrun Zuber-Skerritt’s (1992) summary of the origins and process of action research is;

> *(Action research) is a spiral of cycles of action and research consisting of four major moments: plan, act, observe, and reflect. The plan includes problem analysis and a strategic plan; action refers to the implementation of the strategic plan; observation includes an evaluation of the action by appropriate methods and techniques; and reflection means reflecting on the result of the evaluation and on the whole action and research process, which may lead to the identification of a new problem or problems and hence a new cycle of planning, acting, observing and reflecting (p. 15).*

Birley identified the cyclical character of action research by describing it as being undertaken by a profession studying its activity with the goal of improving practice (Birley & Moreland, 1998). By combining *activity* and *research*, action research aims to bridge the gap between theory and practice (Elliott, 1991). Practitioners of action research do research based on real-world difficulties they meet in the workplace; they then design possible solutions to these problems, implement them, then evaluate, get feedback, and make changes. Furthermore, through collaboration between key stakeholders and practitioners, action research increases the rationale and feasibility of research findings in practice and allows in-depth discussion and comprehension (Altrichter, Posch, & Somekh, 1993; Kemmis & McTaggart, 1988; Mills, 2000). This cyclical approach of planning, acting, observing and reflecting is very similar to the design process of problematizing, research, analysis, synthesis and evaluation (Swann, 2002).

The literature chapters will outline firstly the product development process of industrial design projects by looking at the process of professional and educational design projects, the visual representations in industrial design, and the factors of complexity in educational industrial design projects. Secondly, an overview of mixed reality technologies will be introduced with emphasis on the immersive qualities of the technology.

The research consists of two parts, firstly as an evaluation of existing practice through case studies of four educational industrial design projects that took place in METU Department of Industrial Design in the years of 2017 and 2018. An analysis framework devised of the benefits of immersion brought on by MR technologies matching with the communication needs of complex educational industrial design projects was used as an analysis framework for the design project assessment study. This assessment combined with the outcomes of the literature review was used as problematization for the devisal of the second part of the study, which is an overview of nine projects developed for the Interactive Multimedia Design Course in METU Department of Industrial Design, acting as an implementation/ experimentation for the validity of the analysis framework derived from the first part of the study.

1.4 Structure of the Thesis

The thesis is structured in six chapters. Chapter 1 introduces the problem background, aim of the research and research questions, methodology, structure of the thesis and contribution to knowledge.

Chapter 2 is a literature review on industrial design projects. Firstly, the product development process is introduced by outlining professional design practices, then looking at educational design projects. Secondly, the visual representations in industrial design are explained based on 2D design prototypes, 3D design prototypes and digital design prototypes. Lastly, factors of complexity in educational industrial design projects are described with the role of CAD design in spatial representation, along with audiovisual interactivity and Wizard of Oz prototypes.

Chapter 3 is a literature review on mixed reality technologies. Firstly, the terminology and definitions are outlined by looking at components of MR, brief history of MR, and application areas of MR. Secondly, immersion and presence in MR technology is introduced. In this section, spatial awareness and multimedia stimuli, team work and remote education with MR, and real time interactivity and remote collaboration is discussed. Lastly, commercial and educational usage of MR in industrial design is outlined by looking at commercial use of MR for product design, affordances of MR in learning environments, and MR integration in design education.

Chapter 4 is the first part of the study in this thesis. The research is about the assessment of design project final submissions based on a visual analysis framework developed with the findings of the literature review. A total of 45 design project’s final presentation submissions are analyzed based on their success in representing usage context, audiovisual feedback and 3D fidelity. The assessed material comes from four separate projects developed in METU Department of

Industrial Design. The findings show shortcomings of traditional design representation tools.

Chapter 5 is the second part of the study. The research is a participant observation study of an elective course devised to integrate MR in the final design presentation of students. In this course, the participants attended demonstrations and feedback sessions of assignments aiming to develop interactive MR presentations at the end of the semester. The outcomes are presented for each of the assignments carried out in the design development stages, and the final submissions of MR presentations and videos. The findings of participant observation are outlined as themes that set the grounds for strategies for the integration of MR technologies in industrial design education.

Chapter 6 concludes the thesis by revisiting the research questions, offering strategies to employ while teaching MR to industrial design students to enrich the process and outcomes of their projects, describing the limitations of the study and offering recommendations for future research.

1.5 Contribution to Knowledge

The outcomes of this research hope to contribute to design education and research. The visual analysis framework developed for the design assessment study outlines the difficulties in representation of design detailing in projects of large scale and complex interactivity to be addressed with MR technologies, and the participant observation study aims to put these findings into practice to offer strategies on how MR could be integrated into a design course to overcome the shortcomings of traditional design representation tools. This way, the benefits of MR can be utilized in design education to allow for richer, more immersive and interactive experiences for product design presentations.

CHAPTER 2

INDUSTRIAL DESIGN PROJECTS

This chapter comprises an overview of the design process in professional practice. Firstly, the product development process will be introduced as a compilation of different approaches, and will be followed by types of prototypes.

2.1 Product Development Process in Industrial Design

The responsibilities and working principles of industrial design has been described by many researchers and design institutions. The following sections will cover the definitions of industrial design as well as working models both in professional design practice and educational design projects.

2.1.1 Professional Design Practice

"Everything around us that is not a simple untouched piece of nature has been designed by someone", as Cross states (2000, p. 3). According to Heskett, design is "the human capacity to shape and make our environment in ways without precedent in nature, to serve our needs and give meaning to our lives" (2002, p. 7). The contemporary definition of industrial design practice, as cited 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" (IDSA, n.d.). One of the most recent definitions for industrial design is announced by the Professional Practice Committee of the World Design Organization as "(…) a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences" (WDO, 2017).

It has been proven that following a logical sequence of design processes improves the effectiveness or quality of design (Radcliffe & Lee, 1989), and a flexible-methodical procedure is the road to achieve good solutions to design problems (Fricke, 1993, 1996). It will be beneficial, then, to explore the ways in which the design process can be dissected. According to Cross, industrial design takes place in a three step process: defining the problem, coming up with solutions, and strategizing the process (2006). Likewise, during the design process, designers experience modal shifts from examining, drawing and thinking; and the more rapidly the shifts are made in these activity modes, the more design breakthroughs are made (Akin & Lin, 1995). This finding has been reinforced by Cross, Christian and Dorst (1994) and Atman et al. (1999). It would be a good frame of knowledge to continue this three-mode design activity model for studying new technologies in the design process.

1. Defining the problem/examining/gathering information/analysis
2. Coming up with solutions/drawing/generating ideas/synthesis
3. Strategizing/thinking/evaluation

Roozenburg and Eekels (1995) offer a slightly more detailed basic design cycle (Figure 2.1). Each of these steps contain sub processes that match with appropriate design methods.

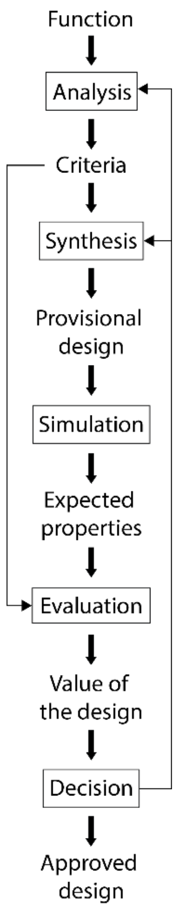


Figure 2.1. Basic design cycle (adapted from Roozenburg & Eekels, 1995)

The authors argue that this cycle, similar to those that have been mentioned by others (Archer, 1992; Lewis, & Samuel, 1989; Manheim, 1967; Rzevski, 1981; cited in Roozenburg & Eekels, 1995), is the foundation to solving any design problem. The starting point of the cycle is defining a function, formulating requirements and setting a goal. The following step is synthesizing the information at hand to create a provisional design. The simulation of the provisional design enables the designer to evaluate the expected properties and the value of the design. After going through a feedback loop, the final decision is made for the approved design. Roozenburg and Eekels argue that these phases assume that a design in the making can exist in three ways.

- *The function structure* is a depiction of the desired behavior of a product and its parts.
- *The solution principle* is an idealized representation of the product in which the qualities of the parts are determined.
- *The embodied design* is the finalized version of the previous design iterations.

Going into the sub processes that take place in these steps, Cross (2000) offers the following design methods to stimulate creative thinking: brainstorming and synectics for idea generation, objectives tree for clarifying objectives, function analysis for establishing functions, morphological chart for generating alternatives, weighted objectives for evaluating alternatives, and others.

- *Brainstorming* is an idea generation session conducted by a group of designers that focuses on generating a large number of ideas. Each member focuses on generating ideas, then these ideas are discussed by the group for further exploration and improvement.
- *Synectics* values the role of analogies in design thinking, to draw parallels between unrelated topics, or to transfer concepts from one field to another. Direct analogies, personal analogies, symbolic analogies, and fantasy analogies can be made for idea generation.
- *Objectives* tree is an elaboration of the design brief to prepare a list of design objectives, which might be abstract or concrete, in the form of a tree, that the designer tries to achieve in the product.
- *Function analysis* is aimed at stating the general function for the design by converting input into output. In other words, the designer tries to address the essential functional requirements of the product by breaking down the objectives and creating a flowchart.
- *Morphological chart* takes a list of all of the features and functions of a product, creating alternatives for each on a matrix. The aim is to widen the range of design solutions to generate new ones.

- *Weighted objectives* is a method in which assessment and comparison of alternative designs are made. These objectives are based on the objectives tree made in the earlier stages of design; however, it considers the design solutions developed in the latter stages of design. Therefore, it creates a prioritized list for the importance of design solutions based on the requirements.

These creative methods belong in frameworks of action for designing new products. Cross (2000) suggests three frameworks of action for different kinds of specific design projects: procedural working models, lateral approaches, and creative working models. Procedural working models are useful when straightforward and linear processes are going to take place in the design process. Lateral approaches are used when the solution cannot be applied in a linear way. Creative working models can be employed when the designer is given more freedom and flexibility. These frameworks for action, matched with appropriate methods are as follows:

Table 2.1 Framework for action for procedural working models (Adapted from Cross, 2000)

Procedural Working Models	
Stage in the design process	Appropriate method
1. Clarifying objectives	Objectives tree
2. Establishing functions	Function analysis
3. Setting requirements	Performance specification
4. Determining characteristics	Quality function deployment
5. Generating alternatives	Morphological chart
6. Evaluating alternatives	Weighted objectives
7. Improving details	Value engineering

Table 2.2 Framework for action for lateral approaches (Adapted from Cross, 2000)

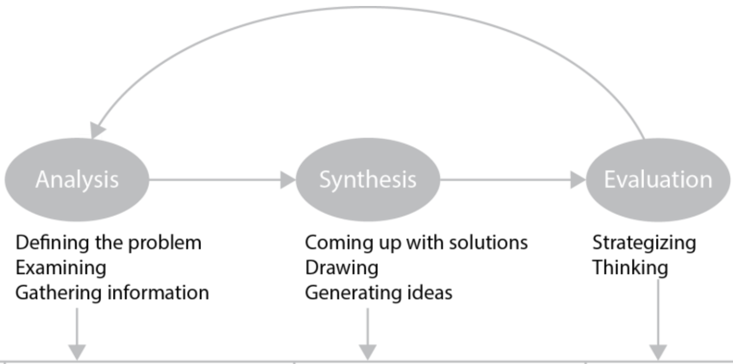
Lateral Approaches	
Stage	Tactics to be used
1. Divergent problem exploration	Morphological chart Brainstorming
2. Structuring of problem	Objectives tree Performance specification
3. Convergence on solution	Synectics

Table 2.3 Framework for action for creative working models (Adapted from Cross, 2000)

Creative Working Models	
Stage	Tactics to be used
1. Recognition	Brainstorming Writing a design brief
2. Preparation	Objectives tree Information search Function analysis
3. Incubation	Taking a holiday Talking the problem over with colleagues Tackling another problem Enlarging the search space: counterplanning
4. Illumination	Morphological chart Brainstorming Enlarging the search space: random input
5. Verification	Performance specification Weighted objectives

Derived from these approaches and methods, a cyclical process for solving a design problem can be developed, based on the analysis, synthesis and evaluation steps mentioned by Cross (2006) and Roozenburg and Eekels (1995).

As can be seen from Figure 2.2, the cycle of analysis, synthesis and evaluation can be a host to multiple iterations. In the first iteration, the designer starts the analysis step with a project briefing, conducts literature, field and user research, and builds an objectives tree. In the synthesis step of the first iteration, brainstorming and synectics can be applied for coming up with a provisional design ready for simulation. In the evaluation step, feedback is taken from stakeholders to complete the first iteration cycle. The outcome of the first iteration cycle is the function structure, in which the general idea of what is aimed with the product's utilization is realized. In the second iteration cycle, the analysis of the first evaluation is made by conducting function analysis, morphological chart and weighted objectives. In the synthesis step of the second iteration cycle, reiteration and prototyping is done, which is utilized in the evaluation step of the second iteration cycle. The outcome of the second iteration cycle is the solution principle, in which the requirements are met with specific solutions for each part of the product. In the third iteration cycle, the product's manufacturing details such as technical drawings are solved and the embodied design is ready for market evaluation.



1st Iteration Cycle	-Project briefing -Literature search -Field research -User research -Objectives tree	-Brainstorming -Synectics -Provisional design -Simulation	-Feedback from stakeholders	Function Structure
2nd Iteration Cycle	-Function analysis -Morphological chart -Weighted objectives	-Reiteration -Prototyping	-User testing	Solution Principle
3rd Iteration Cycle	-Production specifications	-Production	-Market evaluation	Embodied Design

Figure 2.2. Analysis-synthesis-evaluation steps in the design process

2.1.2 Educational Design Projects

It has been pointed out in several studies about design education that the most effective strategy of teaching is learning by doing (Dewey, 2007; Schön, 2017; Lackney, 1999; Oxman, 2004). This way of training design students has been employed since the beginning of the 20th century and is considered to be a progressive point of view in education. Lawson (2006, p. 7) has stated that “it seems almost impossible to learn design without actually doing it”. In design education, students learn theoretical knowledge related to their projects and employ the skills they acquired by working on projects to solve design problems. It should be considered that students and their learning environments are evolving throughout time, and the students’ arsenal of skills develop based on these changes (Barab, Hay & Yamagata, 2001).

The learning environment of industrial design students are, much like other design related professions, typically design studios (Cuff, 1991; Dutton, 1987; Schön, 1985; Webster, 2008). The instructors take on the role of client for the design students and give them a brief and simulate the characteristics of a design project developed in professional practice. The learning during design studio activities comes from desk critiques, where the students present their progress and get feedback from the instructors regarding design choices and their consequences (Mewburn, 2012), and juries, where the educational design project is evaluated by the instructors (Peterson, 1979; Anthony, 1987, 1991; Frederickson, 1990; Attoe & Mugerauer, 1991; Ilozor, 2006).

As the main criterion of design projects enforced on industrial design students by their instructors, the intended interaction experience is vital for developing interactions and user-product/system networks. Traditional design techniques like storyboards or two-dimensional simulations seem to be unfit with the many sided and dynamic characteristics of interactive products (Hu, Ross, Feijs, & Qian, 2007). Several design researchers have developed approaches to solve the problem of complex interaction scenarios that arise in the design process by methods that involve bodily acting out methods, e.g. Experience Prototyping at IDEO (Buchenau & Fulton Suri, 2000), Informance Design (Burns, Dishman, Verplank & Lassiter, 1994), designing actions before products (Buur, Vedel Jensen, Djajadiningrat, 2004), choreographies of interaction (Klooster & Overbeeke, 2005) and gesturing out (Ross & Keyson, 2007). These methods aim to replicate the experience of using a product by making the designer act out the usage scenario. Buchenau and Fulton Suri (2000) argue that acting out techniques have the advantages of understanding interaction experiences and contexts that already exist, assessing design solutions, exploring new ideas, and communicating design concepts to an audience. In educational industrial design projects, acting out usage scenarios during user tests and project presentations during juries and critique sessions can help students communicate their ideas to the instructors.

In the critique sessions and juries, a variety of content is expected from design students to submit to the instructors. These could be outputs of design activities such as research on the project and the user profile, idea generation exercises and initial sketches, iteration of ideas, 3D mockup creation, development and refinement of ideas, prototype building and user testing. Design students' progress as designers depends on their ability to communicate their ideas with their instructors. The complexity of an educational design project can differ based on the experience level of students, and whether the project is developed individually or by a team of designers.

2.2 Visual Representations in Industrial Design

It is crucial to externalize design concepts effectively to prevent reworking of the end product and to cut down on development time (Alisantoso et al., 2006). Visual design representations must sufficiently externalize the design concept and should be easy to understand by the shareholders of the project (Eissen & Steur, 2008; Goldschmidt, 1997; Pipes, 2007). Visual design representations in industrial design are prototypes. The word prototype originates from the Greek word *prōtotupos,* which means “first example”. Going from this definition, anything that makes an idea visible to people other than the owner can be defined as a prototype (McElroy, 2016). In this vein, a prototype is a design concept coming to life in early stages of design prior to manufacturing, and a prototype is on a range between simple 2D sketches and 3D models (Yang, 2005). In this section, two dimensional, three dimensional and digital design prototypes will be explained.

Prototyping is valuable because prototypes help the designer to understand the product, to communicate their ideas, to test and improve their designs, and to advocate for their design decisions (McElroy, 2016). According to Broek, Sleijffers, Horváth and Lennings (2000), the purposes and types of physical models are visualization, functionality testing, physical testing, marketing, proof of concept, editing and communication. To adapt to the design process steps explained in Figure 3.2, prototypes have their place in the synthesis and evaluation stages of design.

2.2.1 Two-Dimensional Design Prototypes

The initial stages of design start with sketches. Before the emergence of digital media, designers relied solely on hand drawings for design activities. Even after digital design tools have been popularized, sketching still remains to be a vital part of any design project. When sketching, designers do not use any instruments, and leave informal marks on paper (Tjalve et al. 1979) that might be comprised of draft lines, text, dimensions and calculations to explain the context, details and size of the design (Ullman et al. 1990, Stacey & Eckert, 2003). A sketch might have attributes such as varying line weights, over-tracing, redrawing and hatches with the purpose of suggesting depth and drawing attention to certain parts (Do, 2005). Various types of sketches as 2D visual design representations are personal sketches, shared sketches, persuasive sketches and handover sketches (Pei, Campbell & Evans, 2011). The key characteristics of sketches are that they are prepared in abundance in a short time period, therefore being disposable and inexpensive (Buxton, 2007).

Industrial designers use sketches to visually represent their designs to communicate concepts to others, create open ended solutions, and externalize a design concept for assessment (Rodriguez 1992; Ehrlenspiel & Dylla 1993; Fish 1996). Many studies have shown that sketching, as a design language, expresses design thinking (Ullman et al., 1990; Goel, 1995; Suwa & Tversky, 1997) and transitions ideas from vision to artifact (Ferguson, 1992). Sketching helps the designer to develop characteristics of the design such as shape with minimal cost and in a flexible manner, along with swift exploration of design alternatives (Prats et al., 2009; Goldschmidt, 1991; Schütze, Sachse, & Römer, 2003; Suwa, Gero, & Purcell, 1999) and store ideas to revisit and improve at later stages (Van der Lugt, 2005). It can also be used to break down each component of the design and develop them individually (Figure 2.3). Designers use sketches to create concepts, visually represent problems, organize their cognitive efforts, encourage problem solving and creative activity, execute visual translations of their ideas (Do et al., 2000) and store the geometric form of the design (Ullman et al., 1990). It has also been found that designers draw to develop for their visual awareness, seek inspiration, collect visual reference, generate ideas and propose concepts, record and communicate ideas, respond to visual sources, test feasibility of their ideas, and resolve and refine ideas (Schenk, 2014).

Quick sketches, while being useful in the intermediary stages of design, usually are not enough for latter stages in design (Tovey, 2012). In the later stages when ideas are more developed, presentation becomes more important. The sketches are refined, more detail is applied, qualities such as material, color and texture are integrated (Figure 2.4). In some cases, it is necessary to provide technical details such as isometric and exploded views of the components of the product (Figure 2.5). This is achieved by using colored markers and different kinds of pencils on different weights, textures and colors of paper and/or sketchbooks.

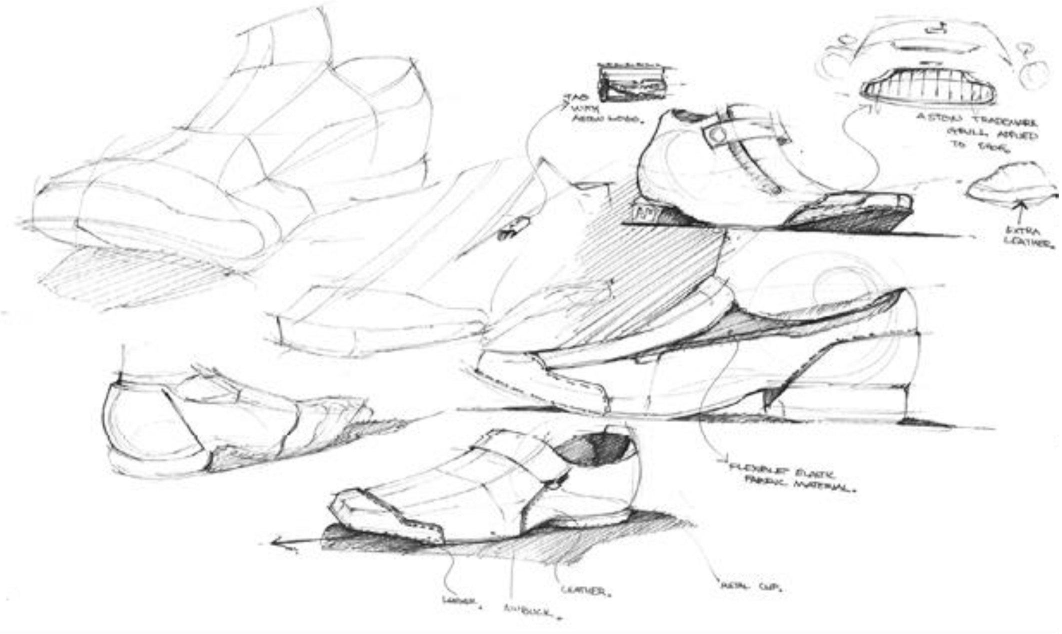


Figure 2.3. Industrial design sketches (McElroy, 2016)

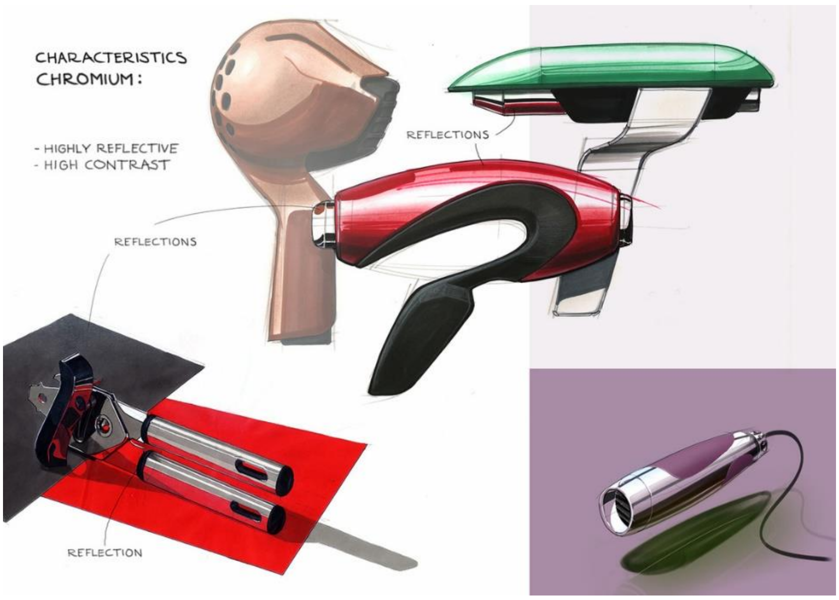


Figure 2.4. Product detail drawing examples with different materials (Delft Design Drawing website, n.d.)

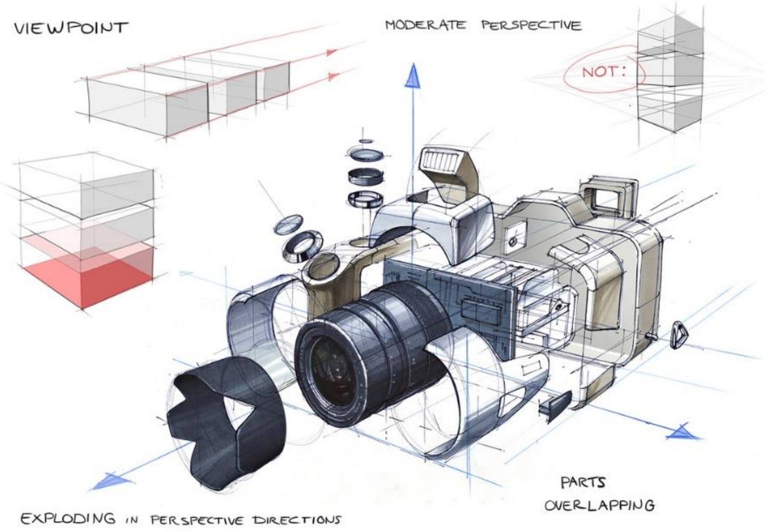


Figure 2.5. Exploded view of a camera (Delft Design Drawing website, n.d.)

In some cases, hand drawings can be enhanced by 2D computer aided design tools and drawing tablets (Figure 2.6). Most of the time, professional 2D design representations are prepared using mostly computer aided design tools, and presented on boards (Figure 2.7). However, there are some disadvantages to using drawings in the design process. Purcell and Gero (1996) have found out that the problem with design students fixating on a design solution too early occurred because they have developed drawings at hand. Even though sketching plays a key role in design, it has been argued that CAD programs can make the drawing activity even more powerful (Tovey, Porter, & Newman, 2003).

Figure 2.6. Hand drawing supplemented with drawing tablet (Delft Design Drawing website, n.d.)

Figure 2.7. Presentation board of an industrial design student with a photograph, 3D renderings, and hand drawn human figures (METU Department of Industrial Design, 2013)

Sketches and drawings are different kinds of 2D visual design representation. A drawing is a formal compilation of lines to visualize a particular form (Lucie-Smith, 2003). In comparison to sketches, drawings have more structure and aim to formalize and specify aspects of the design (Herbert, 1993; Robbins, 1994). Ullman et al. (1990, p. 263) state that drawings are “made in accordance with a set of rules and are drafted with mechanical instruments or CAD systems to scale”; whereas sketches are created in free-hand and are often not to scale.

Tjalve et al. (1979) formalize drawings as the modelled properties of a design (e.g. structure, form, material, dimension, surface) and coded in terms of symbols (e.g. coordinates, graphical symbols, types of projection). The purpose of drawings is analyzing and controlling details and communicating the designer’s ideas to the manufacturer (UIIman et al., 1988, 1990; Bucciarelli, 1994). Drawings may include text and color to provide detailed information about the concept (Yang, 2003, Song & Agogino, 2004).

2.2.2 Three Dimensional Design Prototypes

Physical prototypes, models or mockups can be described as a preliminary three dimensional representation of a design project (Halgrimsson, 2012). Just as the time spent at the table working on drawings, industrial designers spend time in workshops building their three dimensional models. Model making and physical prototyping is argued to be a vital requirement for a successful design process (Halgrimsson, 2012; Yang, 2005). It is even said that basing the product development process on a physical prototype is what brings forth innovation (Schrage, 1993).

Models are necessary to explain the three dimensional attributes of an object, because two dimensional representations lack level of detail (Tovey, 1997). The production of physical prototypes allows designer to clarify issues relating to production and technicalities in a way that cannot be predicted with sketches or drawings (Yang & Daniel, 2005). The purpose of 3D prototypes is to offer the necessary information during the design process to make decisions, as well as communicate and verify the finalization of the concept (Kurvinen et al., 2008).

Physical representations of a design concept can enable the shareholders to interact and finalize aspects of the design (Bødker & Buur 2002; Preece et al., 2002), all the while bringing multi-disciplinary team members to make decisions about refinement in a safe and inexpensive manner (Kolodner & Wills, 1996). Models can be non-functioning objects used to depict the visual appearance of a product concept (Holmquist, 2005), as well as partly functioning to reproduce a visual estimate of the intended product (Buur & Andreasen, 1989). By representing the three dimensional properties of a model, industrial designers can explain function, performance and aesthetic attributes of a design to describe, visualize and sculpt thoughts (Buur & Andreasen, 1989), and develop, reflect and communicate design ideas with others (Peng, 1994). It has been stated that models can be differentiated by their purposes to either communicate information and testing ideas (Garner & Evans, 2012). A scaled down or full size 3D prototype enables the stakeholders to provide feedback on the concept on the issues of design before starting production so that downstream mistakes are avoided (Powell, 2010). Furthermore, models can showcase tactile qualities of the product to help designers think with their hands (Smyth, 1998).

Rough models are suitable for creative work, similarly to rough sketches, to produce a number of alternatives in a short time period, even though they may not contain detailed information. Luzadder (1975) argues that they are full-scale physical representations, whereas according to Holmquist (2005), 3D prototypes only include functional parts and are not look-alikes of the final product. It has also been stated that prototypes can be physical and virtual (Best, 2006). 3D prototypes can be categorized as role prototypes, look and feel prototypes, implementation prototypes and integration prototypes (Houde & Hill, 1997) and the selection of these categories depends on the intended function and feature requirements of the product. Fidelity, in short, is the level of realism of a prototype, and factors such as time, effort and cost are binding for the fidelity of a prototype (Yang, 2005). Exploratory models are usually low fidelity (Figure 2.8) and presentation models are higher fidelity (Figure 2.9). Throughout the development of a product, physical models ranging from low fidelity to high fidelity are made (Figure 2.10). According to Knoblaugh (1958), there are four kinds of physical models based on their fidelity and their place in the design process: *Study models* are for the designers themselves to make their ideas concrete, and are rarely perfected. *Presentation models* are more defined models that the designers use for expressing their ideas to stakeholders, and they usually have a specific scaling. *Mockups* are full sized models that are aimed to look exactly like the finished product, and are aimed at testing with humans. Lastly, *prototypes* are full-scaled working models of the product.

Figure 2.8. Low fidelity physical model of a hair dryer, made from foam and paper (Halgrimsson, 2012)

Figure 2.9. High fidelity model of the same folding hairdryer (Halgrimsson, 2012)

Figure 2.10. The development journey of an Oral-B CrossAction® Toothbrush, (Lunar Design, Palo Alto)

In building physical models, materials such as paper, foam, clay, fabric, wood, plastics and metal can be used. Each material has its own respective tooling and finishing methods, which the designer achieves by power tools and general workshop equipment (Figure 2.11).

Figure 2.11. Finishing wood on a sanding machine (Halgrimsson, 2012)

2.2.3 Digital Design Prototypes

Digital design prototypes are prototypes created with the help of or visualized in digital devices like computers or mobile devices. Computer aided design (CAD) is a vital part of any design process, and goes hand in hand with 2D and 3D design prototypes. Creating 3D design models in CAD systems is helpful for designers because humans think in three dimensions (Israel, Wiese, Mateescu, Zollner, & Stark, 2009) and they showcase increased engagement while viewing three-dimensional models (Cölln et al., 2012). It has been proven that CAD systems support the design process by transforming 2D sketches to three dimensional models (Contero, Naya, Jorge, & Conesa, 2003), help analytical design development and manufacturing (Tovey, 1989), and provide better quality of design representation by specifying details such as size, color, visualization in use environments with relation to human size; along with technical details such as components, assembly, and so on (Figure 2.12). It is also possible to make 3D physical models by using rapid prototyping (Figure 2.13). Rapid prototyping machines are a relatively new technology that turn 3D computer aided design models into physical models.

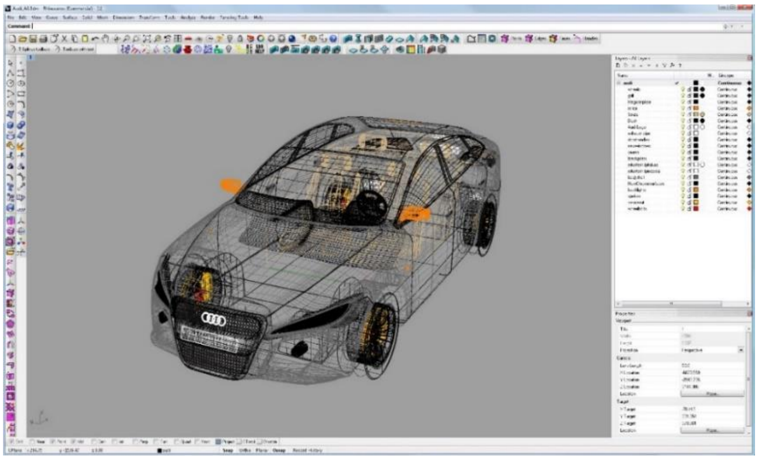


Figure 2.12. CAD model of a car (mrservices, n.d.)

Figure 2.13. CAD modeling, 3D printing and usage of an iPad speaker (Ultimaker, n.d.)

2.3 Factors of Complexity in Educational Industrial Design Projects

The communication needs in presenting the results of the design process are important to consider especially for complex design projects. Educational industrial design projects are developed and monitored in a studio setting. The studio model is considered to be *project-based learning*, a learning-sciences based curriculum. Krajcik & Blumenfeld (2006) have identified five key features for learning environments that are project based:

1. The instructors start the project with a problem question.
2. The question is explored by applying existing knowledge of their discipline.
3. Students, instructors, and collaborators seek answers to the question.
4. Students receive help with technologies that are beyond their ability.
5. Students present products that answer the main question.

The evolving nature of the problems posed by instructors correlate to the complexity of educational industrial design projects. As the theoretical courses continue alongside studio courses, the knowledge and skill levels of the students increase, translating in increased proficiency in solving the more and more complex design problems introduced by the instructors.

In formulating design projects, instructors are responsible to carefully initiate and guide student work by posing open ended problems that have been described as ill defined, or wicked (Rittel & Webber, 1984). Each student creates their own answers to these open-ended problems. In a four-year bachelor degree program for industrial design, the latter two years of the curriculum pose progressively more open-ended questions, and students have longer periods of preparation leading up to the final evaluation (Sawyer, 2012).

To guide industrial design students, design projects typically have a set of constraints to restrict the process, even though the projects are open ended and students each have their own paths to solution. The purpose of parameters in a project is to limit the creative options of students, so that specific learning outcomes can be met. Moreover, students need constraints to break down misconceptions about a project and be guided towards to a more developed concept by giving them clear direction about researching answers to specific problems (diSessa, 2006). A number of cognitive studies show that failure during learning leads to more effective learning (VanLehn, 1988; Bjork & Linn, 2006; Kapur, 2008). It has been noted that not setting enough constraints results in students generating solutions that are too obvious, meaning that their misconceptions were not challenged. In opposition, setting too many constraints results in the students generating too similar solutions (Sawyer, 2012).

In studio based industrial design education, there is a constant need for communication between students, instructors, and other collaborators where necessary. When trying to represent the complexity and the details of an educational industrial design project, factors such as fidelity of presentations must be considered. The matter of fidelity in industrial design presentations depend on, among others, successful representation of scale and audiovisual interactivity.

2.3.1 Role of CAD Design in Spatial Representation

Language of design is comprised of representational tools such as drawings and models (Archer, 1992). Being able to represent a design problem visually enables the designer to see it in a new perspective, and in advanced stages, to reframe the problem (Schön, 1985). Reframing the design problem helps the designer to see the problem from different perspectives and figure out new solutions to pick out the most convenient one. Employing different representational tools would mean the designer has a wide variety of perspectives to look at a design problem, and would consequentially have more ways to solve it. As mentioned in the previous section, the types of prototypes developed by industrial designers are two dimensional, three dimensional or digital. Industrial design presentations usually involve 2D material in the form of posters including digital renderings of the product. The product design is depicted with the help of CAD renders in a variety of viewing angles, zoomed in or out or cut away to show section views. Additional detailing such as the surroundings of the product and how it relates to the space as well as the user’s interactions with the product can be included. Usage scenarios depicted in a narrative fashion can do a good job of portraying how the product design fulfills the design briefing. To get a full sense of the product and go beyond the limits of 2D presentation materials, 3D mockups are used to supplement the presentation. As the fidelity of the mockups rise, the presentations for product design projects become more interactive, providing a dynamic restructuring of visual materials, thus better simulating reality. It is possible to discuss the visual communication needs regarding industrial design projects of larger scale products such as automotive design where the user is meant to walk around in an enclosed space, and projects like large kitchen appliances where the environment surrounding the product becomes a part of the design problem by drawing from the visual communication needs of fields such as interior design, architecture and landscape design where spatial representation is of utmost importance. The link between spatial understanding and creativity has been pointed out by Allen (2010): an interior designer can generate several innovative ideas for a design solution by visualizing a three-dimensional image and mentally rotating and transforming it, creating a mental shift that assists in striking a delicate balance between reality and imagination to generate more ideas, thus improving the chances of coming up with a unique design solution.

In architectural design a static notion of scale, defined as a proportional relationship between the environment of models and the external real world (Boudon, 1971, 1992), or a metric relationship (Licklider, 1966, Dupire et al., 1981, Boudon, 1999), is insufficient to comprehend architectural scaling. The use of scaled down physical models in architectural design has been found to emerge from a non-linear design process (Yaneva, 2005): by shifting from small scale models to large scale models it is possible to work on design iterations involving different usage scenarios, possibilities of improvement, and problems to solve. Jacobsen, Tryggestad & Harty (2021) have found that by challenging the limits of a small-scale physical model and manipulating the scale conflicts, the design team was able to address issues of the façade design fitting into the historic background of the surrounding city. Addressing problematic situations pertaining to scale has been argued to provide negotiations for human scale interactions with buildings and surrounding areas (Callon, 1980).

In landscape design, the user needs to establish spatial orientation to make it possible to interpret 3D information from a 2D representation, and the ability of the user to orient themselves in relation to the surrounding environment is possible with spatial awareness (Reber, 1985). According to Bodner and Guay (1997), spatial skill research revealed two factors: spatial orientation (the ability to not be confused by changes in visual inputs) and spatial visualization (the ability to manipulate visual input components). Factors such as spatial relations in the sense of mental rotation of objects, spatial orientation as recognizing how an object will look from a particular viewpoint, and visualization from a surface creation context were demonstrated by Eliot and Smith (1983). The emphasis is on three variables, according to Juhel (1991): spatial orientation, which defines how an object will look from a particular perspective; spatial representation, which includes the mental transformation of an object; and speeded rotation, which is the mental rotation of objects. Spatial orientation is made possible with 2D representation of topography in the form of landforms depicting hills, valleys, mountains and such as seen in maps, making it possible to orient the user in respect to the environment (Nardi, Newcombe, & Shipley, 2010). However, difficulties in students interpreting 3D topographic information from 2D representations has been noted (Carter et al., 2005), and further research has been found necessary on investigating strategies to address problems of switching between 2D and 3D modes of representation (De Lyser et al., 2010).

3D spatial skills have gained a lot of attention in recent years. Several experiments have used various interfaces to try to manipulate a person's perception of three-dimensional space (Carriker, 2009). Cockburn’s study (2004) used visual cues such as shadows, lighting, and scale to create the illusion of a 3D object, in order to see if people could remember the 3D objects better than their 2D counterparts. Many studies have shown that computer-based 3D visualizations can provide learners with sufficient spatial interactions to help them improve their spatial abilities (Kwon, 2003; Woolf et al., 2003). Furthermore, some studies have looked at the impact of 2D and 3D media representations on undergraduate students' spatial abilities (Wang, Li & Chang, 2006). It can be inferred from previous studies that with the help of software and hardware, students can understand 3D space better, and future research should be encouraged to find most successful tools to strengthen the skill of 3D spatial awareness and visualization (Katsioloudis & Jovanovic, 2014).

In design education, one of the most important goals is equipping the students with the most current technologies so they can visually represent their ideas and the outcomes of their projects with a level of quality that matches professional practice. The emphasis on the importance of representational skills in design students has been established by a number of other studies (Oxman, 1999; 2004). It has been demonstrated that having training to use new representational tools, provided that it has been learned with repetition, enables the design student to interpret, manipulate and evaluate content easily, and the student becomes a professional when they can demonstrate what they have learned with their representations (Eastman & Computing, 2001).

Near the completion of an industrial design project, it is necessary to produce high quality three dimensional physical models to show texture, form, material, user interactions and so on. However, just like with creating high fidelity prototypes in professional practice, design students face problems like monetary expenses and time constraints when developing physical models. In professional practice, the emergence of VR brought on an increase of quality in design output (Sutton, et al., 2007). It can be said that computer aided design (CAD) and digital prototyping tools caused a dramatic shift in design culture (Oxman, 2008; Al-Doy & Evans, 2011). The implementation of computer aided design tools in education has been studied with regards to the nature of its implementation, teacher perceptions and the impact that CAD has had on the activity of designing in an educational context (Hodgson & Fraser, 2005). This means that what is expected of a designer by means of representational skills has changed as well, putting the responsibility on design educators to widen the scope of what they teach their students (Yang, et al., 2005).

2.3.2 Audiovisual Interactivity and Wizard of Oz Prototypes

As technology advances, innovation brings forth new modes of representation. Throughout time, communication media starting with spoken language moved towards written language with the invention of writing, moved on to still images with drawing techniques and photography, and then came the addition of motion pictures with the invention of the camera. The increase in fidelity in representational media brought on the term multimedia.

> *"Multimedia is any combination of text, graphic art, sound, animation, and video that is delivered by computer. When you allow the user – the viewer of the project – to control what and when these elements are delivered, it is interactive multimedia. When you provide a structure of linked elements through which the user can navigate, interactive multimedia becomes hypermedia." (Vaughan, 2006, p.1)*

Dede & Palumbo (1991) have summarized the benefits of hypermedia as follows:

- The need for mapping the representation of data by computers and how humans store knowledge is lessened with the nonlinear, complementing nature of hypermedia.
- Being able to hide and show parts of the content in hypermedia lessens the load of users by creating levels of complexity which the user can manipulate at their own pace.

- Hypermedia enables the user to capture and communicate data in a non-fragmented way, creating a mental model of interconnected knowledge.
- Teamwork and organizational memory can be achieved with hypermedia architecture that enables distributed, synchronized interaction.

In the field of architectural design, Goodwin (1994) has raised the following questions to explore the nature of interactive representations: What are the consequences of the current change in education from two-dimensional drawings to interactive three-dimensional versions if the activities clustered around the creation, delivery, and understanding of architectural representations provide the material and cognitive infrastructure that makes architectural design possible? How does the use of these new technologies communicate with, and possibly reshape, the basic abilities that students acquire through their education? By extending these inquiries to industrial design education, and looking at the current practices of presentation, it is possible to suggest strategies of enrichment and the use of multimedia in raising the fidelity of student projects. Wizard of Oz prototyping technique and virtual reality are examples of the strategies to implement audiovisual interactivity to product design and prototyping.

The Wizard of Oz (WOZ) technique, first coined by Kelley (1984), is a research experiment in the field of human-computer interaction where participants interact with a computer system that is believed by the participants to be autonomous, but is in fact operated by an unseen agent (Bella & Hanington, 2019). This technique has been commonly used in fields such as experimental psychology, ergonomics and usability engineering. As a design methodology, it has been used in quick product development to improve the user experience. Designers can use WOZ prototyping to quickly prepare rudimentary products and test functionalities that have not yet been implemented. It is a method to simulate the product with the ‘wizard’, the designer, pulling the strings in the background without building a prototype of full fidelity. Studies have been conducted in a variety of fields to test and improve the possibilities of the WOZ technique. Adoption of the technique has been encouraged by incorporating WOZ with storyboarding, improvisation, video prototyping and crowdsourced experimentation to design interactions with digital products (Sirkin Ju, 2014), and developing a generic wizard interface as opposed to designated experiments for specific purposes to achieve effective graphical user interfaces in the design of applications (Schlögl, Schneider, Luz & Doherty, 2011). In the design of user interfaces, low fidelity prototypes can be supplemented with WOZ testing to propagate a design change to other related screens, and specify the set of screens that are reachable from a given screen. A study outlining the comparisons between pen-and-paper interface prototyping and a WOZ system has found that the latter can reduce the cognitive load on the participants (Hundhausen et al., 2008). Another study has found that pen-and-paper user interface prototypes have been found to be inadequate due to the difficulty of developing functional prototypes; and despite the delays between end-user actions and wizard updates, a WOZ prototyping system can be used to eliminate designers' inhibitions from participating in the design of interface prototypes (Davis, Saponas, Shilman & Landay, 2007).

The potential of multimedia and hypermedia in education is possible to be reached also with enabling the construction of knowledge by students with the help of creating artificial worlds with VR (Dede, 1993). It has been found that exposure to multimedia in a virtual environment for language education makes the experience functional, efficient, and easily usable (Nurhadi, Rahma & Fadlilah, 2019). Another study concluded that with tasks related to multimedia content manipulation, learning of spatial ability in students are improved in a virtual environment (Molina-Carmona, Pertegal-Felices & Jimeno-Morenilla, 2018). A study developed to visualize multimedia in a 3D interactive system has been found to have several real-world applications (Azzag, Picarougne, Guinot & Venturini, 2006).

2.4 Discussion

The aim of this chapter was to introduce the design process in professional practice. The product development process in industrial design profession can be summarized as a three-step cyclical activity that has analysis, synthesis and evaluation in each cycle, with the end result being the finalized product. Designers first analyze the data they have in hand, they synthesize by generating ideas and engaging in creative activities, and they evaluate the output of their synthesis to gather new data to analyze, in order to improve on their ideas. The synthesis and evaluation steps always happen with prototypes. Anything that comes out of synthesizing activities can be considered a prototype, and the evaluation of the idea is done through said prototype. These prototypes can range from quick hand sketches to fully developed physical models. Physical models usually start with low fidelity, and as the design goes through evaluation steps and the designer refines the design, the model's fidelity increases as well. However, unless a working prototype is completed for user testing, it might be impossible to show all details of a product in a physical model.

2D, 3D and digital design prototypes are developed to represent design details both in professional and educational industrial design practice. It has been found that increased complexity in design projects in terms of scale and interactivity brings difficulties in representations. These difficulties have been shown to be overcome with multimedia representations, which produce a higher fidelity outcome. New technologies for representation can negate drawbacks of high-fidelity prototypes, thus improving collaboration between designers.

The findings from this chapter regarding factors of complexity in educational industrial design projects are that difficulties may arise when representing audiovisual interactivity and large-scale projects with presentation boards and mock ups, and the information related to usage context, audiovisual feedback and 3D fidelity should be the focus in assessing the efficiency of traditional presentation methods (Figure 2.14).

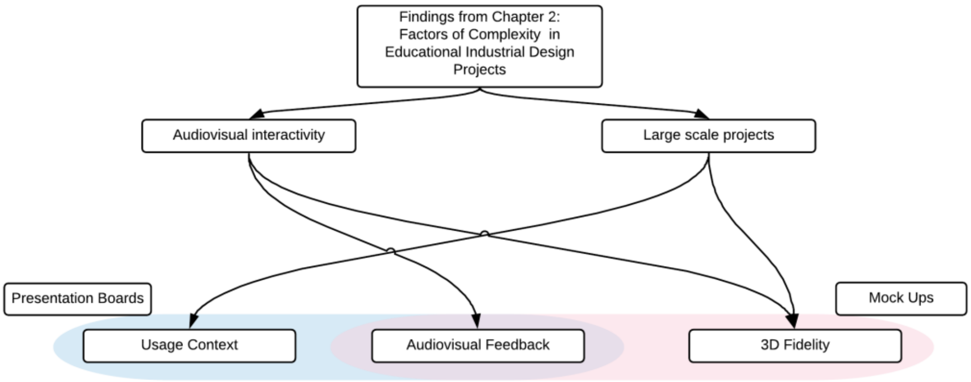


Figure 2.14. Findings from Chapter 2 regarding factors of complexity in educational industrial design projects

This chapter has laid out a foundation on tools and methods in industrial design representations, as well as outlining opportunities to communicate factors of complexity such as spatial representation and audiovisual interactivity with the help of CAD solutions and WOZ prototyping techniques, in order to improve communication between designers, instructors and project stakeholders. The next chapter will offer an overview of mixed reality technologies and pinpoint how the interactive and visual qualities of mixed reality technologies refer to the proposed opportunities of improvement in communication.

CHAPTER 3

MIXED REALITY TECHNOLOGIES

It is necessary to consider the literature on MR technologies to give examples of usage of MR in design related fields. MR technologies will be introduced to later investigate how they can be utilized in the design process to enrich the process and the outcomes of educational design projects, and what types of skills industrial design students need to develop in their education to do so. This chapter will offer an overview of virtual reality technologies by explaining the terminology and definitions related to mixed reality, a brief chronology of MR, the components of a MR system, the industries that use MR and research on usage of MR in industrial design activities.

3.1 Terminology and Definitions

The term mixed reality (MR) was coined by Milgram, Takemura, Utsumi and Kishino (1994) to describe the spectrum of reality and virtuality, as a derivation from augmented reality (AR), to propose taxonomy of the variation of technologies. The authors use a system that separates the real environment from the virtual environment in two steps (Figure 3.1). One step further in the MR continuum from the real environment, which is what humans sense physically through their sensory abilities, is AR, where computer generated data is embedded into the real environment with the purpose of enhancing human perception (Krevelen & Poelman, 2010). One step further is augmented virtuality, which includes real objects embedded in a virtual environment. On the other end of the spectrum is the virtual environment, where the environment is completely made out of computer-generated elements unbound by the laws of physics. The main difference between VR and AR is how complex the projected graphical objects are:

in AR, generating a world or realistic environments is not the goal, unlike VR (Caudell, 1995).

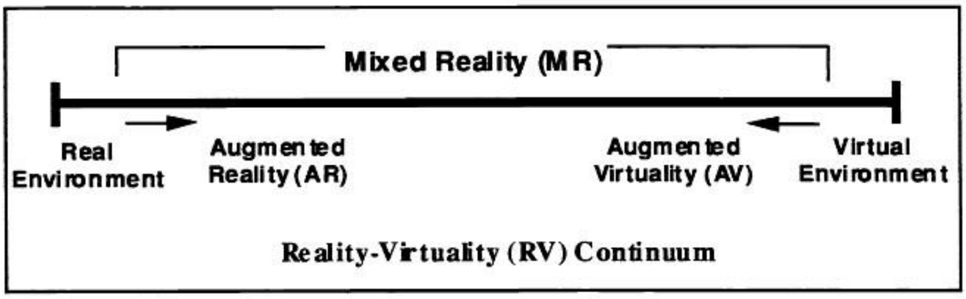


Figure 3.1. Reality-Virtuality continuum (Milgram et al., 1994)

Fuchs and Guitton (2011) offer two definitions for virtual reality: the functional definition states that virtual reality is a vessel through which a person can change the time, place and interaction of an environment by simulating reality; the technical definition offers, utilization of *computer science, behavioral interfaces, virtual worlds, interactions in real time*, and *pseudo-natural immersion*, the five elements that characterize virtual environments.

- *Computer science*, the expertise that makes virtual reality come to life, enables a combination of hardware and software to create a system in which simulations of objects, characters acting within physical laws such as mechanics, optics and acoustics and behavioral laws such as psychology, emotions and sociology.
- *Behavioral interfaces* are made out of sensorial interfaces, the use of a human's five senses in a virtual world, motor interfaces, a human's capability of movement and action with muscles in a virtual world, and sensorimotor interfaces, which is a way of interaction that engages both directions.
- *Virtual worlds* are computer generated environments that are interactive in real time.

- *Real-time interaction*, which is a vital part of any virtual reality system, is achieved when there is no lag between the action of the user in the real world and the virtual world. In other words, if the user raises their hand in real life, their virtual hand must be raised at the exact time.
- *Pseudo-natural immersion* is the immersion that users of a virtual reality system build while using the system. Immersion in virtual reality systems depends on factors like interfaces, software programs, and so on (Fuchs & Guitton, 2011).

3.1.1 Components of MR

A MR system has more components than just a headset. First of all, there are two sides of every MR system: the hardware and the software. On the software side, there is an application or program that makes up the foundation of the virtual environment or the elements, and there is a database that contains the assets in that virtual world. In other words, the elements that the user sees in the virtual environment are stored on a software program that runs the simulation. On the hardware side, there is a computer or engine that runs the program, and there are input and output devices that respectively gather data from the user by using sensors, and give data back to the user in the form of visuals, audio, or haptics (Figure 3.2). To put it in more concrete terms, a computer runs the program, the visuals of the software is displayed on a monitor in a headset or on a physical surface with projectors, speakers provide sound and some MR systems have controllers that enable the user to interact with the system.

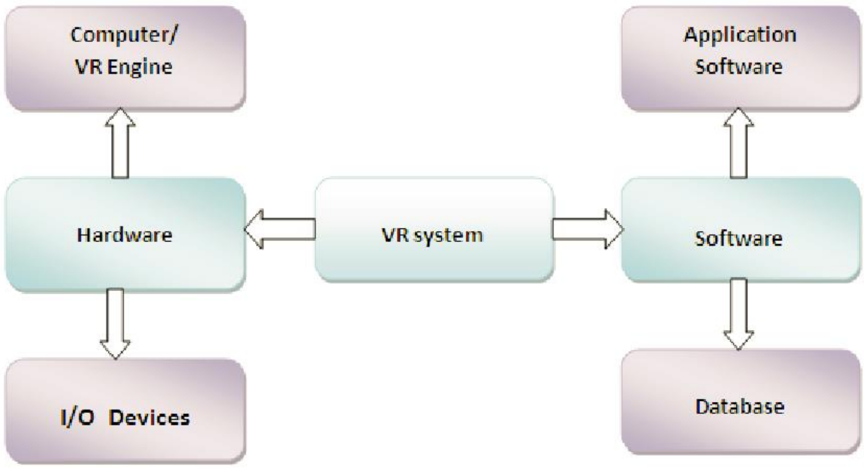


Figure 3.2. Virtual reality system components (Bamodu & Ye, 2013, p. 922)

3.1.2 Brief History of MR

Mentions to the concept of what is called virtual reality today can be seen in science fiction, and are considered to be precursors of the technology. To quote the science fiction author Douglas Adams, “a computer terminal is not some clunky old television with a typewriter in front of it. It is an interface where the mind and body can connect with the universe and move bits of it about” (2009, p. 54). The following quote from William Gibson’s science fiction novel Neuromancer has been deemed as inspiration for virtual reality:

> *“Cyberspace. A consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts... A graphic representation of data abstracted from the banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights, receding...” (Gibson, 2000, p. 31)*

The history of MR dates back to the 1960s with examples like head mounted displays and simulators. The term virtual reality was initially coined by Jaron

Lanier in the 80s, and happened to stay relevant until now. This section, compiled from Chesher (1994), Kipper & Rampolla (2012) and Schnipper (n.d.) outlines and explains the chronology of virtual reality technology.

1962

Morton Heilig's Sensorama (Kipper & Rampolla, 2012) is one of the first examples of multisensory immersion technology. The device simulates visuals, sound, vibration and smell (Figure 3.3) and was a simulator for one to four people to experience a 3D motion picture simulating reality.

Figure 3.3. Morton Heilig's Sensorama, 1962 (Kipper & Rampolla, 2012)

1966

Ivan Sutherland's Sword of Damocles is a head mounted display system that can be used for virtual reality and augmented reality systems (Kipper & Rampolla, 2012) (Figure 3.4). The device consisted of a headset and position trackers positioned above and around the user. The headset was connected to the position trackers to be able to track the user's movements for full integration.

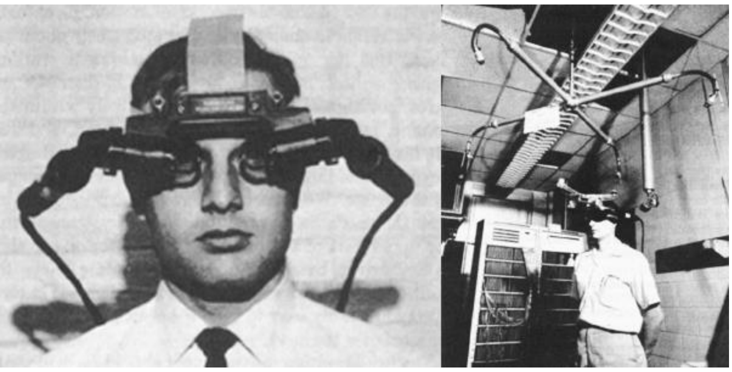


Figure 3.4. The Sword of Damocles by Ivan Sutherland, 1966 (Kipper & Rampolla, 2012)

1975

Myron Krueger's Videoplace was the first example of a system where users interacted with virtual objects, video cameras, projectors, special purpose hardware and silhouettes of humans (Kipper & Rampolla, 2012) (Figure 3.5). Krueger's aim was to create a VR system that enabled the user to experience the virtual environment without being tied to headsets or any other wearable hardware, and fulfilled this goal by using cameras that tracked the user's movements and projected the virtual environment on a screen for the user to interact with directly.

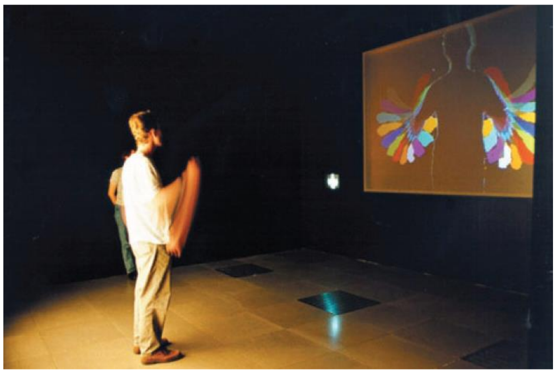


Figure 3.5. Videoplace by Myron Krueger, 1975 (Kipper & Rampolla, 2012)

1987

The first commercial examples of VR systems have been produced by VPL Co. in California, namely the Data Glove (Schnipper, n.d.) (Figure 3.6). This glove was made of neoprene fabric with two fiber optic hoops in each finger, which were connected to knuckles to track movements. The glove had problems such as needing constant recalibration, therefore did not achieve large market penetration.

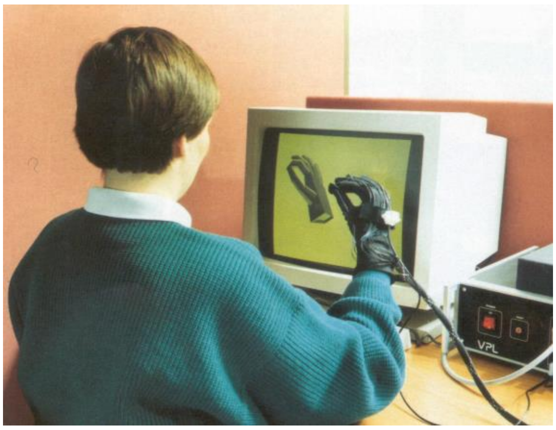


Figure 3.6. VPL's Data Glove, 1987 (Schnipper, n.d.)

1989

NASA, being a pioneer in virtual reality, built Virtual Visual Environmental Display in the early 80s. After prototyping an LCD head mounted display, this project became the Virtual Interface Environment Workstation in 1989. This system consisted of large simulations within relatively small budgets and answered training needs (Schnipper, n.d.) (Figure 3.7).

Figure 3.7. NASA's VIEW system, 1989 (Schnipper, n.d.)

Early 90s

Other virtual reality systems built in the 90s are WorldToolKit by Sense8 Co., now Engineering Animation Inc., VCToolkit by Division Ltd. in UK, Virtual Reality Toolkit VRT2 by Dimension Ltd./Superscape in UK, Cyberspace Developer Kit by Autodesk, W Industries/Virtualiy in UK (Figure 3.8), and later on, Nintendo, Atari, Philips and IBM. These systems included head mounted displays, gloves, and arcade kiosks, and the main commercial area that utilized these systems were arcade centers for video games. During this time, PC boards were still very slow, and graphic rendering architectures were starting to gain emergence. Towards the mid-90s, the expectations of VR hardware quality not meeting up with technological advances resulted in the studies of VR coming to a halt, overshadowed by the new and far more reachable revolution of the internet. Moreover, because these commercialized VR systems were used in arcades for video games, concerns arose from the public about the dangers of losing one’s self in a virtual world. As a result, the popularity of VR had declined (Schnipper, n.d.).

Figure 3.8. VR arcade pods from 1990s by Virtuality (Schnipper, n.d.)

2012

This was the year when a young entrepreneur Palmer Luckey revealed Oculus Rift, the VR headset (Luckey, Trexler, England, & McKauley, 2014). By this time, the hardware problems had been solved by increased computing power and improved display technology. The project was crowdfunded on Kickstarter and the development kit gained worldwide recognition (Schnipper, n.d.) (Figure 3.9). VR technology picked up from where it has left off, the entertainment industry. Video game enthusiasts from all around the world showed that VR still had great potential.

Figure 3.9. Oculus Rift (Kumparak, 2014)

2014

The VR company Oculus was bought by the social media company Facebook. This brought even more attention to the VR headset technology. Google Cardboard was developed for mounting smartphones to turn them into a VR headset (Coz, Henry, Plagemann, & Smus, 2015) (Figure 3.10).

Figure 3.10. Google Cardboard (Cantisano, 2014)

2015

Samsung came up with Gear VR in collaboration with Oculus. The device had intentions similar to the Google Cardboard: the display was a compatible Samsung smartphone that was attached to the headset (Figure 3.11).

Figure 3.11. Samsung Gear VR (Lee, 2015)

2016

This was the year VR headsets became ‘the next big thing’. In March, Oculus Rift released their first official commercial product (Figure 3.12). In April, HTC in collaboration with videogame company Valve released HTC Vive, headset and controllers (Figure 3.13). In October, the videogame hardware company Sony PlayStation released its VR headset, formerly named Morpheus (Figure 3.14).

Figure 3.12. Oculus Rift (Morris, 2016)

Figure 3.13. HTC Vive (Robertson, 2016)

Figure 3.14. PlayStation VR (Alwani, 2016)

2018

Facebook announced the Half Dome VR headset. By this time, especially with smartphone technology making it more accessible, VR is widely used in different fields such as gaming, healthcare, and education.

2019

Facebook's finalized headset called Oculus Quest (Figure 3.15) sold out in many locations and gained immense interest. The standalone headset is proven to be preferable to the average user instead of tethered systems. Nintendo introduced Labo: VR Kit for designing VR experiences for Nintendo Switch.

Figure 3.15. Oculus Quest VR headset (McNamara, 2020)

3.1.3 Application Areas of MR

Some of the application areas of MR are video games, healthcare, the automotive industry, tourism and space studies.

VR has emerged with the entertainment industry, and is still heavily dependent on gaming companies for its development. The increased immersion in the video game is what every videogame company desires, and VR seems to be the perfect medium for achieving this goal. VR headset developers are teaming up with firms in the videogame industry like Valve and PlayStation, which means there will be an increase in VR videogames. For example, the popular videogame Minecraft, developed by Mojang, has been adapted to VR with the help of Samsung Gear VR

(Figure 3.16). Another example of a VR videogame is Keep Talking and Nobody Explodes, developed by Steel Crate Games, in which a team of players help the wearer of a VR headset in dismantling a bomb.

Figure 3.16. A promotional image for the VR version of the video game Minecraft (RT America, 2016)

Besides entertainment, VR is used in many other industries. One example is healthcare. VR has been used in psychotherapy for treatments of disorders such as panic disorder, post-traumatic stress disorder, acrophobia (fear of heights), arachnophobia (fear of spiders), fear of flying, body image disorders, and eating disorders (Riva, 2005). Another use of VR for healthcare professionals is in training, specifically for surgeries, emergency protocols, and clinician-patient relations (Mantovani, Castelnuovo, Gaggioli & Riva, 2003; McCloy & Stone, 2001) (Figure 3.17). It has been proven that VR training for surgery improves operating room performance (Seymour et al., 2002; Westwood, Hoffman, Stredney & Weghorst, 1998).

Figure 3.17. Brain surgery training on a VR system (Medical Futurist, n.d.)

Automotive industry also uses VR, mostly in assemble and manufacture, coined as virtual manufacturing by Ong and Nee (2013). VR aided design in automotive manufacture can be useful for building digital models, testing ergonomics and concepts, assembling parts virtually, detecting collisions, and virtual prototyping (Zimmermann, 2008; Zachmann, 2000; Jayaram, Connacher, & Lyons, 1997). Automotive company Ford has a VR lab specifically built for the product design process called the FIVE, short for Ford Immersive Vehicle Environment lab, in which a virtual prototype of the product is created so that engineers, designers and researchers can experience a concept before actual production (Spears, 2017) (Figure 3.18). It has been stated that multidisciplinary collaboration across many continents has been possible with the help of VR.

Figure 3.18. Ford's virtual factory to make more productive assembly lines (Spears, 2017)

VR has great potential for the tourism industry as well. With VR's characteristic of creating realistic environments in a digital setting, fully developed exhibitions can be developed from archaeological remnants, thus preserving vital cultural heritage (Bruno et al., 2010; Guttentag, 2010). Alternatively, with the help of high definition images that cover the whole vision of the user, people can visit places with just a headset. For instance, a promotional video prepared for Dubrovnik, Croatia has been found to be beneficial for the marketing of the city (Lisnevska, 2017) (Figure 3.19).

Figure 3.19. Setup for experimenting viability of VR to market a destination: Dubrovnik, Croatia (Lisnevska, 2017)

NASA played an important role in the development of VR, and still uses the technology to train their astronauts for missions (Figure 3.20). NASA’s astronauts with experience in missions in space have reported that the zero gravity simulations of the VR training system are very similar to how it feels in real life (Dent, 2017).

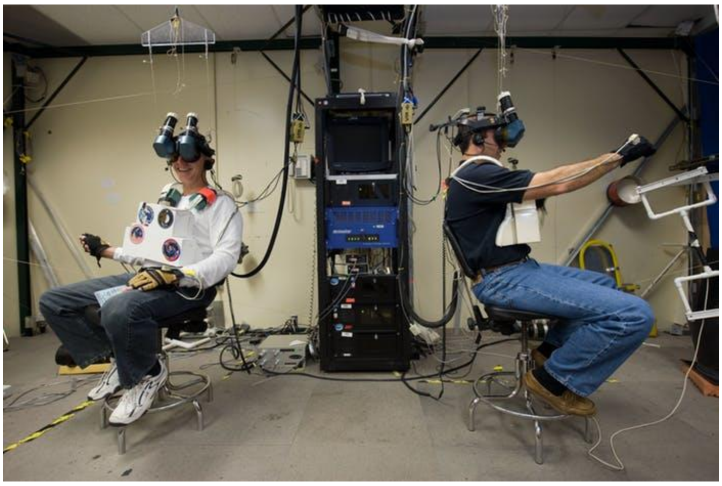


Figure 3.20. NASA's VR system for training astronauts for missions (Patel, 2016).

VR usage in education is also prevalent. It has been argued that VR is a good way to get the attention and involvement of students because of its relation to games, and has proven to be successful in more than one case for teaching topics such as mathematics, geometry and anatomy (Monahan, McArdle & Bertolotto, 2008;

Virvou & Katsionis, 2008; Sala & Sala, 2005; Kaufmann, Schmalstieg & Wagner, 2000; Psotka, 1995) (Figure 3.21).

Figure 3.21. Students experimenting with World of Comenius, an anatomy teaching VR program (James, 2014)

Moreover, virtual learning environments have been found to motivate students and enhance their learning experience (Pan et al., 2006), and further studies on how mixed reality should be conducted to explore how it can supplement education (Billinghurst, 2002). It has been argued that while VR can be used to teach concepts, the content to be taught needs to be generated and readily available first so that VR systems that could teach would be more widespread (Allison, Hodges, 2000). Other challenges for integrating mixed reality into learning environments are cost, usability and fear of the technology (Bricken, 1991).

3.2 Immersion and Presence in MR Technology

The interactive framework of MR consists of immersion and presence. These characteristics of the technology are arguably the reason for the continued interest in both commercial and academic fields for developing new systems for people to experience. The definitions and benefits of immersion and presence in virtual environments have been the source of inspiration for pivotal research on the topic. According to Slater (2003), immersion is an objective phenomenon depending on the fidelity of sensory data provided by a MR system, whereas presence is a subjective psychological response by the user to the MR system. Immersion and presence are sometimes used interchangeably in literature pertaining to MR. It is important to cover the literature around immersion and presence to come to conclusions about their role and assessment in industrial design representations.

3.2.1 Spatial Awareness and Multimedia Stimuli

The benefits of immersion in a virtual environment relate to, most intuitively, spatial understanding. Humans perceive the world as a stable 3D environment using cues such as motion parallax, occlusion, perspective, and stereopsis, which are paralleled in MR by means of stereoscopic imagery and tracking of the head, meaning that high level of immersion results in a higher level of spatial understanding (Bowman & McMahan, 2007). Another benefit is the level of control over the details of the environment. In a real environment, information clutter can be an obstacle to achieving concentration, whereas the comprehensibility of a virtual environment is at the hands of the person designing the experience (Bowman & McMahan, 2007).

Immersion is a concept that can be explained as a multifaceted experience. Being immersed means being inside a real or simulated experience (Pine & Gilmore, 1999) involving physical and mental attendance (Carù & Cova, 2006) to get away from the real world to take on new roles or identities (Pine & Gilmore, 1999). Hansen and Mossberg (2013) define immersion as “a form of spatio-temporal belonging in the world that is characterized by deep involvement in the present moment” (p. 212). It can be argued that immersion and presence are factors to consider the believability of not only computer-generated data in virtual environments, but other reproductions of reality, for instance, a perspective drawing (Bioca & Levy, 2013): humans can instantly perceive perspective in a real environment by three-dimensional depth cues observed with two eyes, but a perspective drawing is a two dimensional “simulation” of the real environment which we need to imagine in 3D. To compare the media represented in environments virtual or otherwise, visuals provide more immersion than text, as the comprehension of a visual merely takes seconds and is registered in the brain instantly, as opposed to text which takes up more concentration because it is dependent upon a translation into a representation (Ryan, 1999). A camera recording would provide more immersion than still images by addressing the sight as well as the hearing, and adding in the time factor, by creating a narrative. Short of physically experiencing the world in 3D, the most immersive representation of media is in a virtual environment.

Humans perceive the world with the five senses of sight, hearing, touch, smell and taste. In virtual environments, immersion is generated by submerging the sensory perception of the user in a computer-generated system with virtual replacements for the senses. A strong sense of presence is achieved by matching the output devices of a computer to the sensory organs of a human to create a realistic and easy to believe simulation of the visuals and the sounds of a virtual environment. The way MR works is by filling in the gaps of a human’s perception with mostly visual and auditory cues and letting the mind connect the rest to perceive the simulation as close to real. The level of immersion in a virtual system depends on factors such as wide field of view, stereoscopic vision, tracking of the head, low latency in matching the user’s movements to the displayed simulation, and high-resolution imagery (Heeter, 1992; Held and Durlach, 1992; Loomis, 1992; Sheridan, 1992, 1996; Steuer, 1992; Zeltzer, 1992; Barfield and Hendrix, 1995; Ellis, 1996; Slater and Wilbur, 1997).

A human in a virtual environment can move their eyes, move their head to look up or down or from side to side, reach out and conduct tasks with their hands (or virtual replacements of the hands), making the concept of *being there* a full body activity (Slater & Sanches-Vives, 2016). Activities such as ducking to see below an object, reaching out and looking around would mean more immersion than afforded by just looking at a screen where you lose the sense of being in the simulation when you look away from the screen (Slater, 2018). Similarly, matching the speed of the user's movement in the display of a head mounted device improves immersion since it mimics the movement of the eye to provide a wide field of view instantly. The immersion is emphasized when the user can perceive a simulation of their own body in the virtual environment. Another factor that heightens presence in a virtual environment is sound. It has been found that spatialized sound results in higher reported presence in comparison to virtual environments with no sound or non-spatialized sound (Hendrix & Barfield, 1996).

3.2.2 Team Work and Remote Education with MR

Industrial designers rarely get to work by themselves in projects. In the case of product development projects with high complexity, it can be vital to establish collaboration between designers of different areas of expertise (Dym, Agogino, Eris, Frey & Leifer, 2005). When a team of designers collaborate on a project, the feasibility of collaboration between designers depends on a couple of factors. For instance, designers in a team often assign roles to accomplish different tasks, and their relationships to each other differ between rankings in an organization (Cross & Cross, 1995). With any new design project, designers use digital tools such as the internet, image editing software, and various computer aided design tools to develop their projects. Some innovative technologies that encourage teamwork have been known to aid industrial designers. For instance, it has been proven that needs of design teams such as information retrieval for projects can be improved with the help of technology that enables teamwork (Poltrock et al., 2003). Moreover, it has been found out that for designers who want to collaborate on a project, a digital sketching environment that emulates traditional sketching would be just as effective; and remote collaboration was found to be feasible in preliminary design stages (Tang, Lee & Gero, 2011).

There are bound to be problems in the design process, maybe even more so when there is more than one designer involved in the development of a project. In order to overcome problems in the design process, analyzing one's own thought process is vital (Busseri & Palmer, 2000); and design education should emphasize the importance of continuous self-reflection (Stempfle & Badke-Schaub, 2002). New technologies can also be helpful in the solution of problems in collaborative design projects. In a study conducted on online collaboration in educational interior design projects, facilitating collaboration by assigning roles to students has been found to be helpful (Cho & Cho, 2014). Examples of distributed design collaborations can be found in fields such as web design (Everitt et al., 2003; Klemmer et al., 2008), mechanical product design (Fan et al., 2008), software interface design (Klemmer & Landay, 2009) or in design teaching (Lahti et al., 2004). Synchronous and asynchronous collaboration in design projects in different design phases can alleviate problems regarding describing physical elements and design ideas (Rahman, Cheng & Bayerl, 2013). Goldberg (2007) has found that collaboration between biomedical engineering and industrial design students on senior design project teams has benefits such as students learning how to communicate with people in other disciplines, students building appreciation for complementary skills each member brings to the project, and learning that there is more than one way to solve a problem.

The complexity of educational industrial design projects increases with industry collaboration where students are visited by professional partners in the industry to get their feedback, and at the end of the project, present finalized design concepts as products to clients. Authentic practice is emphasized for preparing students for professional practice by encouraging them in activities practiced by professionals (Edelson, 2006; Krajcik & Blumenfeld, 2006). Successful intersections between the realm of business and design have shown to result in a "broad understanding of the value of strategic thinking to design practice" (Gajendar, 2003, p. 12). It has been shown that collaboration between industry and universities, in the form of university instruction being up to date on newly available technologies and the practice of professionals benefiting from the research of universities as well as testing their ideas in practice, will help the outcomes of both parties (Elspass & Holliger, 2004).

3.2.3 Real Time Interactivity and Remote Collaboration

Real time interactivity is another factor that heightens immersion in virtual environments. It has been claimed that presence is “tantamount to successfully supported action in the environment” (Zahorik & Jenison, 1998, p. 87). This view argues that actions of people and the functionality of the system create a more realistic experience than mere appearances. In other words, the affordances offered in a virtual environment create the sense of *being there*, based on what the user is able to do there (Sanchez-Vives & Slater, 2005). Other studies have emphasized the necessity of a close match between kinesthesia and the sensory data offered in a virtual system (Slater et al., 1998; Schubert, Friedmann & Regenbrecht, 2001).

The benefits of heightened immersion with MR become more poignant especially during times where online remote education is the only option due to health crises such as the COVID 19 pandemic. Studies on remote collaboration with virtual reality in educational settings have been a rising trend in research. Thorsteinsson, Page and Niculescu (2010) have developed a virtual reality environment to study the impact of student communication on a joint design project: students were able to work online in a virtual classroom to develop drawings and describe their solutions. Tecchia, Alem and Huang (2012) have emphasized the need for remote collaborative systems with more than two participants, and developed a gesture-based MR system that enables a physically distant user to carry out manual tasks to test spatial awareness. Piumsomboon, Lee, Lee and Billinghurst (2017) offered new types of collaboration in CoVAR mixed reality system for users to work together on spatial tasks in a shared environment. Similar experimentation on collaborating in virtual environments has been conducted in fields such as urban planning (Piumsomboon et al., 2018), worker training (Gao, Bai, Lee &

Billinghurst, 2016; Teo et al., 2019; Pouliquen-Lardy et al., 2016, Amores, Benavides & Maes, 2015), vehicle design (Lehner & DeFanti, 1997), physical activity training (Kurillo, Bajcsy, Nahrsted & Kreylos, 2008), and immersive and collaborative data visualization (Donalek et al., 2014). Some researchers have accentuated that head mounted displays are not the only way of achieving immersion, and web-based VR systems can provide mental and emotional immersion (Robertson, Czerwinski & Van Dantzich, 1997).

It has been argued that web-based VR can facilitate learning processes by providing students with realistic 3D simulations and interactions (Georgiou, Dimitropoulos & Manitsaris, 2007), and shifting the education environment from physical classrooms to online networks to facilitate access to information even from their home (Dimitropoulos, Manitsaris & Mavridis, 2008). Web based distant learning VR systems have been studied for panorama based virtual library tours (Xiao, 2000), the correlation of fidelity and usability of interactions in education (Wang et al., 2017), immersive learning environments in natural sciences (Shin, 2002), and content development and problem solving in architectural design in an educational setting (Nguyen, Hite & Dang, 2018). On the topic of distant learning online, VR systems in mobile devices have the benefit of portability in addition to providing a collaborative setting for education and project development (Thakral, Manhas & Kumar, 2010).

3.3 Commercial and Educational Usage of MR in Industrial Design

Apart from the aforementioned application areas of MR, the technology has been utilized for industrial design activities both in commercial and in educational fields. The literature documenting the usage of MR in industrial design education is limited, but there are examples of the use of MR in new product development both in academic field and in the industry. Despite previously being involved in the development of high investment products such as automotive design (Lawson et al., 2016), the tools are becoming affordable and thus more accessible to educational context.

3.3.1 Commercial Use of MR for Product Design

In the industry, MR technology is used to aid the design process in many aspects such as the layout of the manufacturing and assembly lines and educational simulations for assembly workers (Caputo et al., 2018), as well as visualizing customization options in consultation with the client for complex products such as bespoke public transport fit-outs (Górski et al., 2015). In this way, the users have the opportunity to experience the products more frequently throughout the design process. Another benefit is products being visualized in their intended environment to simulate the full experience of usage (Grajewski et al., 2015; Rentzos et al., 2014), therefore being able to recreate impossible or very difficult to represent environments (Wallergård et al., 2008), especially enhanced with animations with sounds for added realism otherwise difficult to achieve with a physical prototype (Roberts, Page, Richardson, 2020). The rising interest for virtual interactions and games alone would arguably raise necessities for virtual reality design methods (Kohler et al., 2011).

As outlined in Chapter 2, designers have to prepare high fidelity physical prototypes for the stakeholders of a project, because a presentation of a design idea is most easily grasped when the physical prototype gets closer to the final product. Moreover, high fidelity physical prototypes are preferable in user testing to gather more detailed and in-depth data. Building multiple high fidelity physical prototypes creates some delays in the development of the design, which is where MR can bridge the gap.

A virtual prototype is a model of a product that simulates its physical form, internal components and characteristics of operation, and is suitable for user testing. There are many benefits to using virtual prototypes over spatial ones:

- Reduced time and costs in manufacturing
- Synchronized design process and prototyping
- Collaborative design from different locations
- No wasted time and cost in re-iterations (Jimeno & Puerta, 2007).

By integrating VR tools with the CAD process designers can go past the boundaries of 2D visualization tools (Jimeno-Morenilla et al., 2016), improve the quality of the final product with the ease of exploration, visualization, testing and validation of designs (Lawson et al., 2016), and speed up the market release (Lawson et al., 2015). Speeding up the market release is a must for product design in an environment where there is increasing competition, and the integration of new technologies to the design process is vital for success (Choi and Cheung, 2008; Lawson et al., 2016). The most expensive and slow attribute of the design process where 70% of the total cost of a product occurs (Lawson et al., 2016) is the iterative aspect: multiple solutions to a problem are constantly created and compared to other options. Virtual prototypes can help designers to save money and time by replacing physical prototypes (Shao et al., 2012), as well as make the iteration process easier since virtual prototypes do not need physical production or modification (Kim et al., 2011). Designers can take advantage of the ease of reiteration in CAD programs to make decisions that respond to the problems that arise during user testing with virtual prototypes so that there are less mistakes in the final physical prototype, which would be financially preferable for the company (Zhong, Yuan, Ma & Shirinzadeh, 2009). In a study that aimed at utilizing VR for design evaluation, a 3D display and a haptic feedback function proved to be easy to use, be similar to real, have good performance and reliability (Ye, Badiyani, Raja, & Schlegel, 2007). To be suitable for user testing, a virtual prototype has to fulfill some requirements, most importantly, be interactive. For best evaluation and reiteration of a design, the virtual prototype needs to characterize and simulate the product’s technical details, provide collaboration by being sharable among stakeholders, be modifiable and systematized, be sensitive to context, and provide multisensory and multimodal real time feedback for full immersion (Bordegoni, Ferrise & Lizaranzu, 2011). Virtual prototypes are more advantageous compared to CAD systems because while 3D CAD systems are useful for getting a grasp of the shape, materials and moving parts of a design, they do not provide real time editing possibilities and immersion in a way that VR prototypes can (Rentzos et al., 2014). This characteristic of immersion of VR environments are especially handy for user testing and evaluation, allowing the designer to track data such as motion capture from the users to test compliance with ergonomic standards (Caputu et al., 2017). It has been proven that using VR for testing human-product interaction can be done to develop external features and functional properties (Rebelo, Noriega, Duarte & Soares, 2012).

The benefits of virtual prototyping have been proven through a number of case studies. Affective qualities of mobile phones have been tested for evaluating satisfaction regarding texture, attractiveness, granularity, harmoniousness, simplicity and rigidity (Lee et al., 2004). Another case study has been conducted on designing an ergonomic electronic cards test bed with an emphasis on multidisciplinary collaboration between styling, ergonomic viability and mechanical requirements (Bennes, Bazarro & Sagot, 2012). In this case study, the industrial designer was able to validate the shape and volume of the bed much more accurately than a mental projection of the surfaces, thus preventing proportional and ergonomic errors and gathering the approval of the other stakeholders. Moreover, Bruno & Muzzupappa (2010) have conducted experiments in which VR usability evaluation has been compared to testing with real products, namely a microwave oven and a washing machine. The experiments were conducted using a VR system called VP4PaD (Virtual Prototyping for Participatory Design) and provided insights on both user testing and participatory design. The results of this study showed that VR is a viable tool for product interface usability testing, and the virtual interface does not prevent the user testing to be done effectively, and end users can take part in participatory design activities concurrent with user testing. Additionally, VR can be adapted to the scenario building activities in product development. During user testing with VR, the designer can create a realistic environment and can take the viewer on a journey of using a prototype. Using VR, it is possible to tell stories that appeal to everyone and make them suspend their belief about not being in a real environment (Pausch, Snoddy, Taylor, Watson & Haseltine, 1996). By using VR to simulate the use of a product, designers are allowed to tell and evaluate stories, and walk people through the experience (Berg & Vance, 2016).

Another study has been conducted for building UnitBathRoom, a bathroom setup manufactured in a factory and assembled in the customer's bathroom. The VR system for designing this bathroom setup, which consists of elements such as sinks, bathtubs, mirror panels, ventilation fans, towel hangers, toilet paper hangers etc., considers factors such as cost, harmony, environmental factors, delivery schedule, product safety, clearance and reachability (Shin, Joo, Choi, Han & Cho, 2000) (Figure 3.22).

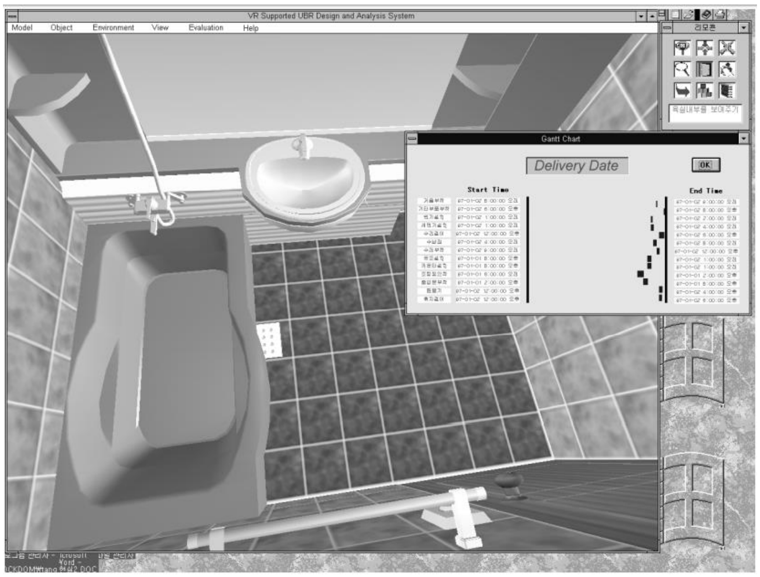


Figure 3.22. A bathroom designed using the UnitBathRoom VR system (Shin, Joo, Choi, Han & Cho, 2000)

Spacedesign VR/AR system developed by Fiorentino, Amicis, Monno and Stork (2002) lays down the foundations to achieve the goal of giving the power of a three dimensionally modified surface creation tool for freeform modelling (Figure 3.23).

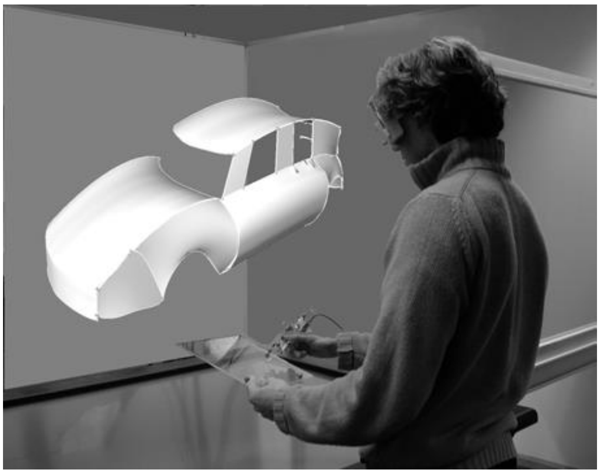


Figure 3.23. Designing a car body using VR/AR visualization (Fiorentino, Amicis, Monno, & Stork, 2002)

According to Ye, Campbell, Page and Badni (2006), interacting with the CAD program on a VR system has proven to be more natural and intuitive than traditional systems. With a 2D screen, mouse and keyboard, the designer has a two-dimensional interaction. On the other hand, the VR-based conceptual design system called LUCID (short for Loughborough University Conceptual Interactive Design) has a two-handed operation interface, a stereoscopic display interface, a haptic interaction interface and a sound feedback interface (Figure 3.24) providing the designer to work quickly and naturally.

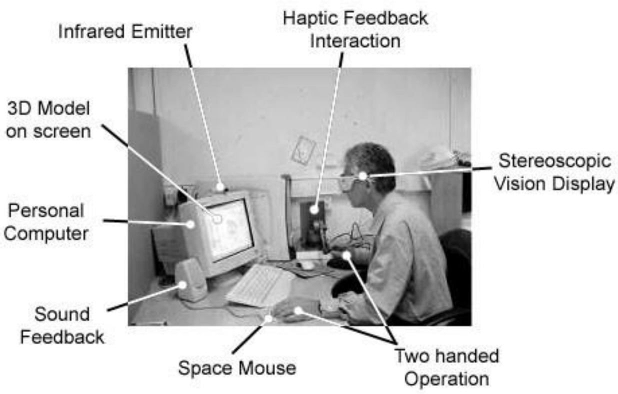


Figure 3.24. LUCID human computer interface framework (Ye, Campbell, Page & Badni, 2006)

Choi and Cheung (2008) have developed a room scale VR system, CAVE, to analyze and renew the design of a product without the cost and manufacturing of a prototype. The system consisted of projectors and reflective screens enclosing the space (Figure 3.25). The designers can rotate, scale up and down, toggle visibility of components to study and evaluate the design (Figure 3.26). This system was used in the design of a multi layered ergonomic footwear design (Figure 3.27).

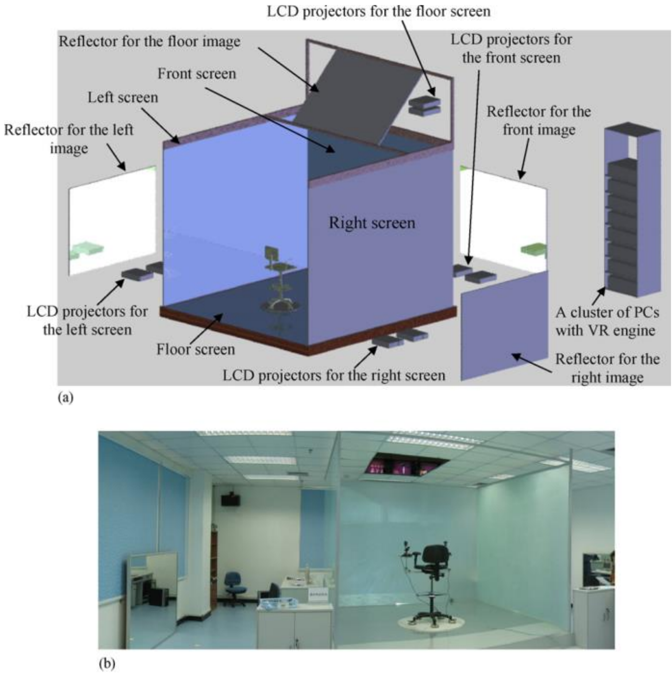


Figure 3.25. The full setup of the CAVE (Choi & Cheung, 2008)

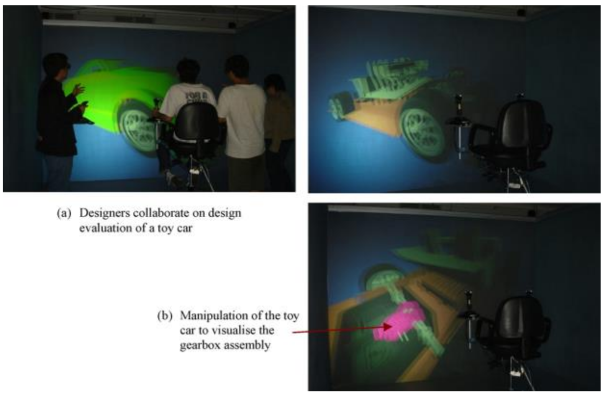


Figure 3.26. Evaluation of a product design in the CAVE virtual environment (Choi & Cheung, 2008)

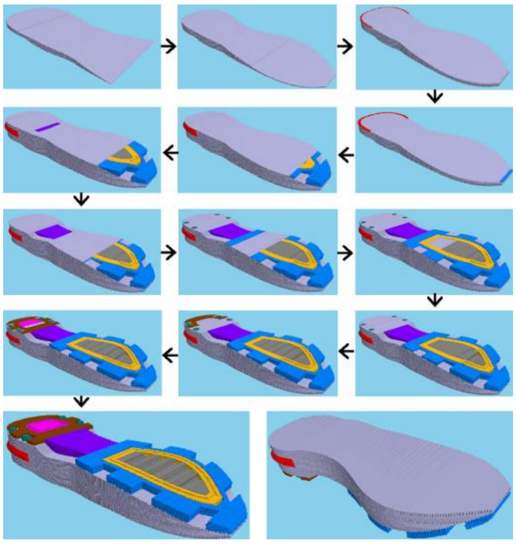


Figure 3.27. Design process of a multi material shoe prototype in CAVE (Choi & Cheung, 2008)

Shao, Robotham and Hon (2012) have created a VR system to enable automotive designers to carry out design reviews with virtual prototypes to speed up the design process by eliminating the effort and costs of physical prototypes. The system includes a headset, controller and projection, and uses tools such as a virtual hand, a virtual turn table, dynamic interaction, collision detection, a 3D pointer, and material and texture alternatives for design evaluation (Figure 3.28).

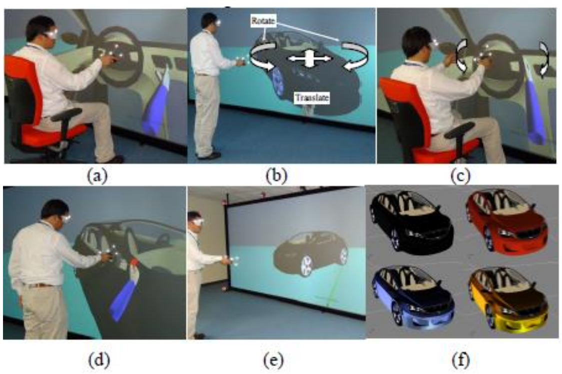


Figure 3.28. Virtual tools for design review: (a) virtual hand, (b) virtual turn table, (c) dynamic interaction, (d) inspection card, (e) 3D pointer, (f) material and texture library (Shao, Robotham, & Hon, 2012)

Rentzos et al. (2014) have developed a design method using VR technology for complex human-product interactions. The system tracks the user's hand motions while using the controls of the aircraft cockpit so that they can evaluate the complexity of the interaction (Figure 3.29).

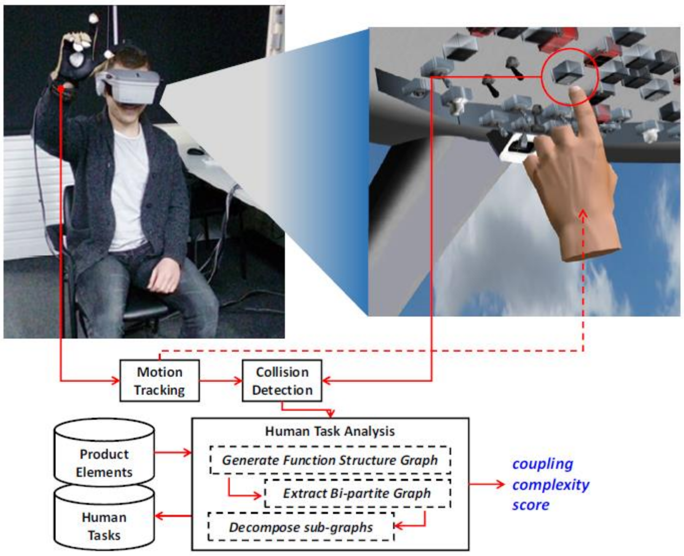


Figure 3.29. Components of the VR system for the aircraft cockpit simulation (Rentzos et al., 2014)

Górski et al. (2015) present a headset VR system built for a city bus manufacturer that can represent functions of the bus during the configuration process to solve client-company communication problems. The system has modes for exploration enhanced with infographics (Figure 3.30), and integration of pictures, movies and animations. The testers of the system used the headset to explore around the virtual city bus (Figure 3.31).

Apart from academic research on the use of VR on product design, commercial VR systems have been developed for design related activities as well. Fiat Chrysler Automotives uses the ImMErsive Technology room (Immersed In A New Reality, n.d.) as an example of interdisciplinary collaboration to design and evaluate in the plants and production processes (Figure 3.32).

Figure 3.30. Exploration mode in the VR system showing 3D notes marked on the bus (Górski et al., 2015)

Figure 3.31. Participant testing the virtual exploration mode (Górski et al., 2015)

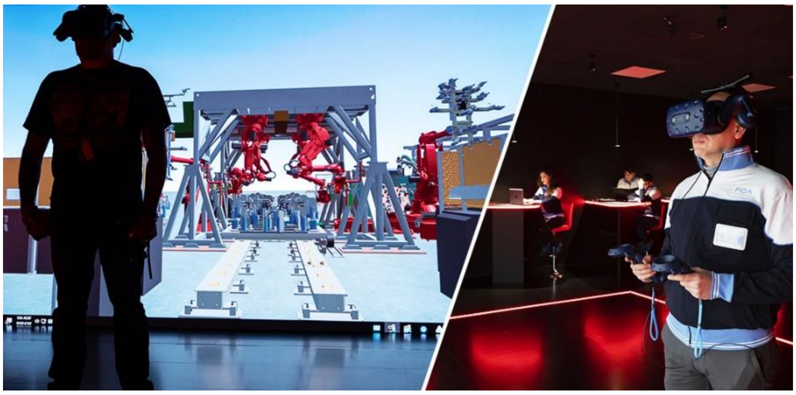


Figure 3.32. ImMErsive Technology room by Fiat Chrysler Automobiles (Immersed In A New Reality, n.d.)

The design firm Bresslergroup used HTC Vive and Solidworks to quickly test a shower setup (Figure 3.33) from the existing CAD files using a VR system, and noted that being able to use native CAD files to complete actions such as moving the shower seat and reaching for shelves, makes the evaluation process very efficient (Murray, 2018).

Figure 3.33. Bresslergroup’s virtual shower setup (Murray, 2018)

ANA Business Class VR (2019), developed by Mbryonic, is a virtual tour with Unity and Oculus Rift showcasing a 777 aircraft interior to be able to experience and evaluate the seat’s features, such as opening and closing cabin doors, ordering food, changing lighting and watching a movie (Figure 3.34).

Figure 3.34. Virtual experience of a 777 aircraft interior by Mbryonic (ANA Business Class VR, 2019)

Dassault Systemes uses HTC Vive in their Immersive Visual Experience and provides VR design tools for very complex products (Figure 3.35). To quote the director Xavier Melkonian, “Just to be in an immersive environment totally changes the way that you perceive your design. We are moving into an era of 3D experience where immersive experience is critical" (Vive Team, 2019).

Figure 3.35. Dassault Systemes' Immersive Visual Experience for designing complex products (Vive Team, 2019).

Since the technology is a vessel for creating unique experiences, software toolkits for designing one's own VR has been made possible. Gravity Sketch is "an intuitive 3D design platform for cross-disciplinary teams to create, collaborate, and review in an entirely new way" (Gravity Sketch, 2020). It has functions such as free form sketching, sketching over a package or 2D Sketch, and conducts collaborative design reviews. Product designer Noah Sussman (Gravity Sketch, 2020) is one of the many designers using Gravity Sketch in their design workflow (Figure 3.36).

Figure 3.36. Workflow in Gravity Sketch showing pen and paper sketching, creation in Gravity Sketch, rendering in Keyshot (Gravity Sketch, 2020)

Microsoft Maquette (Figure 3.37) is a free immersive spatial prototyping tool available for any PC VR set with the feature of using images and 3D content to design immersive interfaces, spaces and experiences (Microsoft Maquette Beta – Home, 2021).

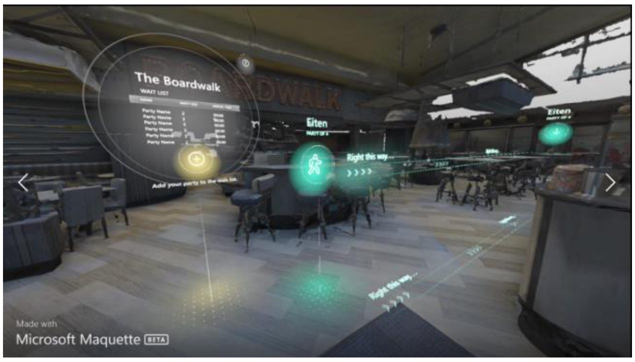


Figure 3.37. Scene created in Microsoft Maquette (Microsoft Maquette Beta – Home, 2021)

3.3.2 Affordances of MR in Learning Environments

Several learning theories are frequently employed to describe educational technology situations. Current learning theories are described by Merriam and Bierema (2013) as behaviorism, humanism, cognitivism, social cognitive theory, and constructivism; however, learning theories that better acknowledge our interconnected and complex relationships with both physical and digital environments, such as connectivism, are also worth considering (Siemens, 2004). The theory of constructivism in learning emphasizes the necessity of students actively developing their knowledge through a more experiential approach. Constructivism is widely regarded as essential to self-directed learning (Zimmerman, 1989) and to Lave and Wenger's concept of contextual learning, which implies that the environment influences individual learning (Lave & Wenger, 1991; Merriam & Bierema, 2013). Connectivism is based on the idea that all learning takes place in a network, a connection of entities that includes not only the learner's mind but also external nodes such as "non-human appliances" such as smartphones and the internet (Scavarelli, Arya & Teather, 2021). Siemens (2004) defines connectivism as the belief that decisions are made on quickly changing foundations, that new data is constantly gathered and analyzed, and that the capacity to distinguish between relevant and unimportant data is critical.

Based on extensive research about virtual learning systems, Scavarelli, Arya and Teather (2021) have outlined the affordances of VR/AR learning platforms (Table 3.1) and argued that by fostering self-learning through real and immersive construction projects, VR/AR can help develop more immersive and experiential learning opportunities that are not available with current learning management systems. The authors have outlined the affordances of VR as providing high presence, not being constrained by physical reality, ability to provide private experiences, increasing embodiment and providing multiple frames of reference. The affordances of AR that has been offered by the authors are bodily, environmental and social awareness and social collaboration. The shared affordances of VR and AR has been outlined as enhanced spatial knowledge, greater opportunities for experiential learning, increased engagement, contextualized and richer learning, and multisensory cues. Steffen et al. (2019) also pointed out affordances of MR such as diminishing negative aspects of the real world by reducing physical risk, enhancing positive aspects of the real world by facilitating additional information, recreating existing aspects of the real world by reducing cost of resources, and creating aspects that do not exist in the real world by depicting the nonexistent and overcoming space-time linearity.

Table 3.1 Affordances of VR/AR learning platforms (adapted from Scavarelli, Arya & Teather, 2021)

Affordances of VR	**Affordances of AR**	**Shared Affordandces**
High presence (HUD)	Body awareness	Enhanced spatial knowledge
Not constrained by physical reality	Environment awareness	Greater opportunities for experiential learning
Allows for private experiences	Social awareness	Increased engagement
Increased embodiment	Context awareness	Possibilities for contextualized learning

Multiple frames of reference	Range of social collaboration	Richer and more effective social learning
Reduced possibility of cybersickness (non-HUD)	Reduced possibility of cybersickness	Multisensory cues

3.3.3 MR Integration in Design Education

In a study conducted with industrial design students, despite foreseen difficulties about learning how to use the technique, the students were interested in using VR in a design project (Shih et al., 2019). Integration of digital learning tools within a traditional context, blended learning (Chen, Huang, & Chou 2017), has grown significantly in the recent years. VR can enable students to learn by engaging in realistic simulations and environments to develop and evaluate their designs (Kirkley & Kirkley, 2005), both at home on their personal computers and in virtual class environments.

Jimeno-Morenilla et al. (2016) have found out that designers can reduce mistakes by having a more direct relationship with the 3D virtual environment and being able to edit real-time, and offered a methodology for learning design techniques and evaluating creativity levels of industrial design students with the help of VR. The authors used a VR system comprised of the Google Cardboard kit for the ease of use with a smart phone, and Sketchfab software (Figure 3.38).

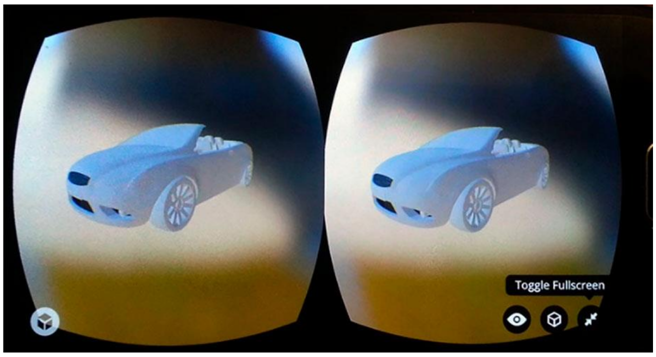


Figure 3.38. VR scene generated with Sketchfab to be displayed on a smart phone with the Google Cardboard (Jimeno-Morenilla et al., 2016)

In line with the experiments of VR among industrial design students, Camba et al. (2017) have used VR to showcase the technology’s ability to enrich presentations and simulations among students following a student centered collaborative approach to creating an integrative and unifying experience. Through tests conducted with a VR system consisting of the Google Cardboard, an Android smartphone running Unity’s VR extension, and a Bluetooth controller (Figure 3.39), Chang (2017) has found out that by engaging with a virtual environment, students have a more intuitive and natural perception of scale and spatial arrangements compared to on a 2D screen.

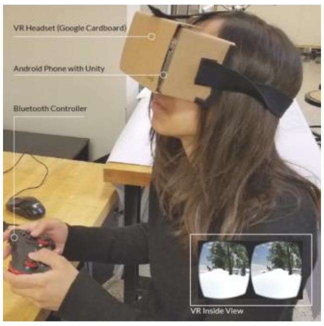


Figure 3.39. VR system consisting of the Google Cardboard, an Android smartphone running Unity’s VR extension, and a Bluetooth controller (Chang, 2017)

Shih et al. (2018) have explored the success of drawing in VR in industrial design education and found that VR can increase the students’ grasp of space and improve the accuracy of representing interaction between people and the relevant components. The authors have used Gravity Sketch to ask industrial design students to design a table, a chair and a mug (Figure 3.40).

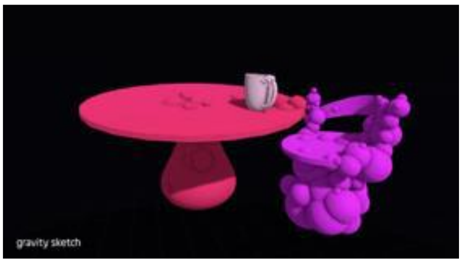


Figure 3.40. Table, chair and mug designed in Gravity Sketch (Shih et al., 2018)

Roberts, Page and Richardson (2020) found out through three case studies that VR was used by design students for early iterations, usability evaluations, and co-designing, and emphasized the benefits and the challenges. They have used a VR headset with a controller, and an environment built in Unity for their testing (Figure 3.41). The benefits were found to be developing and testing designs in a 1:1 scale, being able to quickly modify designs, easily transferring CAD files, options for low cost VR system, easily accessible software, and adapting to new technologies to improve design thinking. The limitations were noted as depth perception difficulties, limiting real life communication, motion sickness, and learning curve.

Virtual environment

Outside the virtual environment

Figure 3.41. VR experience developed to test usability and user experience (Roberts, Page & Richardson, 2020, p. 1637)

To analyze and foresee the optimum VR systems for industrial design students, a study on the wishes of design students for design activities in VR has been conducted (Liang et al., 2016), as well as gathering insights from design students and instructors about using VR technology in industrial design courses (Hamurcu, 2018).

3.4 Discussion

MR has had a sudden increase in popularity within the tech world, following a period of silence since it has first started gaining speed in the 90s, and is now finally becoming available to the public with big companies like Oculus Rift and HTC putting state of the art devices on the market. VR is a kind of mixed reality where humans perceive digitally created environments as if they were physically inside them. A MR system comprises of hardware and software components. Hardware components can be headsets that display visuals and play sounds, projectors that can transform a physical space, sensors that track the movements and sounds of the users and give multisensory feedback. Software components are the programs that compile the information gathered from the sensors, create and run the virtual environments on the hardware components, and store everything in a server or a cloud system. These hardware and software components come together in different combinations and specifications to make a MR system that fulfills whatever purpose the user wants to utilize the technology for. MR has been used in industries such as entertainment and video games, automotive, healthcare, education, tourism and space studies.

Since the most accurate representation of a product is a three-dimensional model or even a working prototype, designers are expected to prepare physical prototypes of high fidelity. Not only is it favored by stakeholders of the project to have a high-fidelity physical model, such models make user tests more elaborate and accurate. However, it can be costly and time consuming to produce high fidelity physical models. By creating virtual prototypes and being able to experience them in a virtual reality environment, designers can evade these problems.

Studies have been conducted for evaluating the feasibility of using virtual reality in the product development process. The most striking examples of utilizing MR for design activities are in virtual prototyping, and user testing. During the design process, the designer goes through cycles of analysis, synthesis and evaluation. In the analysis stage, the designer takes the design brief, or any information that exists about the product, moves on to the synthesis stage to employ creative methods to come up with a prototype of the product, and then conducts user testing and acquires feedback in the evaluation stage. This three-step process takes place in cycles during which the product turns from a crudely sketched idea to a fully formed product. Consequently, the prototypes that come out of the synthesis stage have higher and higher fidelity as the development carries on. Each prototype gets evaluated by users and project stakeholders to begin a new development cycle. In traditional methods where physical prototypes are used, the fidelity goes from quick hand sketches to detailed drawings, and from crude mockups to working prototypes. The quality and attention to detail in prototypes are very important to have accurate information from user testing. However, working physical prototypes can be time consuming and costly. Virtual prototypes can be useful for solving this problem, and have been utilized in a number of studies where their effectivity has not been found to be lesser than physical prototypes.

Apart from prototyping and user testing, MR has also been used for concept creation and freeform modeling. Although the studies about concept design and surface creation are dated, the improved precision and ease of operation brought by the new MR technology can prove to be desirable for such activities in the design process. It is possible to gather inspiration from uses of MR in other industries to industrial design practice as well. For instance, the capability of a MR system to tell a story and take the user on a journey with or without interacting with the elements in the system can be useful for visualizing usage scenarios for products, which could supplement design ideation, user testing and presentation activities. Visualization abilities of MR are not limited to images and videos, and can be utilized for text, to bring any kind of design data presentation. Moreover, the ease of trying out a product in any kind of environment can prove to be a very strong tool for marketing a new product design, or inspiring users.

The way MR provides realistic simulations is creating immersion by filling in gaps in the human perception. Previous studies show that MR in learning environments brings affordances such as heightened sense of presence, overcoming limitations of the real world by providing bodily, environmental and social awareness, contextualization of learning, recreating existing aspects of the real world by reducing cost of resources, and creating aspects that do not exist in the real world by depicting the nonexistent. The findings from this chapter show that opportunities of immersion in MR systems are spatial awareness and increased interactivity, and immersion is improved by presenting multimedia stimuli. These benefits may be useful in representing information related to usage context, audiovisual feedback and 3D fidelity which might bridge the gap in traditional presentation methods used in educational industrial design projects (Figure 3.42) by increasing spatial awareness in large scale projects and using multimedia stimuli to convey audiovisual interactivity (Figure 3.43).

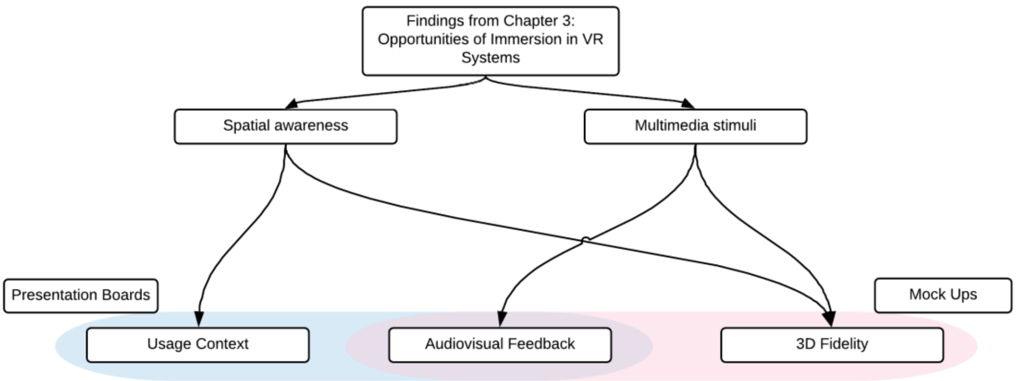


Figure 3.42. Opportunities of immersion in VR systems for industrial design presentations

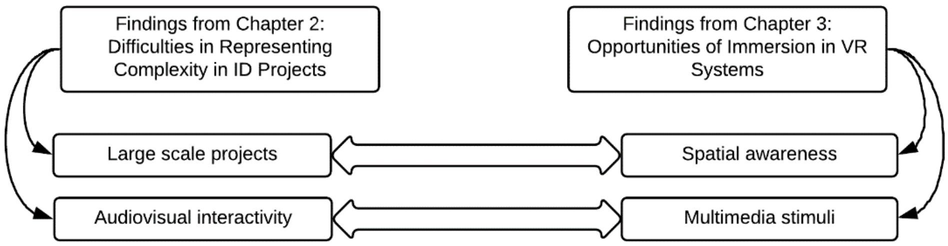


Figure 3.43. Difficulties in representing complexity in industrial design projects which can be answered by opportunities of immersion in MR systems

MR has the potential of becoming a staple skill for representation for industrial designers, and the necessary skills for utilizing the technology should be acquired prior to starting professional practice. However, having close ties with the field of computer science, MR is an underexplored tool in industrial design education. A designerly way of thinking should be applied to training students to use MR so that the process can be strategized based on students' needs. After outlining the design process in professional setting and in education, and introducing MR technology and its potentials for industrial design, it is possible to discuss in detail how MR could be useful in industrial design education.

CHAPTER 4

DESIGN PROJECT ASSESSMENT STUDY

A higher level of immersion has proven to improve spatial understanding, therefore making design reviews, visualizations and prototyping more effective (Bowman & McMahan, 2007). The argument is that a MR experience presenting product designs would provide more immersion than what is possible with traditional presentation tools, better answering the communication needs in an industrial design project especially in projects of large scale and complex interactivity. The findings from Chapter 2 and Chapter 3 support this argument. As outlined by the literature on immersion and presence, 2D visual representations are perceived at a lower level of immersion, which makes additional explanations by the design student compulsory to understand the full characteristics of the design. This proves extra challenges in settings where education can only be conducted online. By outlining the factors that prevent full immersion in viewing 2D presentational boards, experimentation can continue on filling in sensory gaps in industrial design project presentations. Therefore, a design project assessment study based on an analytical review has been conducted to understand the factors that break the immersion in final project presentations. The analysis was conducted on digital images and print outs of the submissions for the final jury 2D presentation boards as well as photographic submissions of the mockups of four 3rd and 4th year team projects. The data was a total of 45 unique design projects' design boards and mockups. The analysis mainly involved visual content analysis.

4.1 Research Questions

Based on the argument, this study seeks answers to the following research questions:

1. What are the shortcomings of traditional design representation tools in presenting complex educational industrial design projects?
2. How can the benefits of immersion provided by MR systems strengthen the shortcomings of traditional representation tools in presenting complex educational industrial design projects?

4.2 Methodology and Analysis Framework

Action research, when combined with data from case studies, was deemed to be particularly appropriate for achieving the study's goals as a recognized approach for supporting improvements in the execution and comprehension of practice. Case study data collection and analysis also includes the collection of unstructured data, as well as qualitative interpretation of such data (Gomm et al., 2000). Moore (1983), Gomm et al. (2000), and Cohen and Manion (1980) define action research as one of the specific approaches used in case study research.

Action research strives to bridge the gap between theory and practice by combining *activity* and *research* (Elliott, 1991). Action research is about identifying the goal the researcher is aiming to reach by examining existing practices for problematizing and taking actions to improve the identified aspects, and by determining the reasons for the action in relation to the researcher's values, as well as collecting and evaluating data to demonstrate that the reasons and values were justified and satisfied. (McNiff, 2015). The cyclical nature of action research was noted by Birley, who described it as being carried out by a profession researching its own activity with the purpose of improving practice (Birley and Moreland, 1998).

In traditional research, conventional criteria such as ‘Are the study findings generalizable and replicable?' and traditional standards such as ‘How well are the criteria addressed?' are used to assess research quality. In action research, the researcher’s values become their criteria, and quality is determined by how well the researcher can demonstrate that they are attempting to improve practice based on those criteria (McNiff, 2015). Looking at the findings from chapters 2 and 3, we can pinpoint that in representing complexity in educational industrial design projects, the need for high fidelity presentations as well as the need for digital collaboration between designers are factors to consider, and immersion provided by MR technology can be the answer. The benefits of increasing immersion with MR in the form of providing spatial awareness, multimedia stimuli, and real time interactivity help answer the difficulties of representation in industrial design projects of large scale and complex interactivity with multimedia presentations and remote collaboration. Based on the matching of the difficulties of representing complexity in industrial design projects in Chapter 2 with the opportunities of immersion in MR systems in Chapter 3 (Figure 4.1), the presentation material has been assessed under the criteria of usage context, audiovisual feedback and three-dimensional fidelity. The representations of the usage context relate to the presentation boards, the 3D fidelity criteria relate to the mockups, and the audiovisual feedback representations relate to both the presentation boards and the mockups. When assessing the representation of the usage context in the presentation boards, details visualizing the product in its intended context, the interaction of the user with the product, and the user acting out the usage scenario have been the focus. When assessing the representation of the audiovisual feedback, details representing the lights, sound, info screens and graphical user interfaces in both the presentation boards and the mockups have been the focus. When assessing 3D fidelity, the mockups have been analyzed based on scaling of the model, the material and surface quality, and lastly component detailing such as moving parts, accessories, cutaway views, and so on.

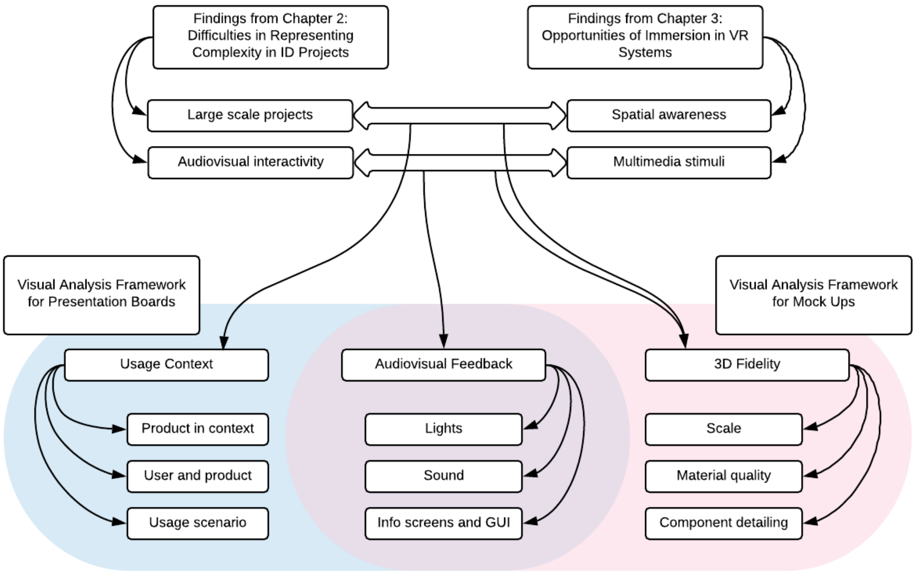


Figure 4.1. Steps leading up to the visual analysis framework for presentation boards and mockups

Difficulties in representing large scale projects can be remedied by the benefit of spatial awareness brought on by immersion in a MR system. In the final design presentation boards, these difficulties can be seen in usage context details such as seeing the product in context, the user and the product in interaction, and the usage scenario. In the final design presentation mockups, these difficulties can be seen under the 3D fidelity criteria of scale, material quality and component detailing.

Difficulties in representing audiovisual interactivity in complex industrial design projects can be remedied by the opportunity of creating immersion via multimedia stimuli. In the final design presentation boards, these difficulties can be seen in audiovisual feedback details such as lights, sound, and GUIs. In the final design presentation mockups, these difficulties can be seen under the 3D fidelity criteria of component detailing.

The analysis carried out for connecting the lacking aspects of the presentation material with the capabilities of MR based on these criteria aims to reveal the specific aspects of design presentation in which integrating a MR system would produce the most effective results. With this information, it is possible to offer specific solutions for integrating MR systems with educational industrial design project presentations.

The visual analysis framework is a unique assessment scale developed in order to provide the chance of going beyond expectations of traditional methods of representation in industrial design education. Because the submissions of the selected projects have been prepared using traditional tools and methods of presentation, i.e. presentation boards and non-interactive mockups, the highest grade of 4 was not reached in any of the assessment categories, as the best option short of a real working prototype has been assumed to be a virtual working prototype. The grading scale of 0 to 4 will be explained in the following sections for each sub-criterion.

4.2.1 Usage Context

The presentation boards have been assessed on the success level of representing the usage context details of product in context, the user and product, and the usage scenario (Table 4.1). The parts of the submissions that presented the relevant information pertaining to the evaluation criteria have been graded between 4 and 0. The assumption was that a full grade of 4 would be appointed to a working interactive virtual prototype, which would be achievable with the aid of MR technology as showcased in the previous chapters. A virtual working prototype would enable the viewer to see a full simulation of the product in the intended usage environment, interact with the product as intended, and carry out the full usage scenario. The second-best grade of 3, which is the ultimate optimum best outcome traditionally expected from the participants, was given to outputs representing the full usage environment from multiple angles and configurations, as well as representing the user interacting with the product in a fully detailed environment to carry out multiple usage scenario sequences including interface screens. The third best grade of 2 was given to outputs representing the product in a less detailed environment with partial user interaction carrying out limited usage sequence. The least satisfactory grade of 1 was given to outputs representing the product in minimally detailed environments with the smallest amount of detailing, carrying out an incomplete usage scenario sequence. The submissions where usage context, user representation and usage scenario details have not been presented would be appointed with a grade of 0 correspondingly.

Table 4.1 Visual analysis framework for assessing final project outcomes based on representing usage context

	Usage Context		
	Product in context	User and product	Usage scenario
4	Working virtual prototype representing intended usage environment	Interactive virtual prototype	Working virtual prototype
3	Representation of full environment from multiple angles and configurations	Representation of user interacting with product in fully detailed environment	Representation of user interacting with the product in multiple sequences, interface screens included
2	Representation of product in partial environment	Representation of user interacting with product with partial environment detailing	Representation of user interacting with product in partial usage sequence
1	Representation of product in minimally represented environment, no user	Representation of user interacting with product with minimal or no environment detailing	Representation of partial usage sequence or no user/product interaction
0	not presented	not presented	not presented

4.2.2 Audiovisual Feedback

The presentation boards and the mockups have been assessed on the success level of presenting audiovisual feedback using lights, sound, and info screens and user interfaces (Table 4.2). For representing lights, the highest grade of 4 would be given to having working lights, sound and graphical user interfaces in a virtual prototype, where the user would interact with the product to get real time feedback upon completing the usage scenario. The second highest grade of 3 was appointed to submissions that represent interior and exterior lights as well as all or most graphical user interface screens in various stages of use to get a full sense of the feedback that the user would get upon interacting with the prototype without interactivity. The third best grade of 2 was appointed to submissions that represent only some of the lights and the graphical user interface screens, and the last grade of 1 was given to submissions that had minimal representation or mention of audiovisual feedback details. The submissions in which the lights, sounds and info screens/GUI were not represented were appointed with a grade of 0.

Table 4.2 Visual analysis framework for assessing final project outcomes based on representing audiovisual feedback

	Audiovisual Feedback		
	Lights	Sound	Info screens and GUI
4	Working lights in virtual prototype	Working sound in virtual prototype	Working graphical user interfaces in virtual prototype
3	Representation of interior and/or exterior lights in various stages of use	Working sound in physical prototype	Multiple scenarios, all graphical user interface screens represented
2	Partial representation of lights	Description of sound in presentation boards	Partial representation of graphical user interface
1	Minimal representation of lights	Mention of sound in presentation boards	Minimal representation of graphical user interface
0	not presented	not presented	not presented

4.2.3 3D Fidelity

Lastly, the mockups have been assessed on the success level of presenting three-dimensional fidelity with scale, material quality, and component detailing (Table

4.3). For representing scale, the highest grade of 4 would be given to having a full-scale virtual prototype where the user can get a true feeling of the size of the product by walking around it and manipulating it. The second highest grade of 3 was appointed to submissions of full-scale physical models, which also provide accurate spatial awareness, but is lacking the opportunity of easy rescaling and manipulation. The third best grade of 2 was appointed to submissions that have scaled down physical prototypes. For representing material quality, the highest grade of 4 would be given to a virtual prototype with intended materials. The second highest grade of 3 was given to physical prototypes with a high level of finishing. The lowest grade of 1 was appointed to crudely finished physical mockups. For representing component detailing, the highest grade of 4 would have been given to a working virtual prototype. The second highest grade of 3 was given to submissions that had high level of component detailing including graphical user interfaces, moving parts, accessories, cutaway views, and so on.

Table 4.3 Visual analysis framework for assessing final project outcomes based on 3D fidelity

	3D Fidelity		
	Scale	Material quality	Component detailing
4	Full-scale virtual prototype	Virtual prototype with intended materials	Fully interactive virtual prototype
3	Full-scale physical prototype	Physical prototype with high level of finishing	Highly detailed prototype
2	Scaled down physical prototype	Physical prototype with moderate level of finishing	Moderately detailed prototype
1	Crude physical mock up	Crude physical prototype	Shell prototype
0	not presented	not presented	not presented

4.3 Data Collection and Sampling

In total, four educational industrial design projects from the 2016-2017 spring term, 2017-2018 fall and spring terms, and 2018-2019 fall term studio courses in METU have been selected for analysis. The analyzed data consists of the final jury submissions of a total of 45 projects developed by each team. The source of the data that was collected are the handouts detailing the submission requirements of the instructors from the third- and fourth-year students, and the presentation boards as well as mockups made by the teams of students for the projects. The titles of these projects are:

- Rethinking the Built-in Electric Oven for Sustainability in Collaboration with Teka (12 submitted projects);
- Autonomous Apron Bus for Airports in Collaboration with OTOKAR (12 submitted projects);
- Rethinking the Built-in Vitroceramic Cooktop and Interface for Sustainability in Collaboration with Teka (12 submitted projects);
- City Bus of the Future in Collaboration with MAN Turkey (9 submitted projects).

The selected projects are fitting for the study because they are all projects of large scale and complex interactivity. By the end of the third year and beginning of the fourth year, industrial design students of METU are considered to have gained the necessary skills for designing highly complex products, and producing high quality presentation material. Other educational objectives are team work, communication skills, distribution of work load, more elaborate level of detailing, high level of prototyping. In each of these projects, the students have gone through steps such as design research (technical, literature, field and user research), brainstorming (for understanding the problem area), initial idea generation (for generating alternative design concepts), preliminary jury, user testing, expert feedback, design detailing and final jury (Table 4.4).

Table 4.4 Details of the projects that have been analyzed

Project Date	ID302 2016-2017 Spring Term	ID401 2017-2018 Fall Term	ID302 2017-2018 Spring Term	ID401 2018-2019 Fall Term
Project Title	Rethinking the Built-in Electric Oven for Sustainability	Autonomous Apron Bus for Airports	Rethinking the Built-in Vitroceramic Cooktop and Interface for Sustainability	City Bus of the Future
Collaborating Firm	Teka	Otokar	Teka	MAN Turkey
Number of Teams	12	12	12	9
Research Exercises	Literature Search	Literature Search	Literature Search	Research Task 1 Poster
	User Observation	User and Use Context Insights	User Observation	Research Task 2 Bus Journey Scenarios
Brainstorming Exercises	Brainstorming	-	Cooking Festival	-
			Brainstorming 1	
			Brainstorming 2	
Initial Idea Exercises	Task Session	✓	Task	✓
			UI 1	
	UI* generation		UI 2	
Preliminary Jury	✓	✓	-	✓
User Testing	✓	✓	UI peer review	
Expert Feedback	✓	✓	✓	✓
Design Detailing Exercises	Technical Drawings	Sketch Problem 1	Peer Review	-
		Sketch Problem 2	Heuristics Evaluation	
			Final Screening	
Final Jury	✓	✓	✓	✓

* UI: User interface

4.3.1 The Projects: Design Briefs and Final Jury Submission Requirements

The projects start with a briefing that explain the objectives and outcomes of the design project. For final evaluation, jury presentations are made, for which the design teams are expected to prepare design boards, technical drawing boards and 3D models depicting their design solutions. These projects have taken half a semester to complete, averaging 7-8 weeks. The construction of the development process is similar across the projects, whereas differences arise in terms of the focal points, the educational outcome goals and the content of each of the development stages based on the project.

4.3.1.1 Electric Oven for Sustainability

In this third-year studio project in collaboration with TEKA, the aim was to redesign a built-in electric oven for small households, focusing on small portion food, energy efficiency and local needs and preferences. The focal points of the project were oven’s internal organization, user interface, and baking and serving accessories. The project took eight weeks to complete. For the final jury, the teams were expected to prepare a design board, a technical drawings board and a 3D model.

The requirements for the design board were colored renders of the product and its accessories, full-scale colored renders of controls and displays demonstrating phases of use, all critical product features, and that the board communicates how and to what extent the design solution supports energy and resource efficiency; cleaning, maintenance, upgrading and repair; and local needs and preferences.

The requirements for the technical drawings board were 1/3 scale orthographic views with dimensions, and isometric drawings; as many drawings as necessary of design details and sections; and an exploded view.

For the 3D full-scale model, the requirements were to show design details of the interior and exterior of the oven; product interface in full color, capable of showing multiple use phases; accessories including trays.

4.3.1.2 Autonomous Apron Bus for Airports

In this fourth-year studio project in collaboration with OTOKAR, the students were expected to work on an autonomous apron bus for airports, taking into consideration factors such as interior layout, visibility, accessibility, vehicle identity, exterior styling, integration of technological advantages and non-fossil power source compatibility. The project took seven weeks to complete.

For the final jury, the requirements for the design boards consisted of showing usage scenario illustrating critical phases of use with users interacting within illustrations, overall shuttle styling consisting of photorealistic views of the vehicle exterior in the appropriate environment of use, and photorealistic views of the vehicle interior from the viewpoint of a standing passenger.

The technical boards were expected to showcase the specialization of the vehicle in regards to autonomous and electric powered design solutions and maintenance requirements, interior layout of the vehicle showing passenger circulation and full capacity, and anthropometric relations between the vehicle and the user.

The mockups were required to be 1:20 scale models showing critical components depicting the appearance and the moving parts of the design.

4.3.1.3 Rethinking the Built-In Vitroceramic Cooktop and Interface for Sustainability

In this third-year studio project in collaboration with TEKA, the students were expected to rethink built-in vitroceramic cooktops focusing on middle income level, energy efficiency, and local needs and preferences for cooking. The main focuses of the design were the cooktop layout, user interface, cooking and serving accessories, and the whole product lifespan. The project took eight weeks to complete.

For the final jury, the students submitted design boards presenting renders of the product and its accessories showing the product's context, controls, displays showing phases of use, as well as critical product features such as placements of pots and pans, turning on, setting time/temperature/program, cooking, pausing, locking, care and cleaning, and so on.

The technical boards were expected to demonstrate orthographic views with dimensions, assembly drawings, sections and exploded views.

The 3D presentations included full-scale models of the cooktops showing design details, product interface in full color capable of showing multiple use phases, and accessories.

4.3.1.4 City Bus of the Future

In this fourth-year studio project in collaboration with MAN, the students were expected to design a city bus of the future with emphasis on communicating a wow factor for the passengers with high functionality and technical viability. The dimensions of the project were electric powered vehicles that provide passenger comfort and convenience, meeting needs of children, elderly, disabled and luggage-laden people using e-mobility and digital services, allowing for local customization and having technical design details like service sets for ventilation, air conditioning and lighting, being lightweight, and reduced energy consumption during use. The project took seven weeks to complete.

For the final jury, the students were expected to present presentation boards describing the future scenario and user experience goals with high quality bus exterior and interior renderings, especially in its intended environment. A tour of the interiors of the bus were required to show passenger activity delivering a good user experience from the point of view of the passenger indicating passenger seating, leaning, standing, circulation, access and clearances.

The requirements for the technical drawing boards were orthographic drawings, ghosted, exploded or cut-away perspective drawings that show details such as form and materials, assemblies of chassis, frames, internal and external panels, as well as added value services such as apps, on-board information, ticketing systems, passenger recognition, and bus stops were required.

The mockups were required to be 1:20 scale models showing ‘wow’/impact factor of concept, state of completion of UX, exterior, interior and technical design.

4.4 Analysis of the Design Project Assessment Study

From four design projects with respectively 12, 12, 12 and 9 teams, a total of 45 unique design projects’ design boards, technical drawing boards and models have been analyzed based on their visual content.

The findings of the design project assessment study will be presented first as an overview of how the project submissions stood up to the assessment criteria based on the aforementioned grading scale. From each of the four project submissions, one of the highest, and one of the lowest ranked submission for each sub-criterion will be used as examples to outline the approach behind the grading.

The next step in presenting the findings will be to pinpoint where the weakest aspects are in the submissions based on the criteria. Each criterion will be analyzed based on examples of projects with repeating difficulties in representation with traditional methods.

4.4.1 Assessment of the Electric Oven Project

For the electric oven project, design teams were expected to provide colored renders of the product and its accessories, including controls and displays demonstrating phases of use, communicating all critical product features. The assessment was done with details relating to the usage context, which were product in context, user and product, and usage scenario; and audiovisual feedback, which were lights, sound, and info screens and GUI.

All 12 teams have been assessed as demonstrated with the examples given for each grade appointed to the submissions for the criteria of usage context and audiovisual feedback. The assessment (Table 4.5) shows that short of a working virtual prototype experienced in an MR system, the representation of the info screens and GUI was the most detailed, with usage context details such as product in context, user interacting with the product and the usage scenario taking second place. The representation of lights was, as per the limitations of the 2D presentation board format, lacking in realism, especially when trying to convey features such as blinking or glowing. The representation of sound in the submissions were non-existent except for one case, where an alarm was mentioned.

Table 4.5 Assessment of submissions for the Electric Oven project

Electric Oven		Content Development and Quality of Presentation												Average
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	
Usage context	Product in context	2	3	3	3	1	1	2	0	2	3	3	3	2.2
	User and product	1	3	3	2	1	2	3	1	1	3	3	3	2.2
	Usage scenario	2	2	1	2	3	3	2	3	1	1	2	3	2.1
Audiovisual feedback	Lights	1	1	1	1	1	1	1	1	1	1	1	1	1.0
	Sound	0	0	1	0	0	0	0	0	0	0	0	0	0.1
	Info screens and GUI	3	1	3	3	3	3	2	3	3	3	3	3	2.8
3D Fidelity	Scale	3	3	3	3	3	3	3	3	3	3	3	3	3.0
	Material quality	2	2	2	2	2	2	2	2	2	2	2	2	2.0
	Component detailing	2	2	2	3	3	3	3	3	3	3	2	2	2.6
General average		1.8	1.9	2.1	2.1	1.9	2.0	2.0	1.8	1.8	2.1	2.1	2.2	2.0

4.4.1.1 Usage Context

Team 4 was given a grade of 3 for representing full environment from multiple angles with the user interacting with the product (Figure 4.2). The images show different perspectives, realistic lighting with shadows and reflections, somewhat realistic textures and materials in the countertops and oven, and oven accessories such as baking trays as well as open and closed views of the oven. The cropping of the full kitchen view makes it difficult to understand the full layout of the kitchen. The materials used in the cupboards, the backsplash, and the ventilation hood seem flat and unrealistic. The images lack environmental detailing such as kitchen appliances, serving dishes and food, thus breaking immersion.

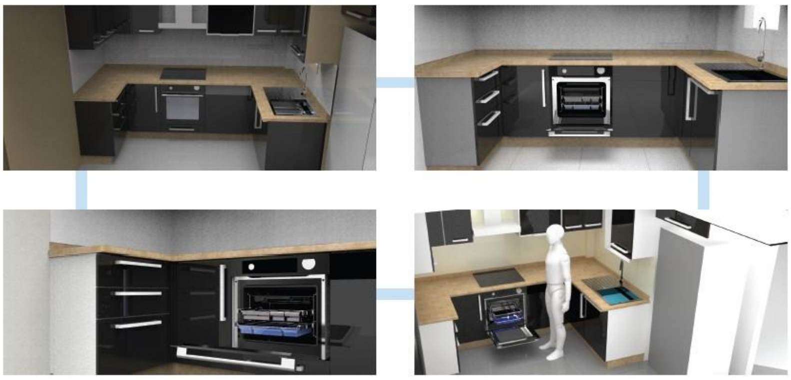


Figure 4.2. Full representation of product in context in the electric oven project with a grade of 3 (Team 4)

Team 11 was given a grade of 2 for representing the product in a partial environment, without the user present (Figure 4.3). The rendered images are highly realistic; however, the viewing angles and configuration of the oven are lacking in variety. The lack of a human silhouette makes it difficult to gauge the accuracy of the height, width and placement of the oven and the stove. Not being able to see how the doors of the oven open up makes the understanding of the usage context difficult. Accessories such as baking trays, serving dishes, cutlery and the food itself break the immersion and make the environment feel like a studio setting and not a real kitchen. Some of the placements of the cabinet handles look counter-intuitive.

Figure 4.3. Partial representation of product in context in the electric oven project with a grade of 2 (Team 11)

Team 6 was appointed with a grade of 1 for minimal environment representation with no user (Figure 4.4). The image quality, material and surface detailing of the render is low. The material chosen to represent the texture quality of the cabinets makes it seem like the surfaces are one continuous piece of wood, it is impossible to discern the edges of the cabinet doors. Combined with the lack of kitchen appliances, serving and food preparation accessories and food, the usage context is reminiscent of a studio instead of a kitchen. Moreover, the viewing angle seems high and unnatural. The open door of the oven seems to have happened on its own since the viewing angle does not simulate the viewing perspective of a user. The placement of the cabinet handles does not work with the placement of the cabinet right next to the wall. There is light reflected on the wall next to the oven; however, it is impossible to see what is inside the oven door.

Figure 4.4. Minimal representation of product in context in the electric oven project with a grade of 1 (Team 6)

Team 7's submission included a silhouette of the user interacting with the product in a well detailed environment, earning a grade of 3 (Figure 4.5). The silhouette seems in proportion with the environment, is in a realistic and dynamic pose, and is directly interacting with the oven. However, it is difficult to distinguish features of the silhouette beyond the fact that it's a woman crouching towards an open oven door. The silhouette appears to be holding a round object; however, it is difficult to guess whether it's a plate, a baking dish, or a piece of food ready to be placed on the oven tray. Both of the oven doors are open, which might suggest that there needs to be two different dishes; however, it looks like there's only one dish. The oven does not give any indicators that the preheating setting has been selected. Moreover, the color choice of the silhouette blending in with the background and lack of transparency make the image difficult to read.

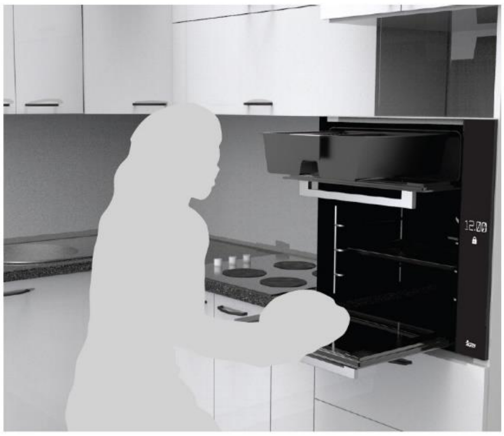


Figure 4.5. Full representation of user and product in the electric oven project with a grade of 3 (Team 7)

Team 4's representation of the user and the electric oven was appointed with a grade of 2 for partial environment detailing (Figure 4.6). The mannequin is in an unnatural pose, looking at the screen of the oven while he is actively cooking down below. The lower tray where the user is holding pieces of food with tongs is a moving part, about to be raised into the chamber above, but there are no indicators for a control or a handle that achieves this motion. The pose of the silhouette seems static, and the lack of accessories such as heat proof gloves and baking dishes makes it look like it's a robot cooking, and not a human being. Only a small portion of the environment is visible, and the counter area is very dark, making it difficult to discern the food and the tongs in the user's hand. The almost mirror-like reflections of the metal materials in the scene such as oven parts and the sink create a high contrast in an otherwise dangerously dark kitchen counter.

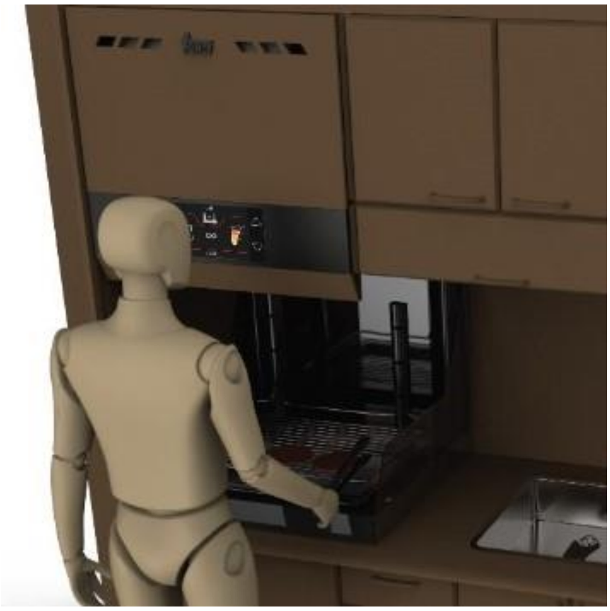


Figure 4.6. Partial representation of user and product in the electric oven project with a grade of 2 (Team 4)

Team 8's user and product representation does not include any environmental detailing, and therefore was graded with 1 (Figure 4.7). The oven and the user seem to be floating on an empty background. There is no floor, walls, kitchen cabinet, or a kitchen counter. This depiction is unrealistic, because the parts of the oven like the side view and the top view which would not normally be visible to the user are in view. It can be inferred that this depiction shows a confusion between a studio view and an in-context view. The user is acting out the usage scenario in the step where they would put food in the oven; however, there is no food in the tray being pushed into the chamber. Moreover, the lack of accessories such as baking gloves, baking dishes and such breaks the immersion of the user interacting with the oven. The height of the placement of the oven is also questionable, it is difficult to discern whether the oven is supposed to be placed in the lower part of a kitchen counter, or placed higher up in a tall cabinet section.

Figure 4.7. Minimal representation of user and product in the electric oven project with a grade of 1 (Team 8)

Team 12's usage scenario representation worthy of a grade of 3 included a user interacting with the oven in multiple sequences, including interface screens (Figure 4.8). The scenario has three different scenarios with each step of the action explained with detailed captions, high quality renders and appropriate silhouettes of users carrying out the actions. The semi-transparent silhouettes of the user make it easier to understand what the user is doing, because it is possible to see the full view of the oven behind the user. The kitchen appliances, accessories such as plates and cups, detailing of the kitchen cabinets and the backsplash make the scene more believable overall. It is possible to follow the narrative of the actions taken in each step of the usage scenario; however, the high number of images makes the presentation board look crowded. The lack of representation of food makes it look like the user is cooking imaginary dishes.

Figure 4.8. Full representation of usage scenario in the electric oven project with a grade of 3 (Team 12)

Team 1's submission for usage scenario details included the user interacting with the oven in partial usage sequence, and was appointed with a grade of 2 (Figure 4.9). The captions are not very descriptive. The scenario features only some of the components of the oven, such as the preheating, insertion of induction plates, placing and holding the tray. This usage scenario does not include the action of baking any food, just interactions with the parts of the oven, and even that depiction is not complete. For instance, only one of the three controls are described. The interface details are not elaborated. The renders do not feature food, baking or kitchen accessories, and the oven seems to be floating on an empty background without any kitchen environment or background detailing. Cropping of the images leave out parts of the oven, and the mannequin is in a static, unnatural pose.

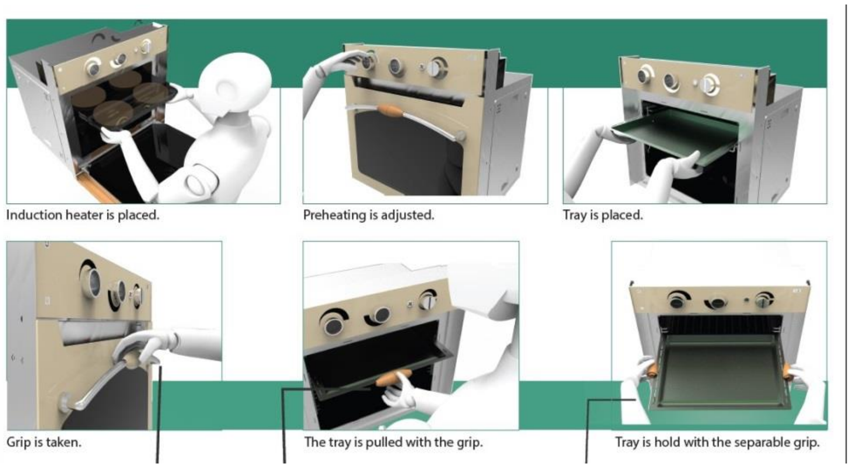


Figure 4.9. Partial representation of user and product in the electric oven project with a grade of 2 (Team 1)

Team 9's usage scenario representation did not include the user or the product, instead had some of the interface screens, therefore it was appointed with a grade of 1 (Figure 4.10). This graphic was included to depict usage scenario; however, it does not show how the user interacts with the oven on a physical scale, since it is lacking the physical body of the oven and the depiction or silhouette of a user. Only the interface screens are shown, and the caption suggests that these screens are on the app in a tablet accompanying the oven. Therefore, it is impossible to tell whether the interface screens are placed on the oven or the tablet. The scale of the interface screens seems ambiguous due to the lack of a user. The reading direction and the order of the interface screens are unclear.

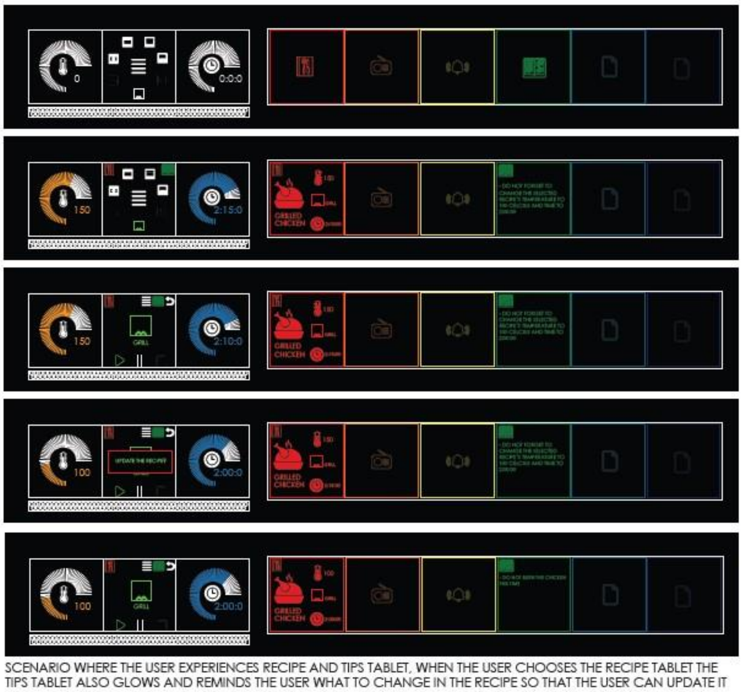


Figure 4.10. Minimal representation of user and product in the electric oven project with a grade of 1 (Team 9)

4.4.1.2 Audiovisual Feedback

The representation of lights in the electric oven have been minimal across all of the teams, with no complete visualization of interior and exterior lights in various stages of use in the presentation boards. None of the mockups had any simulation of audiovisual feedback in the form of light and sound. In the presentation boards, most have shown either the interior lights, or made mention of changes in the interface lighting with text, as exemplified from Team 3 (Figures 4.11 and 4.12). In the interface screen, there is a mention of a red warning light telling the user to remove the condensation tank after steam cleaning; however, the section of the interface with the text does not reflect the cleaning status as being finished. There is no mention of whether the red light is blinking or glowing, making it difficult to guess the changes between being in the process of cleaning or having finished the act of cleaning. In the image depicting the interior lights of the oven, the lack of food or baking trays inside the chamber of the oven makes it difficult to understand how well the illumination works with lighting up the food. The representation of the lights both in the interface and inside the oven is merely symbolic.

Figure 4.11. Minimal representation of lights in the electric oven project with a grade of 1 (Team 3)

Figure 4.12. Minimal representation of lights in the electric oven project with a grade of 1 (Team 3)

For sound, only Team 3’s submission made any mention of audio feedback from the product (Figure 4.13). The image shows an interface screen showing the cooking settings including a 15-minute alarm. Apart from the textual mention of an alarm and the icon of a bell, there is no information about the alarm itself. It is unclear what the alarm sound is like, and no context has been given in regards to turning on and off the alarm. The lack of detailing about the alarm makes the representation symbolic, and it is difficult to discern the actions related to the alarm, making the auditory feedback process ambiguous.

Figure 4.13. Minimal representation of sound in the electric oven project with a grade of 1 (Team 3)

Representation of info screens and GUI in the electric oven project exists in parallel in the presentation boards and the mockups. All of the mockups had print-outs of the interface screens, some even had sliding mechanisms to show multiple steps. However, it is difficult to discern the consequences of actions in the usage steps and the reactions that happen in the oven. Additionally, a full flowchart of different baking actions has not been successfully represented in these print out screens (Figure 4.14). The connection of the control buttons with the changing of the screens is unclear. As the presentation boards show more detail relating to the interfaces, the assessment focused on the boards.

Figure 4.14. T5's mockup featuring a sliding system for showing interface screens (left: preliminary jury submission; right: final jury submission; both shown on final presentation boards)

Team 4's submission included multiple scenarios with all graphical user interface screens represented, and was given a grade of 3 (Figure 4.15). The submission featured a flow chart showing the actions of the interface. Two separate actions of using the oven and the grill have been included in the flowchart. However, the lack of an approval button makes it difficult to depict the resulting changes on the screens as decided by the selections that are made. Even with the flowchart it is unclear how the selections made by the user result in the changing of the screens.

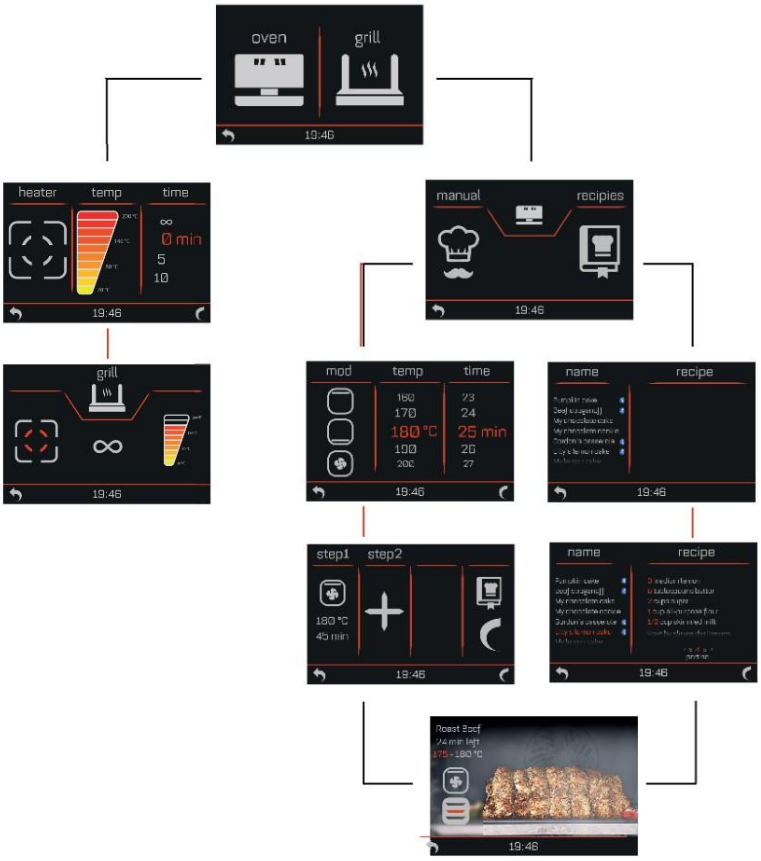


Figure 4.15. Full representation of info screens and GUI in the electric oven project with a grade of 3 (Team 4)

Team 7’s representation of info screens and GUI was appointed with a grade of 2 for partial representation of graphical user interface (Figure 4.16). The GUI screens show no intermediary steps between opening the menu and the screen showing the active setting selections. When viewing the interfaces, it is impossible to judge which settings have been selected without moving on to the next screen. It is possible to see changes in each screen; however, it is not possible to distinguish how the user has moved from one screen to the next.

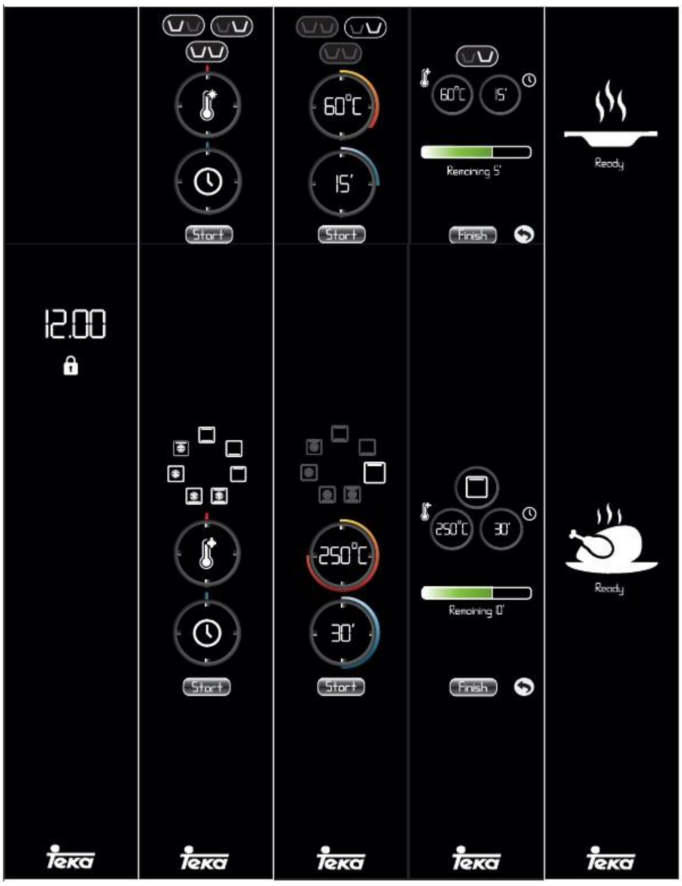


Figure 4.16. Partial representation of info screens and GUI in the electric oven project with a grade of 2 (Team 7)

Team 2's submission for info screens and GUI had minimal representation of the graphical user interface, and was given the grade of 1 (Figure 4.17). The submission featured only one screen from the interface. The caption suggests that only one knob is necessary to carry out the usage scenario in the interface, but the interface screens for the pre-heat and the ready screens are not included. The icons on top of the knobs in the lower section of the image seem to be depicting heating direction, temperature and time, but there are no indicators as to where these icons would be placed on the screen, and what kind of feedback is given for each of the settings. The caption mentions one knob only, but the image shows additional buttons seemingly for adjusting the time and the temperature. No explanation has been given for how these buttons are incorporated into the usage steps. The knob also seems to be functioning as a button because of the play/pause icons, but the caption contradicts this functionality of the knob, which seems to give the affordance of turning.

Figure 4.17. Minimal representation of info screens and GUI in the electric oven project with a grade of 1 (Team 2)

4.4.1.3 3D Fidelity

Figures 4.18 to 4.26 are photographs of the mockup submissions from the teams. All of the mockups for the projects were full-scale models and were given a grade of 3 for scaling, below a grade of 4 for a full-scale virtual prototype, as physical models lack the capability of making instant changes.

The mockups of the ovens and accessories were created using corrugated cardboard, card stock and carved foam as structure materials, printed paper for user interface details and finishing, and acetate sheets for transparent parts. The mockups have differing levels of detailing, some not having much printed sections in the shell design (Figures 4.18, 4.19, 4.20, 4.21, 4.23, 4.24, 4.25, 4.26) and some fully outfitted (Figure 4.22), but the lightweight quality of cardboard and foam made the mockups feel flimsy. Therefore, a grade of 2 was given to the mockups of all the teams for having a moderate level of finishing.

The teams had working oven doors (Figures 4.18, 4.19, 4.20, 4.22, 4.23, 4.24, 4.25). Team 4’s oven had a high kitchen counter placement with a drop down base, represented in the mockup (Figure 4.21). A range of oven dishes and trays were featured in the mockups of T3 (Figure 4.24), T5 (Figure 4.25), T6 (Figure 4.19), T7 (Figure 4.20), and T10 (Figure 4.18).

T10's oven mockup submission (Figure 4.18) was appointed with a grade of 3 for component detailing. The components pictured are baking trays and grills crafted out of card stock. The walls of the oven chambers have slots where the tray frame is inserted, and the tray frame is hinged on the sides so that the trays can rotate inside the chamber for equal temperature distribution of the food for baking. The solid trays feature a lid made to look like a wood-based material.

Figure 4.18. T10's oven mockup submission earning a grade of 3 for component detailing

T6's oven mockup (Figure 4.19) has also been appointed with a grade of 3 for component detailing. The trays can be inserted either in the main chamber of the oven, or the warming section on top of the oven. The side walls of the chamber feature adjustable slots for insertion of the trays. The holder accessory acts as a heat barrier between the user's hand and the trays, and is stored hanging from the handle of the oven door.

Figure 4.19. T6's oven mockup submission earning a grade of 3 for component detailing

T7’s oven mockup (Figure 4.20) has also been given a grade of 3 for component detailing. Attention has been paid to the mechanical details for inserting the baking dishes into the top and the bottom sections of the oven chamber. The insertion of the baking dishes is smooth thanks to the accurate fit of the notches in the sides of the dishes to the slots on the chamber walls.

Figure 4.20. T7’s oven mockup submission earning a grade of 3 for component detailing

T4’s oven mockup (Figure 4.21) have also been graded 3 for component detailing. This oven is meant to be installed high up on the kitchen counter, and instead of a door that opens, it has a descending bottom to reveal the baking tray. The mockup correctly simulates the descent of the tray, albeit the material being flimsy.

Figure 4.21. T4’s oven mockup submission earning a grade of 3 for component detailing

T1’s oven mockup (Figure 4.18) has a corrugated cardboard body covered with a colored paper. The controls have been outfitted with print outs showing interactive detailing such as screens on the buttons and dial displays showing intensity of heat and timing. The oven door is created with a clear acetate sheet, making it possible to see inside the chamber. The usage of carved foam makes the handle bar and the gripper more realistic and accurate.

Figure 4.22. T1’s oven mockup submission

T2’s oven mockup submission (Figure 4.23) also includes a clear oven door, making it possible to see inside the chamber, where there is a tray, also made of corrugated cardboard. The frame for adjusting the tray height increases the mechanical interactivity of the mockup.

Figure 4.23. T2’s oven mockup submission

T3’s mockup (Figure 4.24) features baking trays with semi transparent lids for usage outside the oven to store food. In the chamber of the oven, there are slots in the side walls for insertion of baking trays; however, the baking trays included with the mockup seem to be smaller than the full width of the oven. A separate very thin piece of material seems to be hung between the two side walls to carry the trays.

Figure 4.24. T3’s oven mockup submission

T5’s oven mockup (Figure 4.25) features two baking trays, and a sliding interface screen section showing different stages of the user interface. However, the featured screens only make it possible for one action. Steps for different settings of the oven are not included.

Figure 4.25. T5’s oven mockup submission

T9’s mockup submission (Figure 4.26) has additional accessories such as separate handles for opening the oven door, and a cleaning accessory for scraping the inner surfaces of the oven chamber.

Figure 4.26. T9’s oven mockup submission

4.4.2 Assessment of the Apron Bus Project Presentation Boards

For the apron bus project, design teams were expected to provide a usage scenario illustrating critical phases of use, users interacting with the product taking into consideration the experience of a full bus using photorealistic views of the vehicle exterior in an appropriate context, and the vehicle interior from a natural vantage point of a standing passenger in daytime and nighttime. The assessment was done with details relating to the usage context, which were product in context, user and product, and usage scenario; and audiovisual feedback, which were lights, sound, and info screens and GUI.

Table 4.6 Assessment of submissions for the Apron Bus project

Apron Bus		Content Development and Quality of Presentation												Average
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	
Usage context	Product in context	3	1	3	3	1	1	3	3	3	3	1	3	2.3
	User and product	3	3	3	2	2	1	3	3	2	2	3	3	2.5
	Usage scenario	3	3	3	2	3	1	1	3	3	2	3	3	2.5
Audiovisual feedback	Lights	1	2	3	3	3	3	2	3	1	2	1	2	2.2
	Sound	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Info screens and GUI	2	1	3	3	1	0	0	2	2	1	2	2	1.6
3D Fidelity	Scale	1	1	1	1	1	1	1	1	1	1	1	1	1.0
	Material quality	2	3	3	1	1	1	2	2	3	2	2	2	2.0
	Component detailing	2	2	2	2	3	2	2	2	3	2	2	2	2.2
General average		1.9	1.8	2.3	1.9	1.7	1.1	1.6	2.1	2.0	1.7	1.7	2.0	1.8

All 12 teams have been assessed as demonstrated with the examples given for each grade appointed to the submissions for the criteria of usage context and audiovisual feedback. The assessment (Table 4.6) shows that short of a working virtual prototype experienced in an MR system, the representation of usage context details of user interacting with the product and the usage scenario were the most detailed, followed by the representation of the product in context. The representation of the info screens and GUI was, as per the limitations of the 2D presentation board format, lacking in realism, especially when trying to convey the sequence of interaction. The representation of sound in the submissions were non-existent.

4.4.2.1 Usage Context

Team 3’s submission showing the product in context was appointed a grade of 3 for fully representing the environment in multiple angles and configurations with the users included (Figure 4.27). The images include a day and night view of the bus in a studio setting without environmental detailing, a view of the bus next to the aircraft, a view of the bus moving across the apron, and a view of the bus at the gate. The viewing angles are from the side, from the front, and at an isometric angle. The renders of the bus are placed in photographs of a plane apron setting. In the renders of the bus it is possible to see human models inside the bus. There are no human models depicted getting in and out of the bus. The reflections on the body of the bus do not seem to match with whether the bus is situated in sunlight or in the shade. In the image showing the bus next to the aircraft, the bus seems to be parked either far away from the aircraft, or the scaling of the bus is not fitting for the scale of the aircraft. It is difficult to discern where the exit points are on the surface of the bus.

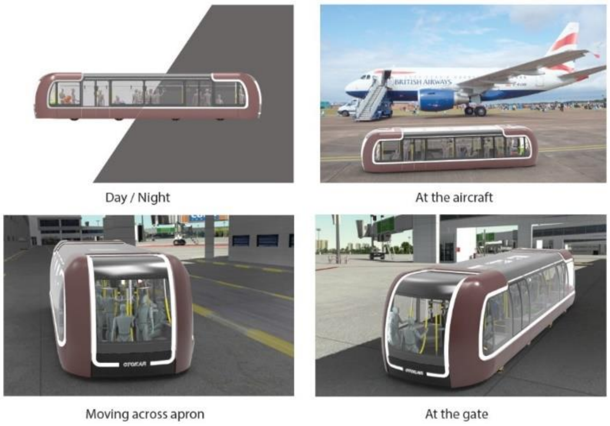


Figure 4.27. Full representation of product in context in the apron bus project with a grade of 3 (Team 3)

Team 4's representation of the product in context had less detail showing a partial environment, with no users present, and was graded 2 (Figure 4.28). There are two images showing the view of the rendered bus next to a photograph of the aircraft in night time, and in daytime. The materials used on the renders of the bus do not feature any texture details or reflections. The glass panels on the windows of the bus are opaque, and it is not possible to see the passengers inside the bus. Even though the illumination level of the environment shows different times of the day, the visibility of the bus seems to be the same on both images. The images do not show any variety in terms of location, there are no views of the bus on the apron, on the gate, or moving through the lanes. The angles of the placement of the bus do not relate to the placement of the entry points of the aircraft.

Figure 4.28. Partial representation of product in context in the apron bus project with a grade of 2 (Team 4)

The representation of product in Team 11's submission had minimal environmental detail and was graded 1 (Figure 4.29). In this image the bus is situated near the gates of the airport, on the pedestrian crossing lines. A photograph of the airport pedestrian crossing has been superimposed with a render of the bus. The airport building has a lot of contrast compared to the materials used in the body of the bus, which have a high level of illumination and reflectivity. With how illuminated the body of the bus is, the interior lighting should have been perceived more subdued. It is possible to see almost the whole interior of the bus, which features realistically dressed passengers sitting and standing. The lower part of the bus seems to be situated very close to the ground, and the figure of the female passenger to the left almost looks like she is walking on the ground, not on the surface of the bus.

Figure 4.29. Minimal representation of product in context in the apron bus project with a grade of 1 (Team 11)

Team 1’s submission was appointed with a grade of 3 for representing the user interacting with the product from a wide angle in a fully detailed interior as well as depicting the movement of the users within the bus (Figures 4.30 and 4.31). Figure 4.30 is a wide view of the interior from the angle of a passenger standing on the front end of the bus, looking toward the back. It is possible to see the opened doors. Some of the passengers are leaning on the railings on the side and on the front of the bus, some passengers are holding on the handles placed on the center of the bus, a passenger is sitting on the seat in the center of the bus, and a passenger is interacting with their luggage placed on the designated platforms. The human models are robotic silhouettes and are not realistic. Only one passenger seems to have luggage, and the apron bus is about half full. Figure 4.31 shows a bird’s eye view of the interior of the bus, with the raised platforms, sitting and leaning areas, and the railings on the ceiling. From these images it is possible to see the trajectory of the passengers circulating inside the bus, and the full passenger capacity count of the bus including sitting, leaning and standing passengers.

Figure 4.30. Full representation of user and product (wide angle in fully detailed interior) in the apron bus project with a grade of 3 (Team 1)

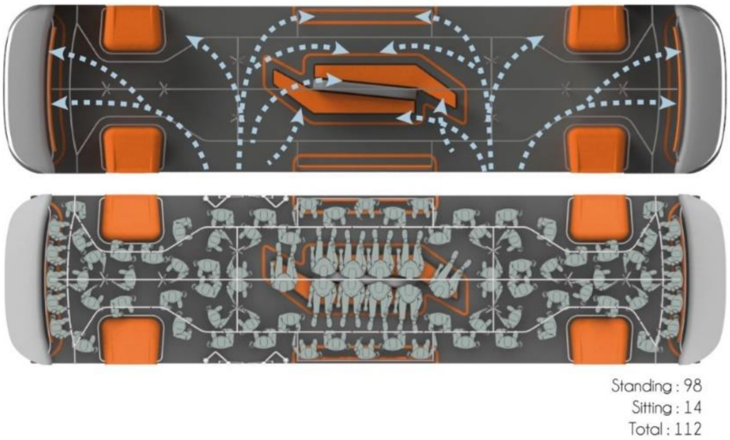


Figure 4.31.Full representation of user and product (circulation and layout) in the apron bus project with a grade of 3 (Team 1)

Team 9's representation of user and product was less detailed with a narrow viewing angle showing less interior detailing, and was given a grade of 2 (Figures 4.32 and 4.33). In figure 4.32, four passengers are depicted, two holding on to the central railing, one leaning on the perimeter, and one sitting in the seat. The human figures are robotic models with static, unrealistic poses. It is difficult to distinguish whether the two standing figures are holding their luggage up, or if they have hung them on the railing. The hands of the standing figures are not fully grasping the railing. The seat looks two dimensional and lacks texture, material thickness and shading. Figure 4.32 shows a top view of the interior of the bus showing sitting, standing and leaning passengers, but the bus does not seem to be at full capacity, and the numbers are not included. The lower image showing the side view features even less passengers.

Figure 4.32. Partial representation of user and product (narrow viewing angle) in the apron bus project with a grade of 2 (Team 9)

Figure 4.33. Partial representation of user and product (layout and section view) in the apron bus project with a grade of 2 (Team 9)

Team 4’s submission was graded 1 for representing minimal interior detailing and not including the full layout of the bus with passengers (Figure 4.34). In this image it is not clear which section of the bus is depicted due to the lack of a wide angle and features of the bus such as windows or doors. The materials chosen for the interior of the bus seem flat and lacking detail. The human figures are unshaded drawings of robotic models and have static, unrealistic poses. The sitting passenger seems to be floating on top of the seat. The luggage of the sitting passenger does not fit under the seat, and even though there is a stroller in the scene, a child has not been included.

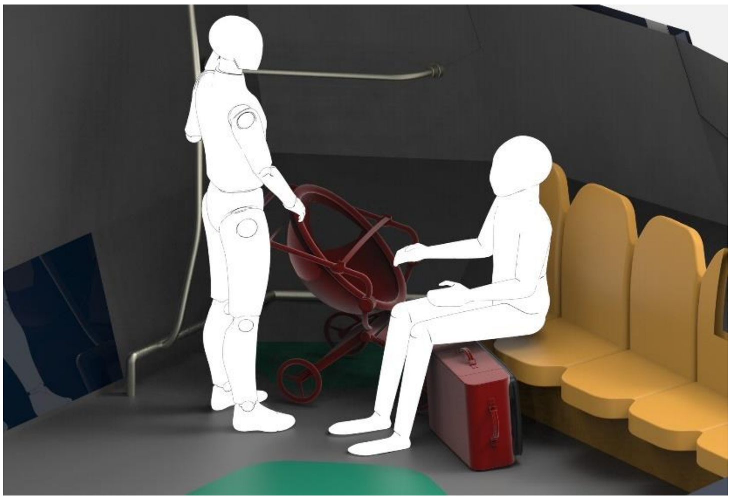


Figure 4.34. Minimal representation of user and product in the apron bus project with a grade of 1 (Team 4)

Team 8's usage scenario worthy of a grade of 3 included highly detailed steps of use depicting passengers waiting for the bus, getting on the bus, and interior usage details including multiple angles and user interfaces (Figure 4.35). The usage scenario depicts the passengers waiting for the bus at the airport gate, passengers getting on the bus, the buses moving back in the apron, the doors of the bus closing to unfold the railings, the information screens on the walls of the bus, passengers getting off the bus and getting on the aircraft. The passengers are depicted doing a variety of actions such as standing while holding the handrails, leaning their backs and elbows on the supports, securing their luggage on the designated areas, and sitting down. The colors and textures of the materials show a high level of detailing. The image showing the apron bus charging does not feature any shadows on the ground, making the view look unrealistic. The interior of the bus features several passengers. The robotic human figures have a variety of poses depicting the different actions of waiting, walking, sitting, leaning, adjusting luggage, and some variety in the passengers are depicted, such as a pregnant woman, and some passengers carrying luggage.

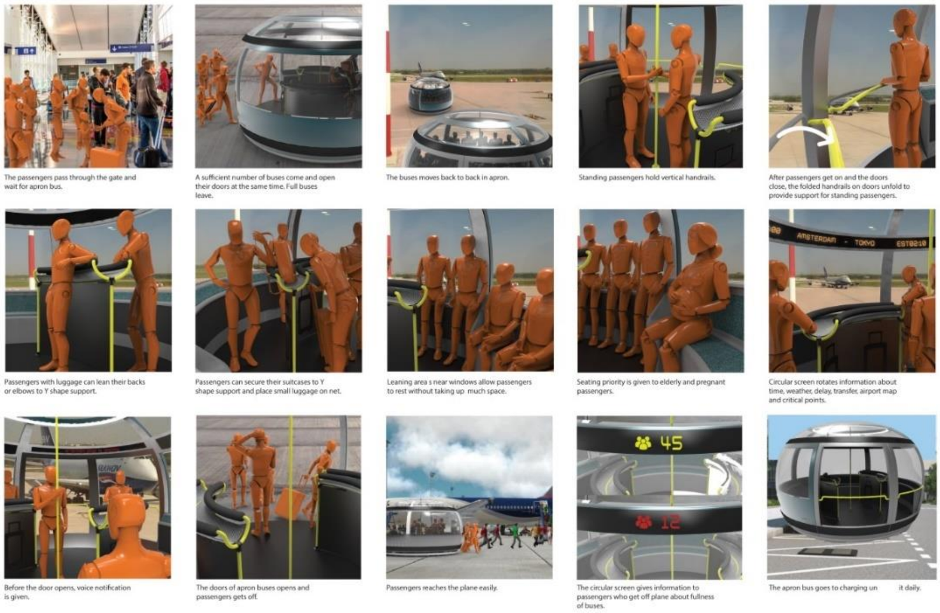


Figure 4.35. Full representation of usage scenario in the apron bus project with a grade of 3 (Team 8)

Team 4’s usage scenario had less detail in the form of fewer passengers and a studio environment instead of real context, and was graded 2 (Figure 4.36). The usage scenario depicts passengers waiting outside the bus trying to decide where to enter the bus, some passengers inside the bus sitting, standing and leaning. The different types of passengers pictured are a family with a stroller and luggage, as well as a passenger with hand luggage and a backpack. The storage solutions for a stroller, backpack and hand luggage are depicted, albeit not being very detailed in terms of material and texture quality. The interior of the bus is shown with differing levels of illumination, mostly flat and without shadows. The lack of material detailing makes the interior of the bus look like a gray box, even though the floor is explained to have a non-slip surface to prevent the movement of the luggage. The specialized storage area for the stroller does not feature any detailing as to how it is secured in place. The interface screen is shown as a flat, dark panel inside the bus, and a separate section in the scenario is appointed for showing the information given to the passengers in the screen.

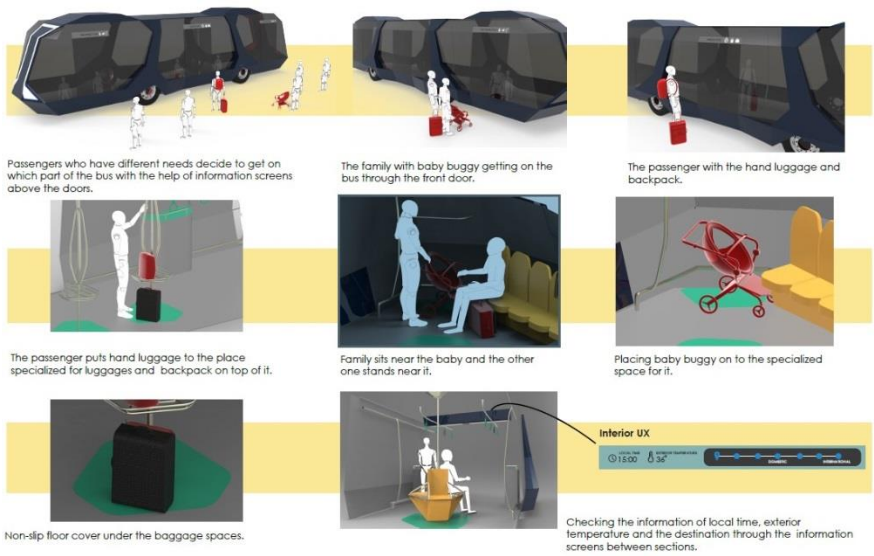


Figure 4.36. Partial representation of usage scenario in the apron bus project with a grade of 2 (Team 4)

Team 7's submission did not have a sequence depicting a usage scenario, earning a grade of 1 (Figure 4.37). The passengers are depicted getting on the bus, placing luggage, leaning, standing and sitting. No information has been included as to how the interior looks while at full capacity, how the passengers get out, or get information from the interface screens. The human figures are flat silhouettes, and it is difficult to distinguish the features of the passengers. The figure standing next to the luggage placed on the designated platform is not depicted as holding on to any railings. Some of the human figures are placed partially outside the frames of the images, and they do not cast any shadows on the interior of the bus, making their placements look unrealistic.

Figure 4.37. Minimal representation of usage scenario in the apron bus project with a grade of 1 (Team 7)

4.4.2.2 Audiovisual Feedback

Lighting details were an integral part of this project. None of the mockups had any simulation of audiovisual feedback, whereas the presentation boards have depictions of interior and exterior lighting. Team 6 got a grade of 3 for the level of realism reached in the exterior and interior lightings shown in daylight, nighttime and in a studio setting (Figures 4.38 and 4.39). Figure 4.38 shows front, side and angled views of the bus next to the aircraft in daytime, in nighttime and in a studio setting. The image showing the bus next to the aircraft during daytime depicts the illuminated body of the bus consistent with the angle of the sun illuminating the aircraft. The shadow of the aircraft has sharp edges, whereas the shadow of the bus has soft blurred lines. In the image showing the bus at nighttime, the lighting on the interior of the airport building and the inside of the aircraft seem consistent with the interior lighting of the bus. The exterior lights of the bus are strong, and some of the ground below the bus is illuminated by the exterior lights of the bus. The bus does not have any shadows, which should have been cast by the lighting poles pictured in the image. The studio views of the side and front of the bus show linear glowing green lights crisscrossed on the body. In Figure 4.39, the interior lights on the ceiling of the bus are on, and some illumination is visible on the ceiling as reflections of the light panel. How the lighting panels illuminate the rest of the interior of the bus are not included.

Figure 4.38. Full representation of exterior lights in the apron bus project with a grade of 3 (Team 6)

Figure 4.39. Full representation of interior lights in the apron bus project with a grade of 3 (Team 6)

Team 2 had less detail in the representation of lights in the form of interior lighting, and was given a grade of 2 (Figure 4.40). The lighting depicted in the two images are the lighting between the poles, and the general interior lighting. The interior of the bus and the parts of the bus near the lights such as seating, railings and the floor are illuminated. The exterior lights are not depicted.

Figure 4.40. Partial representation of lights in the apron bus project with a grade of 2 (Team 2)

Team 1's representation of lights was lacking realism and was given a grade of 1 (Figure 4.41). The image shows only the exterior of the bus next to the aircraft, and no extra interior lighting views have been included. The exterior lights of the bus are shown as white panels on the top of the bus, and blue sections in the front, back and the side of the bus. The placement of the bus in the photograph is in a dark corner, and the environment around the bus is not illuminated by the exterior lights. The passengers inside the bus are visible despite no interior lighting having been specified.

Figure 4.41. Minimal representation of lights in the apron bus project with a grade of 1 (Team 1)

None of the submissions for the apron bus project had any mention of audio feedback.

Representation of info screens and GUI in the apron bus project in Team 3's submission included the screens for the mobile app as well as the info screens on the bus, and was given a grade of 3 (Figures 4.42 and 4.43). The information included for representing the interfaces relevant to the bus are in the form of isolated information screens inside and outside the door screen, handle screens integrated on the handrails, and graphical user interface of the mobile app accompanying the bus. The information screens are also pictured on the interior of the bus relaying information regarding flight status, bus trajectory, date and weather details. A passenger has been situated next to a handrail screen to give an idea of the scale of the screen in relation to the passenger.

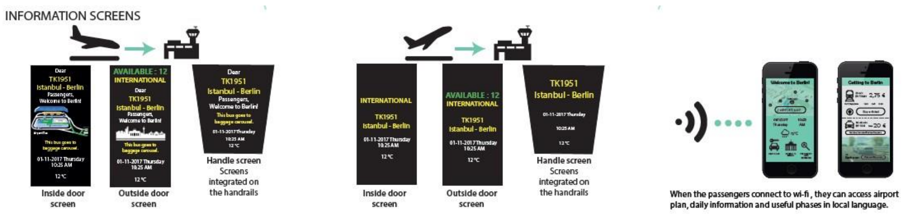
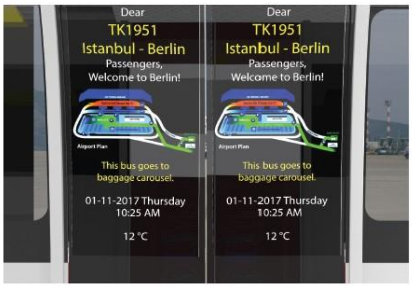


Figure 4.42. Full representation of info screens and GUI (mobile app) in the apron bus project with a grade of 3 (Team 3)



Several types of information screens about airport and route are placed on Mercury's diverse parts.

Passengers can easily see screens placed on top of handles.

Figure 4.43. Full representation of info screens and GUI (on the bus) in the apron bus project with a grade of 3 (Team 3)

Team 1's representation of info screens and GUI was appointed with a grade of 2 for partial representation of the graphical user interface (Figure 4.44). The screens depicted are placed on the interior and the exterior of the bus, relaying information about the name and number of the flight, the closeness of the bus to the aircraft, and the name of the bus. No information has been included as to where the screens are located, and how they function in relation to a user.

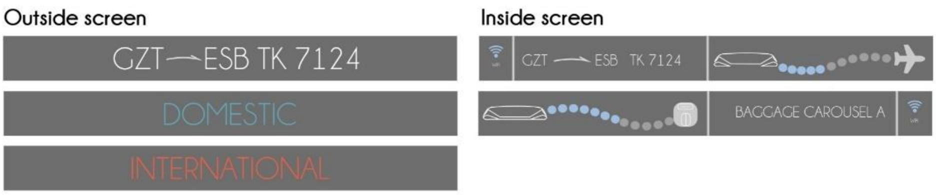


Figure 4.44. Partial representation of info screens and GUI in the apron bus project with a grade of 2 (Team 1)

Team 10's submission for info screens and GUI had minimal representation of the graphical user interface and was appointed with a grade of 1 (Figure 4.45). The information screen is integrated with the window panels of the bus, and shows the name and visuals of the destination city. Because the window is curved, the text in the screen is distorted and difficult to read. Lack of transparency and reflections in the screen make it difficult to perceive the window panel as a part of the bus. There are no additional images showing what relevant information the full screen is displaying to the passengers.

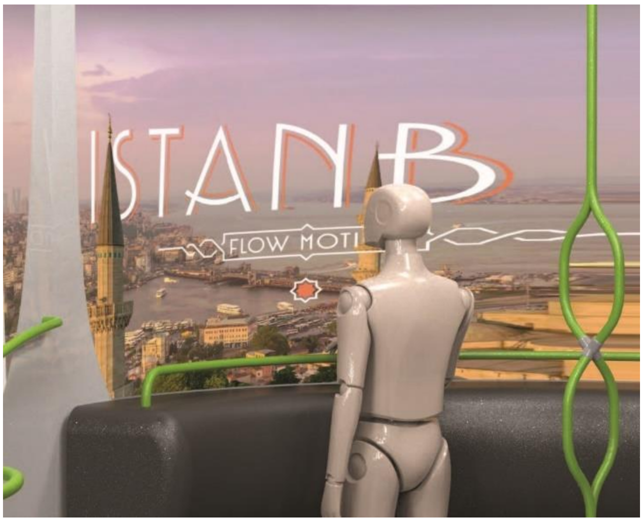


Figure 4.45. Minimal representation of info screens and GUI in the apron bus project with a grade of 1 (Team 10)

4.4.2.3 3D Fidelity

Figures 4.46 to 4.53 are photographs of the mockup submissions from all of the teams. All of the mockups for the projects were 1/20 scale models and were given a grade of 1 for scaling.

The mockups of the buses were created using a variety of materials such as corrugated cardboard, card stock, finished and unfinished carved foam, and wire as structure materials, printed paper for user interface details and finishing, and acetate sheets for transparent parts. Some of the mockups were 3D printed (Figures

4.47, 4.48, 4.50). The mockups have differing levels of detailing, some having fully finished smooth surfaces (Figures 4.46, 4.47, 4.48, 4.50), some with printed card stock (Figure 4.51), some left with raw cardboard (Figures 4.49, 4.53) and some a combination of card stock and carved foam (Figure 4.52). Some of the less detailed finishing (Figures 4.51, 4.52) made the mockups feel flimsy due to the lightweight quality of cardboard and foam. The fully finished surfaces of T2, T3 and T9 were given a grade of 3 for material quality. The less detailed finishing of T1, T7, T8, T10, T11 and T12 was given a grade of 2 for material quality. T4, T5 and T6 were appointed with a grade of 1 for material quality due to the easily collapsible nature of card stock showing deformities around the folding points.

For component detailing, T5 and T9 were given a grade of 3 for having fully outfitted interiors with smooth surfaces of the relevant components such as railings and seats, and in T5's case, a removable outer shell that reveals the interiors of the mockup. The other teams' mockups also had interior detailing, but less continuous and smooth, deserving a grade of 2.

T9’s bus mockup (Figure 4.46) was created using carved and plastered foam. The organic lines of the front bumper as well as the asymmetrical placement of the window panels were skillfully smoothed and sanded down with plaster, with added detailing on the top of the bus for lighting and air vents. The window panels are not transparent, but painted on the shell, making the edges of the panels uneven. The outer shell of the mockup is removable, and reveals the interior of the bus. The interior features a cutaway view of the ceiling towards the back, and the inner components such as the seats, railings, luggage platforms, doors and windows. The cardboard base is cut away in the front section to depict depressions in the floor of the bus.

Figure 4.46. T9’s bus mockup submission earning a grade of 3 for material quality, and a grade of 3 for component detailing

T2’s bus mockup (Figure 4.47) features a 3D printed outer shell painted in the intended colors of the bus, a light gray accented and contrasted with yellow edges. The 3D printed surfaces are plastered to a smooth, matte texture. The color variation carries out to the interior of the mockup, on the walls of the bus and the seats. The components are difficult to see inside the bus due to the solid walls, but the window panels are left open for visibility.

Figure 4.47. T2’s bus mockup submission earning a grade of 3 for material quality, and a grade of 2 for component detailing

T3’s mockup (Figure 4.48) has a 3D printed outer shell, plastered to a smooth and reflective surface, and painted dark red with black accents around the edges of the windows and the doors. The window panels are covered with curved clear acetate sheets to mimic glass. The interior of the bus mockup is visible through the clear window panels and the openings for the doors. The components inside the bus are seats and luggage platforms with less surface finishing, and railings painted a contrasting yellow color.

Figure 4.48. T3’s bus mockup submission earning a grade of 3 for material quality, and a grade of 2 for component detailing

T1’s bus mockup (Figure 4.49) features an outer shell made mainly with stacked cardboard cut along the curves of the body, leaving a non-smooth texture left unpainted. The windows consist of a clear acetate sheet curved to match the silhouette of the body of the bus, and the divisions between window panels are depicted using strips of unfinished cardboard glued on to the clear acetate. The inner components are seats and railings, meant to be viewed through the clear panels instead of removing the shell to reveal the interior.

Figure 4.49. T1’s bus mockup submission earning a grade of 2 for material quality, and a grade of 2 for component detailing

T8’s mockup (Figure 4.50) has a 3D printed outer shell made from a semi transparent teal material without further surface finishing. The inner components are railings made from bent galvanized wire covered with a fabric-like material to mimic cushioned hand rails. The windows are made from a clear acetate material and shows errors in assembly in the form of glue marks and dents. The mockup does not feature any wheels.

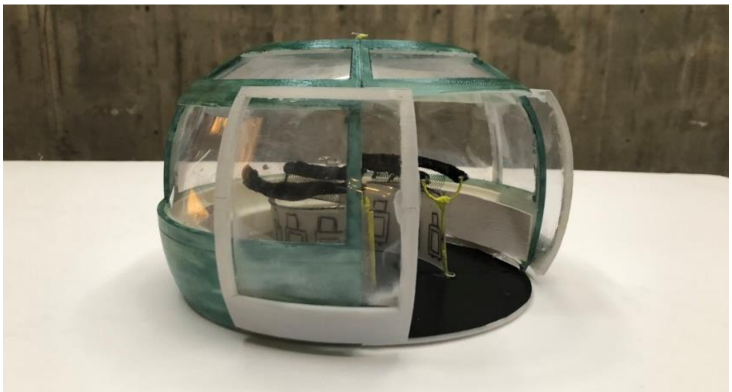


Figure 4.50. T8’s bus mockup submission earning a grade of 2 for material quality, and a grade of 2 for component detailing

T5’s mockup (Figure 4.51) has a partially finished outer body made from card stock. The material shows wear around the folding areas and the cut edges, and the bottom surface of the bus shows bowing resulting from the weight of the components situated on top of it. The cutaway nature of the outer body also factors into the deformations caused by the flimsy card stock material. The windows are made from a tinted clear acetate sheet. The inner components are seats and platforms made from the same card stock material, which does not mimic the material thickness needed for stability. The plastic covered wire used for the railings is irregular and misshapen in places, and the connections are made from wrapping the wire on top of each other, not correctly depicting how they would be connected in a full-scale prototype.

Figure 4.51. T5’s bus mockup submission earning a grade of 1 for material quality, and a grade of 3 for component detailing

T4’s mockup (Figure 4.52) is made from cut and folded card stock in the front half of the bus, and carved unfinished foam in the back half of the bus. The folded card stock shows signs of deformity around the folding marks, and lacks realism due to the nonexistent material thickness necessary for stability, especially in the sections where the doors and the windows are framed. The interior components such as the seats, the luggage platforms and the railings are white, like the front half of the bus made from card stock.

Figure 4.52. T4’s bus mockup submission earning a grade of 1 for material quality, and a grade of 2 for component detailing

T6’s mockup (Figure 4.53) features an outer body made from unfinished cardboard, which shows signs of wear around the cut edges and the folding marks. The stability of the shell is reduced also due to the side wall being left open to expose the interior of the bus. The components such as ceiling lights, seats and luggage platforms are also made from card stock, and lack the material thickness a full-scale prototype would have.

Figure 4.53. T6’s bus mockup submission earning a grade of 1 for material quality, and a grade of 2 for component detailing

4.4.3 Assessment of the Vitroceramic Cooktop Project Presentation Boards

For the vitroceramic cooktop project, design teams were expected to provide colored renders of the product and its accessories, including controls and displays demonstrating phases of use, communicating all critical product features. The assessment was done with details relating to the usage context, which were product in context, user and product, and usage scenario; and audiovisual feedback, which were lights, sound, and info screens and GUI.

All 12 teams have been assessed as demonstrated with the examples given for each grade appointed to the submissions for the criteria of usage context and audiovisual feedback. The assessment (Table 4.6) shows that short of a working virtual prototype experienced in an MR system, the representation of the info screens and GUI was the most detailed, followed by the usage context detail of product in context, then by the usage scenario and by the user and product interaction. The representations of lights and sounds were, as per the limitations of the 2D presentation board format, lacking in realism, especially when trying to convey features such as blinking or glowing.

Table 4.7 Assessment of submissions for the Vitroceramic Cooktop project

Vitroceramic Cooktop		Content Development and Quality of Presentation												Average
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	
Usage context	Product in context	3	3	3	3	3	1	3	3	3	3	2	3	2.8
	User and product	3	3	1	2	2	1	1	3	3	3	0	3	2.1
	Usage scenario	2	3	2	3	2	2	2	2	2	2	2	3	2.3
Audiovisual feedback	Lights	0	2	0	0	3	1	0	2	0	3	0	2	1.1
	Sound	0	1	0	0	0	1	1	0	0	1	0	0	0.3
	Info screens and GUI	3	3	3	3	3	3	3	3	3	3	3	3	3.0
3D Fidelity	Scale	3	3	3	3	3	3	3	3	3	3	3	3	3.0
	Material quality	2	2	2	2	3	2	2	3	3	2	2	2	2.3
	Component detailing	2	1	3	1	3	2	3	2	2	2	1	1	1.9
General average		2.0	2.3	1.9	1.9	2.4	1.8	2.0	2.3	2.1	2.4	1.4	2.2	2.1

4.4.3.1 Usage Context

Team 3 was given a grade of 3 for representing the full environment details and all of the accessories (Figure 4.54). The cooktop is pictured in the kitchen counter, with the relevant accessories such as the accompanying grilling tray, as well a pan, a pot, and a tea kettle placed on the burners. The food on the grill, the pan and the pot are cooked. The area surrounding the cooktop has relevant kitchen accessories such as bottles, serving utensils, a fabric napkin, oil and seasoning holders, and a vase. The lighting of the scene successfully simulates sunlight shining through a window, creating a balance of soft diffused shadows, and sharp shadows. An additional image shows the grilling tray used as a serving dish, featuring grilled vegetables. The dinner table is fully outfitted with cutlery, plates, napkins, glasses filled with drinks, as well as a variety of serving trays, all pictured with food.

Figure 4.54. Full representation of product in context in the vitroceramic cooktop project with a grade of 3 (Team 3)

Team 11 was given a grade of 2 for representing the product in partial environment with only the product present (Figure 4.55). Pictured are the cooktop with two of the burners on, and the accompanying tablet showing the controls for cooking a specific dish. No additional accessories such as pots, pans, utensils, serving dishes are featured. The image is a close up of the cooktop and the tablet, leaving the kitchen environment hidden from view. The reflections on the surface of the smooth vitroceramic cooktop suggest that the environment detailing has been developed for the scene; however, the narrow viewing angle prevents them from being visible.

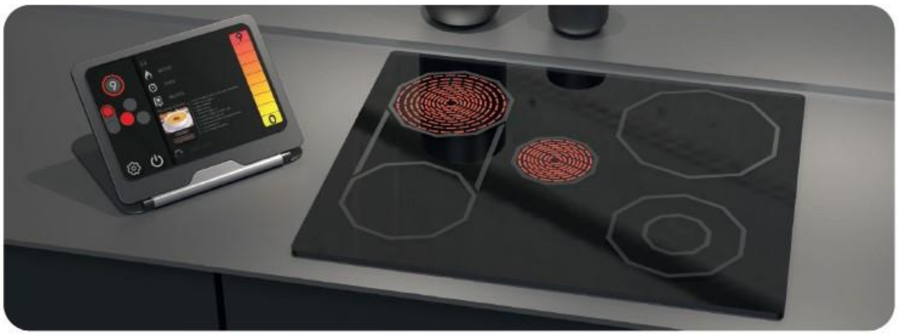


Figure 4.55. Partial representation of product in context in the vitroceramic cooktop project with a grade of 2 (Team 11)

Team 6 was appointed with a grade of 1 for no environment representation (Figure 4.56). The cooktop is presented in a studio environment with no kitchen environment detailing, such as a countertop or cabinetry. The cooking tray is shown with cooked food. The hobs of the cooktop are pictured in the off position.

Figure 4.56. Minimal representation of product in context in the vitroceramic cooktop project with a grade of 2 (Team 6)

Team 1's submission included a silhouette of the user interacting with the product in the kitchen environment and was appointed with a grade of 3 (Figure 4.57). The user is depicted as a gray semi transparent silhouette pouring oil in the pot situated on top of the cooktop, with a bottle taken from the cooktop accessory condiment and seasoning stand. The full kitchen counter is in view, where the cooktop and the condiment and seasoning stand are visible in front of the human silhouette. The surface of the cooktop shows the reflection of the cabinetry and the condiment bottle, but the reflection of the human is missing.

Figure 4.57. Full representation of user and product in the vitroceramic cooktop project with a grade of 3 (Team 1)

Team 4 was appointed with a grade of 2 for partial environment detailing and only the silhouette of the user’s hand (Figure 4.58). The cooktop is placed in a kitchen environment including a countertop, backsplash, cabinetry, as well as a pot and a serving dish. The close up view of the user pressing the touchscreen buttons on the cooktop only includes the hand of the user, and the rest of the user’s body is hidden from view. There is no cooking equipment on top of the cooktop as the user is adjusting the heat setting, coming in from a side angle instead of facing the cooktop from the front. The silhouette of the hand is semi transparent, and the fingers are emphasized with white lines to increase realism.

Figure 4.58. Partial representation of user and product in the vitroceramic cooktop project with a grade of 2 (Team 4)

Team 3’s user and product representation included only a silhouette of a hand operating the user interface, getting a grade of 1 (Figure 4.59). The image is not a rendering of the cooktop in a kitchen environment, but instead, a zoomed in view of the interface screen showing how to operate the heat intensity dial. It is not possible to discern where the interface is located on the cooktop, and it is not clear whether the silhouette of the user’s hand is of the right scale comparative to the controls.

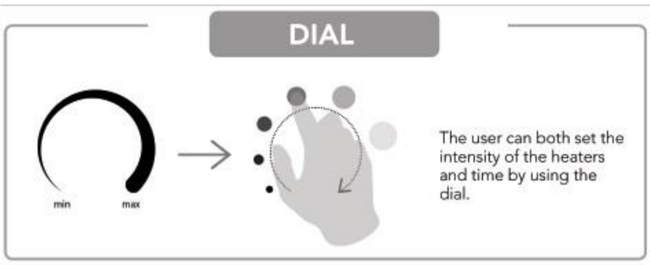


Figure 4.59. Minimal representation of user and product in the vitroceramic cooktop project with a grade of 1 (Team 3)

Team 4's usage scenario representation was worthy of a grade of 3 for including both the steps of preparing food using the accessories and the steps of using the graphical user interface (Figures 4.60 and 4.61). The scenario depicts the user switching on the cooktop, adjusting the control shortcuts with the mobile app, the user controlling the heating levels and placing the pot on the cooktop, using the accompanying chopping board to chop the ingredients and pour them into the container, selecting different cooking methods such as grilling, the placements of the cooking hobs, and the accessories being used as serving dishes on the dinner table. The interface on the cooktop is not very visible, and the screen of the phone is left blank. Additional information has been provided about the advantages of the accompanying accessories, such as ease of cleaning, and triple functionality of the accessories consisting of chopping board, storage container and serving dishes. The user's hands and arms are visible, as well as zoomed in and wide-angle shots of the kitchen environment and the fully outfitted dinner table.

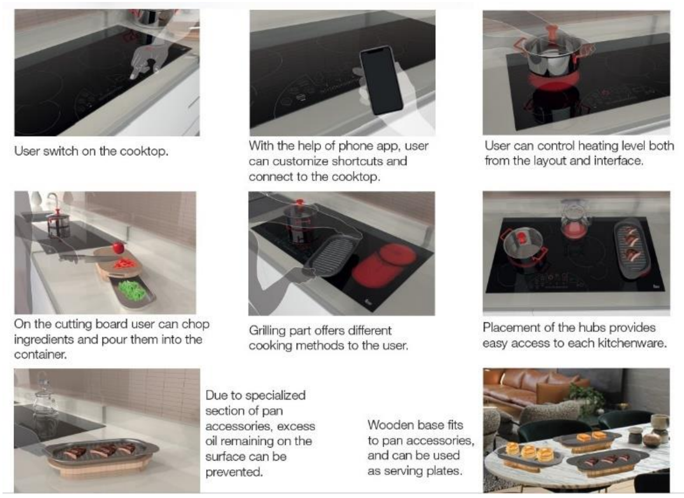


Figure 4.60. Full representation of usage scenario (preparing food) in the vitroceramic cooktop project with a grade of 3 (Team 4)

An additional image (Figure 4.61) shows the interface of the cooktop showing the controls for layout options, shortcuts for the most common cooking methods, the indicators warning the users about the heating status of the hobs, and the buttons for controlling the wifi, heating temperature, the timer, the lock, and the start. The usage steps of the interface include the layout system, and the locking of the layout settings. The hand silhouette of the user is shown changing the layout system, adjusting the heating degree, and operating the wifi with the shortcuts. The interface screens of the mobile app are shown as well.

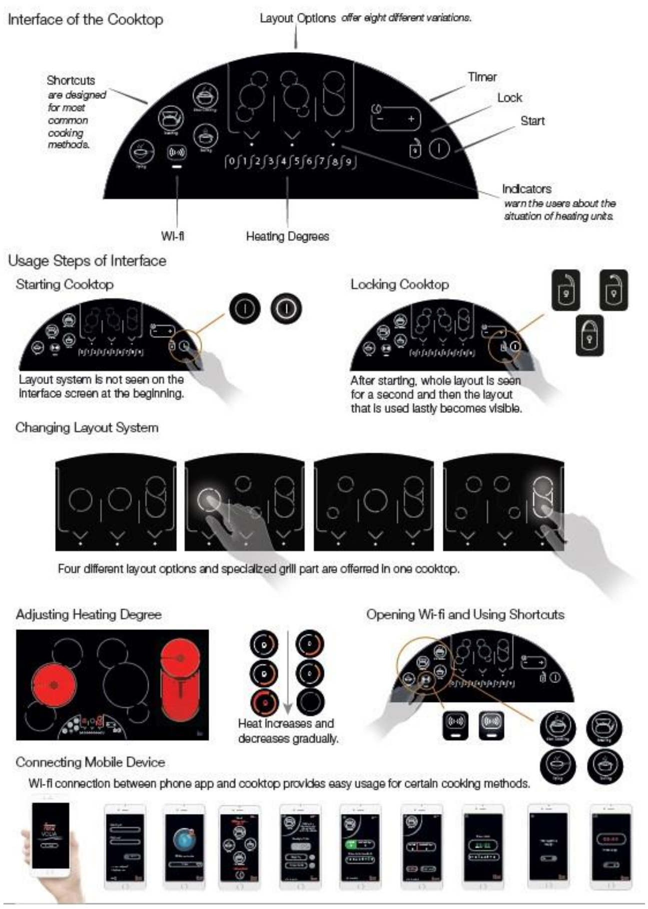


Figure 4.61. Full representation of usage scenario (graphical user interface) in the vitroceramic cooktop project with a grade of 3 (Team 4)

Team 3’s submission for usage scenario details was appointed with a grade of 2 and included the steps of operating the cooktop’s interface (Figure 4.62). The scenario is shown with the silhouette of the user's hand operating the user interface: turning the power on, setting a heater, adjusting the heat level, extending the heating rings with a long press, turning the grill heaters on, receiving feedback about the state of the heaters with the icons, selecting the timer settings, and activating the child lock. Each action by the user results in a marked change in the user interface, communicating the results of the action as feedback to the user. The changing states of the cooktop itself are not pictured.

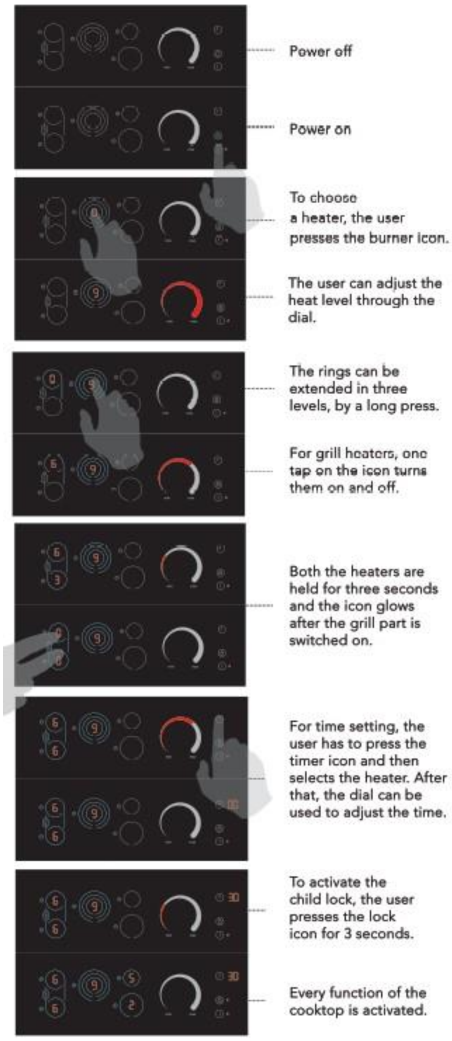


Figure 4.62. Partial representation of usage scenario (operating steps) in the vitroceramic cooktop project with a grade of 3 (Team 4)

4.4.3.2 Audiovisual Feedback

Team 10 mentioned a blue light for a visual feedback feature, as well as a sound for alerting the user. Team 10 was given a grade of 3 for the visual representation of the light, and a 1 for the mention of sound with no descriptions (Figure 4.63). None of the mockups had any simulation of audiovisual feedback.

T10 made a textual mention of the visual and audial feedback, and represented the light feedback with blue rings around the buttons to communicate to the user which function is on, and which cooking hub they selected. There is no detail given as to when and how the interface gives auditory feedback.

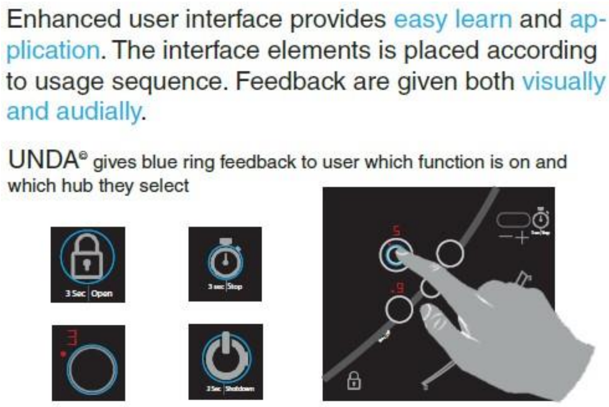


Figure 4.63. Full representation of lights and minimal representation of sound in the vitroceramic cooktop project with a grade of 3 for lights and a grade of 1 for sound (Team 10)

Team 2 had mentions of light and sounds with fewer details, and was graded 2 for lights, and 1 for sound (Figure 4.64). The light feedback is depicted in the middle section with two different intensities of blue light emanating from the adjusted timer indicator. The text mentions blinking and beeping without any further details about when and how the feedback occurs in the usage steps.

Figure 4.64. Partial representation of lights and minimal representation of sound in the vitroceramic cooktop project with a grade of 3 for lights and a grade of 1 for sound (Team 2)

Team 6 mentioned light and sound with no visual or textual descriptions, and was graded 1 for both lights and sound (Figure 4.65). The image shows the interface screen without any detailing as to how the audiovisual feedback is given in the usage process. The text mentions light and feedback making it easy to understand the usage of the interface, but no additional details have been provided.

Figure 4.65. Minimal representation of lights and sound in the vitroceramic cooktop project with a grade of 1 for lights and a grade of 1 for sound (Team 6)

As exemplified by Team 5, all of the teams had very detailed GUI representation, earning a grade of 3 each (Figure 4.66). The usage steps of the interface of T5 includes turning on, extension of the heating rings, adjustment of temperature and the time, selection of the hubs, and the interface screens of the mobile application. In each step, the visual changes of the interface are depicted in compliance with the actions symbolized with the hand icon moving across the screen. The selected buttons are mentioned as showing indicators with red lights and increasing color gradation. The mobile application is shown as a communication vessel to do actions such as reaching recipes, sharing information regarding recipes and tricks with the forum tab, and searching for additional information in the help tab. The control panel of the mobile app is shown to enable the users selecting hubs, adjusting extending heating rings, as well as adjusting the time and heat settings. Rotating the phone is depicted as enabling the users to control the cooktop in the control panel by viewing the overall layout of the cooktops to see the adjustments the user has made. It is difficult to visualize with the user interface graphics how the actions take place from start to finish, and a flowchart of the full action for each usage setting is not included, preventing the understanding of a narrative of actions. The icon of the human hand is symbolic, and it is not possible to make the connection that a real human hand is operating the interface. The interface is depicted with a large number of images to show each step clearly; however, the large number of images with fine details such as text and icons makes it difficult to follow the actions.

Figure 4.66. Full representation of GUI in the vitroceramic cooktop project with a grade of 3 (Team 5)

4.4.3.3 3D Fidelity

Figures 4.67 to 4.72 are photographs of the mockup submissions from the teams. All of the mockups for the projects were full-scale models and were given a grade of 3 for scaling, below a grade of 4 for a full-scale virtual prototype, as physical models lack the capability of making instant changes.

The mockups of the cooktops and accessories were created using a variety of materials such as printed paper and glass sheets for the cooktops, and corrugated cardboard, card stock and carved foam for the accessories, printed paper for user interface details and finishing, and acetate sheets for transparent parts. Some of the cooktops were only printed paper (Figure 4.68), whereas some of the cooktops were made of thicker material covered with a reflective layer as finishing (Figures 4.67, 4.69, 4.71, and 4.72). As for the accessories, some mockups had fully finished surfaces mimicking the texture and color qualities of the intended materials (Figures 4.67 and 4.70), some mockups had plastered smooth surfaces without color or texture detailing (Figure 4.68, 4.69 and 4.70), and some mockups had been left as raw surfaces (Figures 4.71 and 4.72). Teams 5, 8 and 9 were appointed with a grade of 3 for accurately mimicking the intended material qualities, whereas teams 1, 2, 3, 4, 6, 7, 10, 11, and 12 were appointed with a grade of 2 for moderate material quality.

The component detailing grading distinctions were based on whether the user interface has been prototyped in an electronic device such as a tablet or a phone, as per the example of T3 (Figure 4.69). The teams in which the mockup submissions for the accessories have been moderately developed in terms of component detailing and mechanical interactivity have been appointed with a grade of 2 (Figure 4.68). The mockups with components without surface finishing have been appointed with a grade of 1(Figures 4.71 and 4.72).

T5’s cooktop mockup (Figure 4.67) was a thick printed material with a reflective surface finishing featuring easily readable heating rings and interface icons. The mockup for the grilling dish fitting over two of the heating hubs has a finished surface mimicking a heat conducting material with speckling.

Figure 4.67. T5’s cooktop mockup submission earning a grade of 3 for material quality, and a grade of 3 for component detailing

T9’s mockup submission (Figure 4.68) features a printed paper material showing the heating rings of the hobs, and a four-piece cooking and serving accessory set made from carved foam material with unpainted surface finishing.

Figure 4.68. T9’s cooktop mockup submission earning a grade of 3 for material quality, and a grade of 2 for component detailing

T3’s cooktop mockup (Figure 4.69) consisted of a thick printed material with a reflective surface for the vitroceramic cooktop, a two-piece grilling and serving accessory made from finished and partially painted foam and cardboard material, a controller, and an interactive prototype of the interface displayed on a mobile electronic device.

Figure 4.69. T3’s cooktop mockup submission earning a grade of 2 for material quality, and a grade of 3 for component detailing

T7 has prepared a grilling and serving accessory (Figure 4.70) consisting of an inner tray made from laser cut cardboard, a clear acetate lid, and a container with handles made of laser cut cardboard. The cardboard surfaces are left partially unfinished.

Figure 4.70. T7’s cooktop accessory mockup submission earning a grade of 2 for material quality, and a grade of 3 for component detailing

T10’s cooktop mockup (Figure 4.71) consists of a thick printed material with reflective surface finish mimicking the material qualities of a vitroceramic cooktop, and a grilling accessory made from laser cut cardboard. The accessory has been painted, but the surfaces are left unfinished, revealing the layers of the laser cut cardboard pieces that make up the body of the accessory.

Figure 4.71. T10’s cooktop mockup submission earning a grade of 2 for material quality, and a grade of 1 for component detailing

T12’s cooktop mockup submission (Figure 4.72) consists of a printed surface with a reflective overlay for the vitroceramic cooktop, and a cooking accessory made from laser cut pieces of cardboard stacked on top of each other and left unfinished, showing the layers of the cardboard edges.

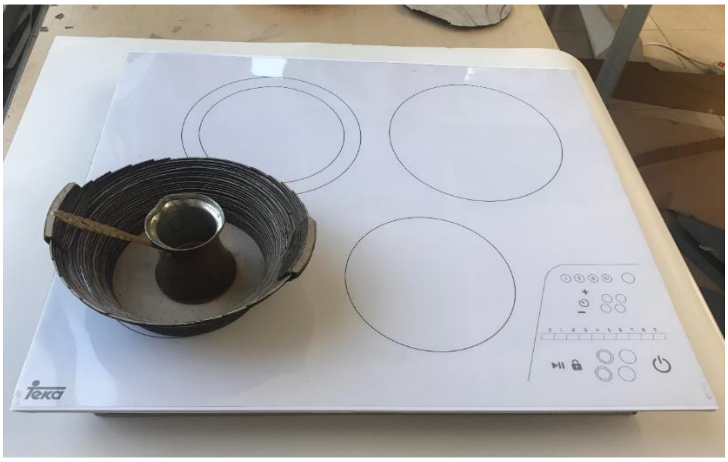


Figure 4.72. T12’s cooktop mockup submission earning a grade of 2 for material quality, and a grade of 1 for component detailing

4.4.4 Assessment of the City Bus Project Presentation Boards

For the city bus project, design teams were expected to provide a usage scenario illustrating critical phases of use, users interacting with the product taking into consideration the experience of a full bus using photorealistic views of the vehicle exterior in an appropriate context, and the vehicle interior depicting the features and qualities from the passenger's point of view. The assessment was done with details relating to the usage context, which were product in context, user and product, and usage scenario; and audiovisual feedback, which were lights, sound, and info screens and GUI.

All 9 teams have been assessed as demonstrated with the examples given for each grade appointed to the submissions for the criteria of usage context and audiovisual feedback. The assessment (Table 4.8) shows that short of a working virtual prototype experienced in an MR system, the representation of the usage context details of user and product interaction and the usage scenario were the most detailed. This was followed by the visual feedback details of lights, and info screens and GUI. The representation of the product in context, as well as info screens and GUI were, as per the limitations of the 2D presentation board format, lacking in realism, especially when trying to convey the sequence of interaction. The representation of sound in the submissions were non-existent.

Table 4.8 Assessment of submissions for the City Bus project

City Bus		Content Development and Quality of Presentation									Average
		T1	T2	T3	T4	T5	T6	T7	T8	T9	
Usage context	Product in context	2	2	2	3	3	3	2	3	2	2
	User and product	2	3	2	3	3	3	3	3	3	3
	Usage scenario	3	2	3	3	3	3	3	2	3	3
Audiovisual feedback	Lights	3	3	3	3	2	2	3	2	3	3
	Sound	0	0	0	0	0	0	0	0	0	0
	Info screens and GUI	2	3	2	3	3	3	2	3	3	3
3D Fidelity	Scale	1	1	1	1	1	1	1	1	1	1
	Material quality	1	2	3		3	3				2
	Component detailing	2	1	3		2	3				2
General average		1.8	1.9	2.1	2.3	2.2	2.3	2.0	2.0	2.1	2.1

4.4.4.1 Usage Context

Team 4 was given a grade of 3 for representing the product in the full environment from multiple angles and levels of light, including users (Figure 4.73). The three images show different configurations of the bus modules to accommodate rush hour crowds. The bus is shown firstly at 10:00 am, with only one module, in an overcast lighting setting, approaching the bus stop viewed from the side. The bus stop and the bus are superimposed on a photograph. The scaling of the bus stop seems to be on the smaller side than what would have been the accurate size, and does not have any shadows on the sidewalk or the road. The bus render on the other hand, does cast a diffused shadow. The passengers are visible inside the bus, and waiting at the bus stop. The second image shows the bus approaching the barely visible bus stop during the evening rush hour. The bus has three modules to accommodate more passengers, shown both on the interior of the bus, and waiting at the bus stop. The rush hour is only depicted with the crowded bus stop. The modules of the bus are not crowded with passengers, and there are no other cars in traffic. Lastly, the third image shows two modules of the bus at nighttime. The bus is partially full, with a moderate number of passengers waiting at the bus stop. The headlights of the bus are illuminating the pedestrian crossing in front of the bus.

Figure 4.73. Full representation of product in context in the city bus project with a grade of 3 (Team 4)

Team 1’s submission showed two angles in a studio context and in daylight, earning a grade of 2 (Figure 4.74). The studio context image of the bus is a close up from the side, with the interior detailing of the bus such as the seats and the railings visible. The in-context image of the bus is placed in a 3D modeled environment with buildings, landscaping, stop lights and signs as well as outdoor furniture. The environment surrounding the bus is blurred and faded to put emphasis on the bus. The scene is captured during daytime. There are no passengers featured on the bus in either of the images.

Figure 4.74. Partial representation of product in context in the city bus project with a grade of 2 (Team 1)

Team 2’s submission included a silhouette of the user carrying out a specialized user and product interaction of traveling with a bicycle, earning a grade of 3 (Figure 4.75). The first two sections of the image depicting the user and product interaction are of an eco-bike user getting off the bike and collapsing the locking joints of the bike prior to getting on the bus, emphasizing the ample clearance on the entrances for bikes to be carried into the bus. The collapsed bike is shown as stored under the seat, where the bike is attached for energy transfer, allowing the passengers to get refunds for supplied energy. The human figures pictured inside the bus seem to be different people, one resembling a woman with a backpack, one man in a suit holding a laptop or a book in front, and one more casual human looking at something not easily discernible. The usage steps look like they should be depicting a usage scenario, but the inconsistency between the human figures as well as the lack of discernible edges inside the silhouettes make it difficult to follow the actions as consecutive.

Figure 4.75. Full representation of user and product in the city bus project with a grade of 3 (Team 2)

Team 3’s user and product interaction representations were side view technical drawings of passengers sitting and leaning, and were appointed with a grade of 2 (Figure 4.76). In these drawings it is not possible to see how the lounge, the seating units and the leaning units relate to the interior and exterior of the bus, as they are shown only with ground lines and not with the full outline of the bus. It is not possible to get a feeling of how a user would interact with the bus in a three dimensionally dynamic way, as the technical drawings are only side views. There are no environmental details, the human figures are all robotic sketches with no clothing or luggage, and the drawings are not colored.

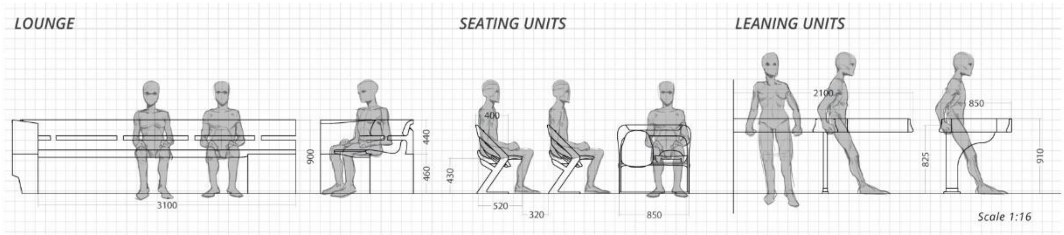


Figure 4.76. Partial representation of user and product in the city bus project with a grade of 2 (Team 3)

Usage scenario details of Team 5 included a variety of passengers waiting for the bus, getting on the bus and making a journey, and were given a grade of 3 (Figure 4.77). The usage scenario included ten steps depicting the bus station accommodating passengers with varying needs, a special needs passenger using the bus stop interface so that the bus is notified for adjusting the door entry to accommodate a wheelchair, the bus approaching the passengers and opening up a ramp, the wheelchair seating area alerting the seated passengers about the entering of the wheelchair user, the seats in the wheelchair area folding up to make space for the wheelchair user, the leaning area offering interchangeability for passengers carrying bikes and luggage, a bike and an e-scooter being stored in the specified areas, and work tables folding out in front of the passengers in the work seating area. A variety of passenger types are shown as semi transparent silhouettes matching in pose and position based on what part of the bus and the bus stop they are using.

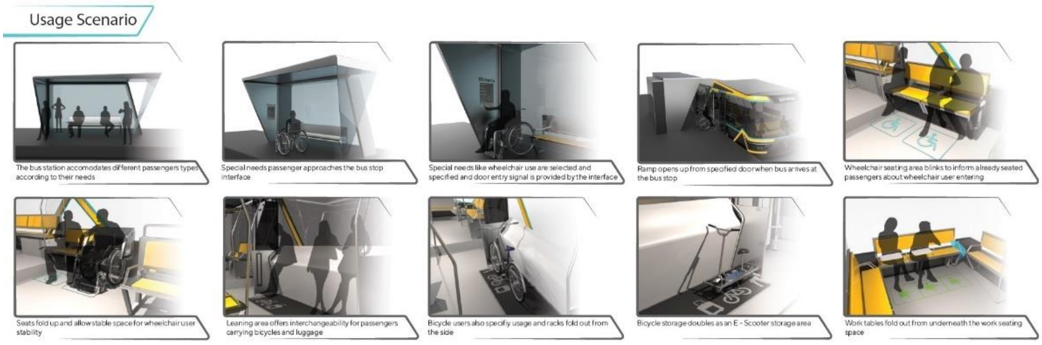


Figure 4.77. Full representation of usage scenario in the city bus project with a grade of 3 (Team 5)

Team 3's usage scenario included sketches showing the steps of a passenger carrying out steps of usage, and was given a grade of 2 (Figure 4.78). This user scenario features a numbered list of the actions, supported with crude sketches of the passengers, the interior and the exterior of the bus. The usage steps are numbered to suggest a sequence of actions taking place; however, the captions for the sketches are not necessarily narrative in fashion: the mentioned actions are different time management for each passenger, seats being assigned from a distance, promptitude and spontaneity, bus coming to the stop, reading of the assigned seat with personal device, the seat opening for assigned person, and passengers traveling in the way they desire. Only two of the sketches show fully developed passenger silhouettes actually interacting with the bus. The sketches where the assigned seat system is explained with arrows symbolizing movement of parts are removed from the full view of the bus. It is not possible to see how the seating areas are placed inside the bus.

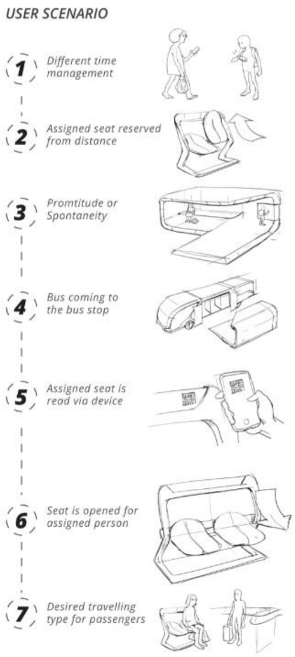


Figure 4.78. Partial representation of usage scenario in the city bus project with a grade of 2 (Team 3)

4.4.4.2 Audiovisual Feedback

None of the mockups had any simulation of audiovisual feedback.

Team 7’s submission included lights of the headlights, stop lights and exterior lights and was given a grade of 3 (Figures 4.79 and 4.80). The exterior lights are shown in a fully developed environment (Figure 4.79) in a nighttime setting. The lights that are visible consist of blue headlights in the front surface of the bus, and red rear lights on the back surface of the bus. The door surfaces of the bus are also illuminated, and it is possible to see some of the interior lights. The headlights and the rear lights are shown in close up views of the front and back angles as well (Figure 4.80).

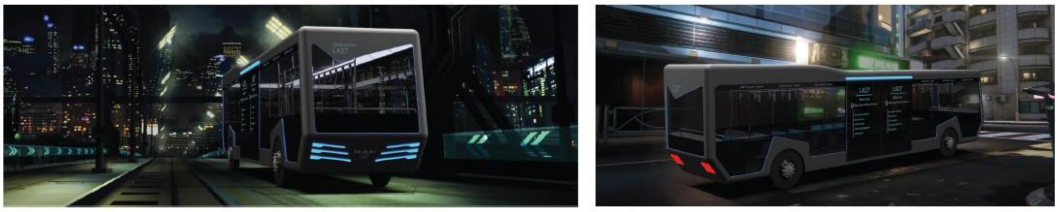


Figure 4.79. Full representation of lights (exterior) in the city bus project with a grade of 3 (Team 7)

Figure 4.80. Full representation of lights (headlights and stoplights) in the city bus project with a grade of 3 (Team 7)

Team 8’s submission represented the interior lights on the ceiling, earning a grade of 2 (Figure 4.81). The interior of the bus is rich in detail with color and texture distinctions adding realism to components such as seats, railings, interior walls, ceiling detailing, and the ceiling lights whose shapes are inspired by the angular lines on the exterior design of the bus. The interior of the bus is well illuminated, and the reflection of the lights are visible on the windows and other reflective surfaces inside the bus. The exterior lights are not depicted.

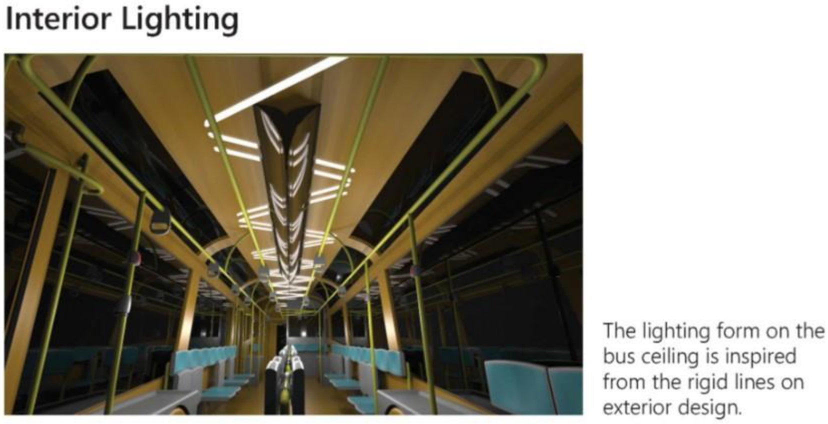


Figure 4.81. Partial representation of lights in the city bus project with a grade of 2 (Team 8)

None of the submissions in the city bus project mentioned any auditory feedback.

Team 8 had detailed representations of bus stop info screens, mobile application screens and info area user interfaces, earning a grade of 3 (Figures 4.82, 4.83 and 4.84). Firstly, the bus stop wall has an integrated information screen showing the city map (Figure 4.82). There is one clothed human figure looking at the screen, with the other human figures not as detailed, with static, unrealistic poses. Secondly, some interface screens of the mobile app accompanying the transportation system consisting of the bus stop and the bus are pictured (Figure 4.83). The interface screens show the selections of connecting scooters or bikes to the bus, the map of the city and the route of the bus, the remaining time period for the journey, and available bus routes reachable from the selected bus stop. Thirdly, the interface screens inside the bus (Figure 4.84) are pictured as two sided-advertisement boards fixed on the bus ceiling, giving information about the journey, tourist attractions and the cultural events taking place in the city. The surfaces are mentioned as being graphed with AR.

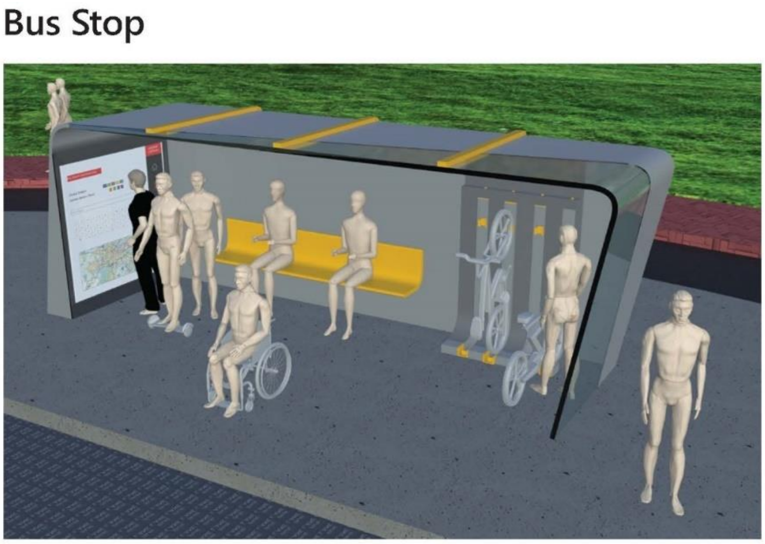


Figure 4.82. Full representation of info screens and GUI (bus stops) in the city bus project with a grade of 3 (Team 8)

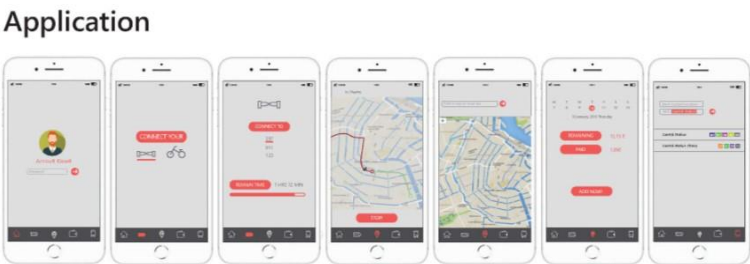


Figure 4.83. Full representation of info screens and GUI (mobile app screens) in the city bus project with a grade of 3 (Team 8)

Figure 4.84. Full representation of info screens and GUI (info areas) in the city bus project with a grade of 3 (Team 8)

Team 1 represented less details of info screens and GUI by depicting isolated info panel screens and phone application screens, earning a grade of 2 (Figure 4.85). The interface screens are of a mobile app showing bus information, ticketing, city map, crowdedness level of the bus, bus stop function, and timing details. The screens placed on the doors of the bus show a city map, the bus route, and the progress of the bus throughout the route. There are also digital displays placed on the bus stop that give information about the city, and provide help for solving the problems faced while traveling in an autonomous vehicle. There are no detailed in context views of the interface screens on the bus and the bus stop.

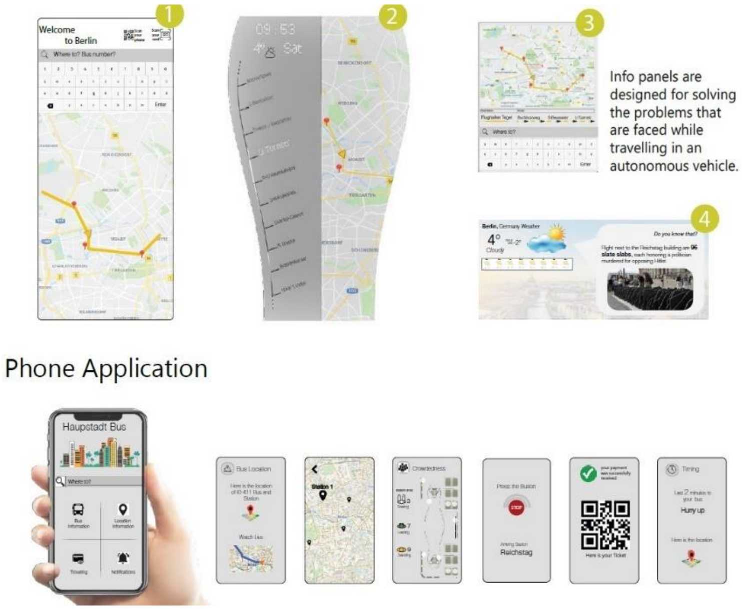


Figure 4.85. Partial representation of info screens and GUI (info panel and app screens) in the city bus project with a grade of 2 (Team 1)

4.4.4.3 3D Fidelity

Figures 4.86 to 4.90 are photographs of the mockup submissions from of the teams. All of the mockups for the projects were 1/20 scale models and were given a grade of 1 for scaling.

The mockups of the buses were created using a variety of materials such as corrugated cardboard, card stock, finished and unfinished carved foam, and wire as structure materials, printed paper for user interface details and finishing, and acetate sheets for transparent parts. The mockups have differing levels of detailing, some having fully finished smooth surfaces made of plastered and painted foam (Figures 4.87 and 4.88), some with printed card stock (Figure 4.89), some left with raw card stock (Figures 4.90) and some a combination of card stock and carved foam (Figure 4.86). Some of the less detailed finishing (Figures 4.89, 4.86 and 4.90) made the mockups feel flimsy due to the lightweight quality of cardboard. The fully finished surfaces of T3, T5 and T6 were given a grade of 3 for material quality. The less detailed finishing of T2 was given a grade of 2 for material quality. T1 was appointed with a grade of 1 for material quality due to the easily collapsible nature of card stock showing deformities around the edges.

For component detailing, T6 and T3 was given a grade of 3 for having fully outfitted interiors with smooth surfaces of the relevant components such as railings and seats, and separate removable outer shells that reveal the interiors of the mockup. The other teams' mockups also had interior detailing, but were less continuous and smooth, deserving of a grade of 2.

T6's bus mockup (Figure 4.86) has two separate components. The left side is made of carved and sanded foam to show the exterior contours of the bus, with separations between the windows, the bumpers, and the wheels visible. The right side shows the interior of the bus, as if to achieve a cutaway view of the arrangement of the inner components of seats, leaning ledges, and railings. The materials used in this section are card stock and paper.

Figure 4.86. T6’s bus mockup submission earning a grade of 3 for material quality, and a grade of 3 for component detailing

T3's bus mockup (Figure 4.87) consists of two separate parts. The outside of the bus is prepared with carved, plastered and painted foam showing clear lines in the placement of the back bumpers, window edges and wheels. The windows are painted black and do not provide transparency. The front windows have printed indicators for the bus number. The second part showing the interior of the bus has components such as leaning areas, platforms, seats and railings. The edges of the platforms and seats are painted a contrasting color for emphasis. The floor is covered with a printed paper showing the entry points of the bus. The upper railing is made of card stock material and shows signs of unintended irregularity.

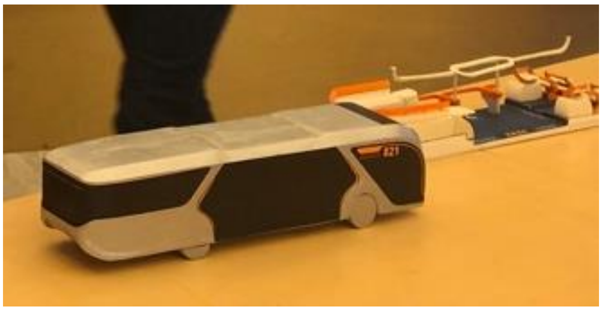


Figure 4.87. T3’s bus mockup submission earning a grade of 3 for material quality, and a grade of 3 for component detailing

T5's bus mockup (Figure 4.88) has a carved, plastered and painted upper surface, side walls and floors made with card stock, and clear acetate sheets for windows. The inner parts of the side walls are left unfinished, and the edges of the card stock shows deformation. The doors are not removable, and the edges of the clear panels of the doors are irregular. The railings inside the bus are not as visible as the decorations on the outside surfaces of the bus.

Figure 4.88. T5’s bus mockup submission earning a grade of 3 for material quality, and a grade of 2 for component detailing

T1's bus mockup (Figure 4.89) is made of a card stock body with wire accessories. The edges of the card stock are left white and unfinished, while the outer and inner sections are printed. The areas where the ceiling surface is not supported by side walls are partially deformed. The outer shell is removed from the front and the side to make the interior components visible. The wire material used for the railing components are irregular at places.

Figure 4.89. T1’s bus mockup submission earning a grade of 1 for material quality, and a grade of 2 for component detailing

T2's mockup (Figure 4.90) has card stock material on the side walls, the floor, and the interior components such as the seats and the railings. The card stock is left unfinished, and the areas where the material is cut thin are bent and deformed. The ceiling of the bus features green landscape model material covered with clear acetate, to mimic plants growing in a clear casing. The corrugated cardboard used on the doors of the bus is painted, but left unfinished in terms of the texture, and has jagged edges.

Figure 4.90. T2’s bus mockup submission earning a grade of 2 for material quality, and a grade of 1 for component detailing

4.5 Findings of the Design Project Assessment Study

The visual analysis framework is a unique assessment scale to go beyond expectations of traditional methods of representation in industrial design education, based on the unique needs of increasingly complex products. Therefore, a grade of 4 has been appointed to an imagined/proposed scenario of students being able to utilize MR technology to fulfill needs of representation. The visual analysis grading system was divided into categories as color coded in Table 4.9. All the grades appointed to each of the teams in the four design projects were compiled to show averages for each criterion (Table 4.10). From this table the averages for each criterion have been deducted, and ranked based on the levels of success (Table 4.11). It can be seen that representations of sound have a failing ranking, followed by a poor ranking of representations of lights. The representations of user and product and the usage scenario have been average, and representations of product in context as well as the info screens and UI have been acceptable. The significance of this ranking is that there are no examples that go beyond the arguably low expectations in representing the full attributes of the product.

Table 4.9 Grading system for the assessment of submissions

0-0.9	Failing
1-1.9	Poor
2-2.4	Average
2.5-2.9	Acceptable
3-4	Excellent

Table 4.10 Averages of the assessment of submissions

		Electric Oven	Apron Bus	Vitroceramic Cooktop	City Bus	Average
Usage context	Product in context	2.2	2.7	2.8	2.4	2.5
	User and product	2.2	2.5	2.1	2.8	2.4
	Usage scenario	2.1	2.5	2.3	2.8	2.4
Audiovisual feedback	Lights	1.0	2.2	1.1	2.6	1.7
	Sound	0.1	0.0	0.3	0.0	0.1
	Info screens and UI	2.8	1.7	3.0	2.6	2.5
3D Fidelity	Scale	3.0	1.0	3.0	1.0	2.0
	Material quality	2.0	2.0	2.3	2.0	2.1
	Component detailing	2.5	2.2	1.9	2.0	2.2

Table 4.11 Averages of each category, ranked

0.1	Sound		
1.7	Lights		
2.4	User and product	Usage scenario	3D Fidelity
2.5	Product in context	Info screens and UI	

4.5.1 Sound

The biggest difference with MR integration in the analyzed projects is to be achieved in representations of sound and lights, especially since the projects are highly complex products such as vehicles and kitchen appliances. Lights and sound are vital components of feedback often used together to guide the user. Such audiovisual feedback is impossible to depict in a 2D presentation board, because the nature of feedback in the form of lights and sound is a dynamic and interactive experience.

Sound feedback can help the user remember timed actions, warn the user, or provide information for the user. For representing sound, only a text mention or a graphical representation are possible in a 2D design board. This means that duration, pitch or volume of the sound is not represented. Short of a fully working prototype, a virtual working prototype with the sound feedback integrated into the MR system would provide the best result. Across all of the teams, only five had any sound detailing in their presentation boards. Alarms are mentioned twice: in the electric oven project in T3's presentation board, and in the vitroceramic cooktop project in T7's presentation board (Figure 4.91). In the vitroceramic cooktop project, two teams mention sound feedback, whereas one team specified the sound as bleeping. Since all of the MR display components have the ability to emit sound, creating a virtual environment to present a design project would have enabled these teams to simulate the user interactions leading to the audio feedback they mentioned in their presentation boards.

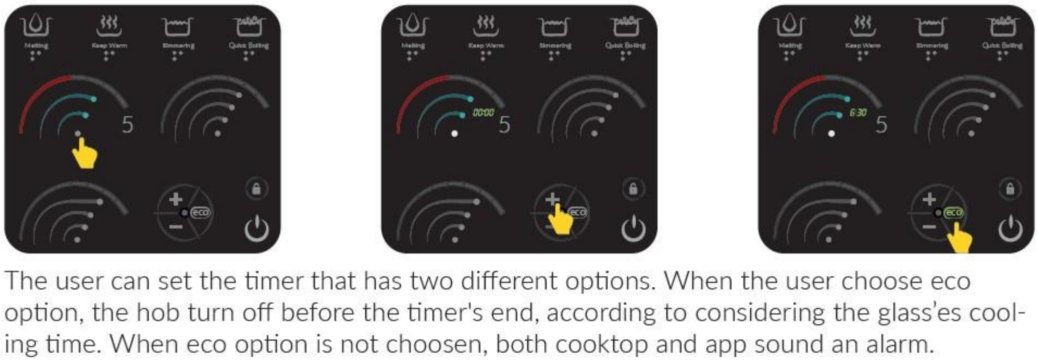


Figure 4.91. Mention of alarm in T7's vitroceramic cooktop presentation board

4.5.2 Lights

Lights can communicate vital details about the usage of a product, be a safety feature, as well as become an integral part of the operation of the product. Traditionally, the best way of depicting light in a design project would be to get sequences of different stages of lighting of the exterior and (when applicable) interior, including interface details. This would mean that details such as movements in light, changing intensities, blinking, glowing, the effects of lights on surrounding environments are not able to be represented. Short of a fully working prototype, a virtual working prototype with the light feedback integrated into the MR system would provide the best result. In the vitroceramic cooktop project T12 mentions a blinking red light directing and informing the user, in the electric oven project T3 mentions a warning light (Figure 4.92).

Figure 4.92. Mention of a warning light in T3’s electric oven presentation board

Besides the use of lights in the interfaces, interior and exterior lighting of vehicles are a difficult detail to visualize. In the apron bus and city bus projects, across all the teams' submissions where light has been visualized, it can be seen that visualization of a light could look washed out or look unrealistic (Figure 4.93).

Figure 4.93. Visualization of interior lights in T2's apron bus project presentation board (top), visualization of exterior lights in T3's apron bus project presentation board (bottom)

4.5.3 User-Product Interaction

The visualization of the user's interaction with the product across the team has been analyzed through the criteria of user and product depictions, and usage scenario depictions. Visualization of the user and the product is necessary for relaying information about the ergonomic suitability of the product in relation to the human proportions. Usage scenarios are similar in the sense that the user-product interaction is depicted, but with the difference of combining multiple images along with text to tell a story about the usage of a product through the steps taken to complete tasks. The viewer identifies with the human figure in the board to get an idea of the form and function of the design. The teams have achieved the visualization of the user-product interaction by placing a silhouette or virtual 3D dummies in the frame. This is standard practice for educational design presentations; however, the drawbacks become apparent considering what a MR experience can add to the way of relaying information about the design. The main problem with visualizing user with the product with traditional methods is the discrepancy of level of detail between the user, the product, and the environment. Lack of environment detailing makes the product look like it is floating in air, and it is difficult to understand the height dimension of the product in relation to the human body. Moreover, the very high viewing angle to show the user interacting with the product seems unnatural and forced, and makes the human figure look distorted, once again making it difficult to understand the scale of the product in relation to the human body (Figure 4.94).

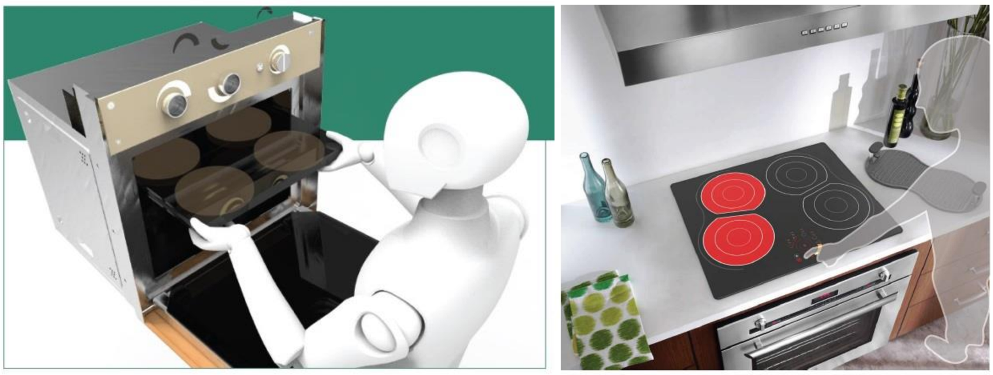


Figure 4.94. Visualization of user interacting with the product in T1's electric oven project presentation board (left), visualization of user interacting with the product in T5's vitroceramic cooktop project presentation board (right)

When using human dummies for representing user-product interaction, stiffness and lifelessness in the human figure can be a problem. The human figures may appear uniform, the poses may look unnatural and forced, no carriage or accessory detailing makes the scene look unrealistic (Figure 4.95). Additionally, it can be seen that these dummies do not vary in height, size, gender or age, and details such as clothing, accessories such as different kinds of carriages, walking canes, and strollers are not represented.

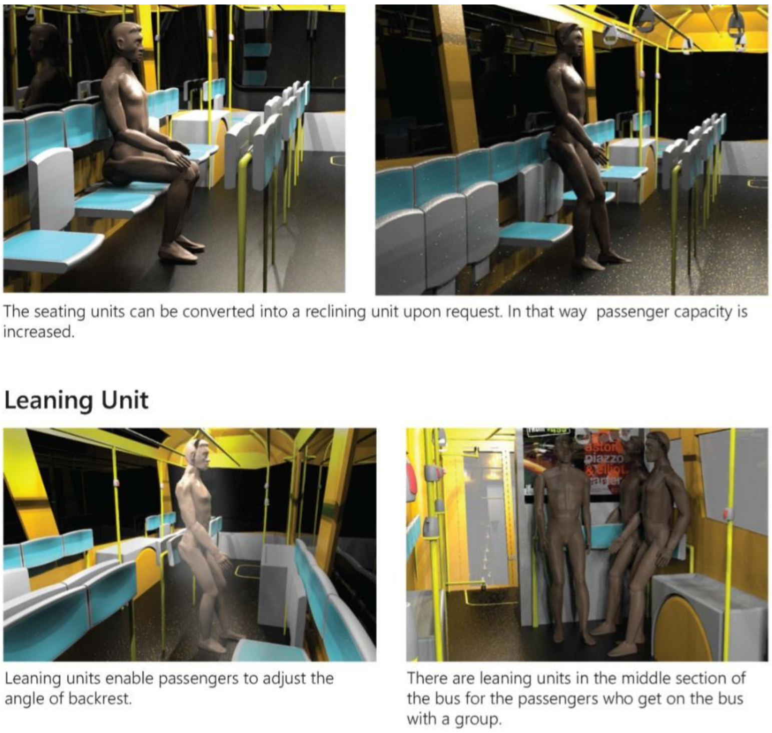


Figure 4.95. Visualization of user interacting with the product in T8's city bus project presentation board

4.5.4 Usage Scenario

Usage scenarios have to balance between showing all the necessary interactions between the user and the product, and being hard to follow. There is either a risk of the scenario being too removed from the real usage environment as well as the interface screens where the relevance of the user interface to the product is diminished with the examples of the hand silhouettes on interface screens not being in proportion to the interface, or being too graphically dense and having an excess of text and therefore difficult to read (Figure 4.96). The user not carrying out an action from start to finish causes problems with following the sequence of actions taking place as it would do in a scenario. This problem is more apparent in cases where the usage sequence is not linear, but rather branches out to several different usage options.

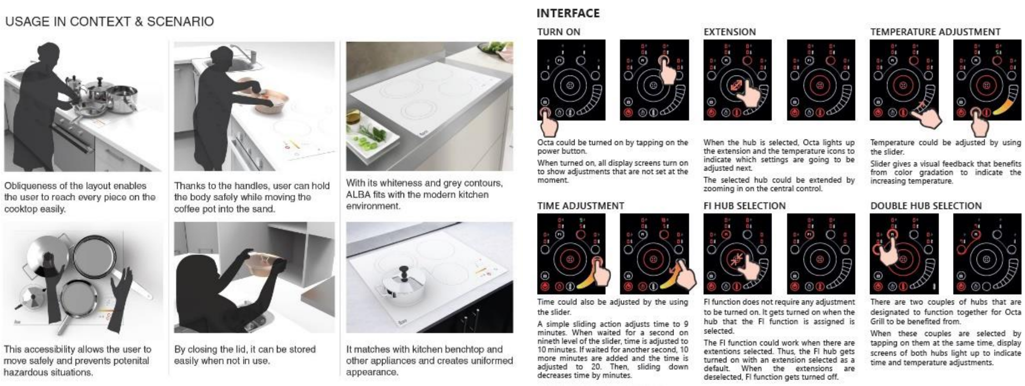


Figure 4.96. Visualization of usage scenario in T12’s vitroceramic cooktop project presentation board (left), visualization of the usage scenario on the interface in T5’s vitroceramic cooktop presentation board (right)

Inclusion of environment details makes usage scenarios more engaging compared to studio settings; however, the discrepancy in the level of detail in depicting the environment and the human figure breaks the immersion (Figure 4.97). The lack of immersion in presenting usage scenarios in 2D presentation boards makes it difficult to understand whether the workflow is user friendly due to the disconnect of trying to put one’s self in the shoes of the human figure. Engagement and immersion would be the benefit of a MR system where instead of viewing a human figure using the product, the viewers can interact with the product themselves.

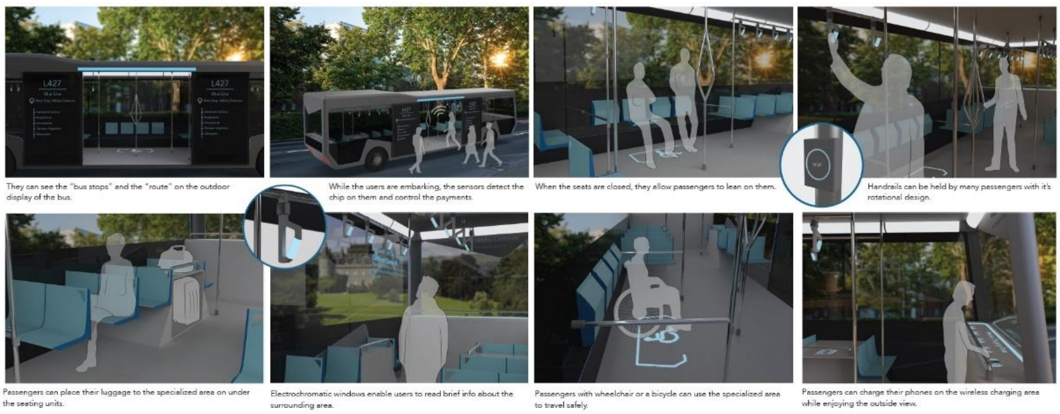


Figure 4.97. Visualization of usage scenario in T7’s city bus project presentation board

4.5.5 Product in Context

The representation of product in context is important in understanding the scale of the product with its surroundings. As detailed in the visual analysis framework, the best option for visualizing the design short of building a physical working prototype would be a working virtual prototype simulating the intended usage environment. The second-best option is a 2D representation of the full environment from multiple angles and configurations. In the presentation boards, the students either did partial environment detailing, or aimed at realism. Partial environment detailing makes the scene look unrealistic, and the designed products may look as if suspended in air. Lack of environment details such as reflections also break the immersion of a scene. Even in depictions in realistic settings, the lighting of the product may seem unmatching with the realistic background, and the scale as well as the viewing perspective of the product might be disproportionate to the environment (Figure 4.98). Either way, an AR scene where the product is virtually placed on a desired spot representative of the intended usage environment could dramatically improve these visualizations.

Figure 4.98. Visualization of product in context in T10's electric oven project presentation board (left), visualization of product in context in T1's vitroceramic cooktop project presentation board (middle), visualization of product in context in T2's apron bus project presentation board (right)

4.5.6 Information Screens and Graphical User Interfaces

Graphical user interfaces and information screens are an integral part of a complex product. The operation might be carried out through a touch interface or a mobile app, and information related to the operation of the product might be displayed on screens. The traditional way of showing these details would be with GUI wireframes showing each screen as the action is carried out, and overlaying a frame of the screen *in situ*. Including many screens of a GUI wireframe might make a presentation board very crowded. The interactive nature of the interface, and the changes in the screens render the 2D representation lacking in realism. The submissions include wireframes of GUIs, and information screens placed on the body of the design. There are examples of interfaces being shown separated from the product and the environment, and examples of hand icons not being scaled to match the buttons, making it difficult to guess how the user interacts with the screen (Figure 4.99). Positioning and overall layout of screens may also cause problems in following the steps of use in the interfaces. Even when the interface screens are shown in a detailed environment with the user included, scaling problems might occur.

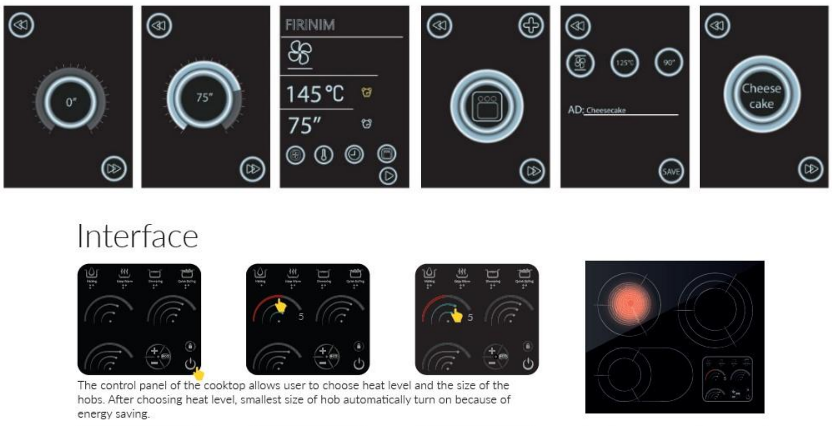


Figure 4.99. Visualization of graphical user interface in T8’s electric oven project presentation board (top), visualization of graphical user interface in T7’s vitroceramic cooktop project presentation board (bottom)

T8’s city bus design actually has an AR feature (Figure 4.100). In this example, the scene has been created with overlaying the rendered bus interior and the screens onto a photograph of the real environment. The viewing angle on the photograph does not match the interior of the bus, and the AR experience has not been developed enough to match the capabilities of AR technology. Overlaying an AR experience on a photograph and not a real environment creates a simulation of a simulation, lacking realism. Since AR for tourism industry creates a simulation overlay on top of the real environment, creating an actual AR scene where the bus has been placed properly in a real location would have produced a more realistic outcome.

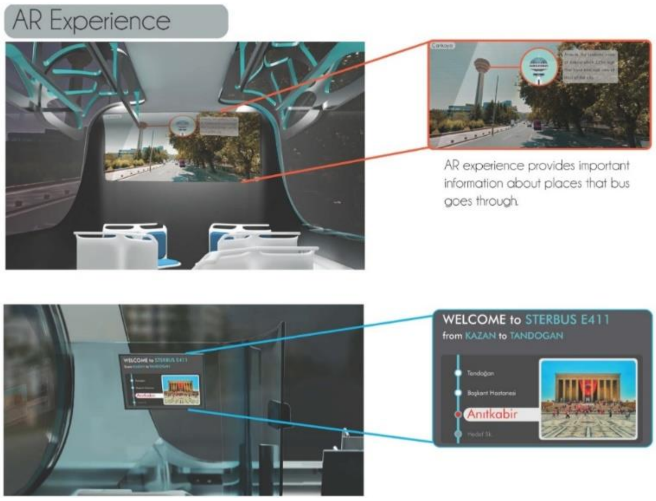


Figure 4.100. Visualization of AR info screens in T8's city bus project presentation board.

4.5.7 3D Fidelity

The representation of 3D fidelity as observed from mockups can give detailed three dimensional information regarding size in relation to the user and the environment, material and texture qualities of the surfaces of the product, as well as layout and mechanical assembly of components. With regards to scale, a virtual system can enable the viewer to experience a full-size product fitting into the real environment, eliminating problems of scaling. Similarly, in a virtual prototype it is easier to get better representation of material and texture qualities, since the work is done with CAD software without the need of material and production cost and the labor of producing high quality physical prototypes. A virtual prototype can also enable the user to make instant changes to the product, better interact with the moving components of the product, and bring interactivity in the form of audiovisual feedback and working GUI's.

The apron bus and the city bus projects, because of the large-scale nature of the vehicle, were represented with 1/20 scaled down mockups. These scaled down mockups eliminate experiencing a big part of the product: the viewer is not able to walk around in the bus, making it impossible to get an idea of what it feels like to fully interact with the features of the design. Instead, the mockups depend on imagination to consider the design elements. Even though the electric oven and the vitroceramic cooktop projects have full sized mockups, it is not possible to view the product in its intended area of use, a kitchen, and it is not possible to make instant changes in the design in terms of component detailing. These problems of scaling can be negated in a virtual prototype, where the product would be experienced in full size and in its intended usage environment, and easily manipulated to achieve different configuration of components.

The mockups used materials such as corrugated cardboard, card stock, foam, paper, acetate sheets, and wire, in addition to the 3D printed examples. The quality of finishing in the mockups have differing levels. The examples where mockups have less finishing in the surfaces do a sub-par job of representing the material and texture qualities, which is especially in the selected cases of kitchen appliances and vehicles where smoothness and reflectivity of surfaces are integral to the design. Component detailing is another area where mock-ups do not match the design. As outlined in the analysis of sound and lights, audiovisual interactivity especially in complex products with digital components is difficult to represent even in physical mockups. Even though some of the presentation boards have mentions of sound and lights, none of the mockups have integrated any audiovisual feedback. Even though some mockups had the option of removable and separate pieces to showcase different interactions and component detailing, the low quality of materials and lack of full-size components make it difficult to complete the picture when interacting with the mockup (Figure 4.101).

Figure 4.101. T5's city bus mockup submission (left), T9's oven mockup submission (right)

4.6 Outcomes of the Design Project Assessment Study

By interpreting the findings of the design project assessment study, it is possible to answer the two research questions and make a transition into the next chapter, which is an experimental study investigating the gathered insights.

1. What are the shortcomings of traditional design representation tools in presenting complex educational industrial design projects?
2. How can the benefits of immersion provided by MR systems strengthen the shortcomings of traditional representation tools in presenting complex educational industrial design projects?

4.6.1 Shortcomings of Traditional Design Representation Tools in Presenting Complex Educational Industrial Design Projects

The analysis shows that traditional presentations in educational industrial design projects have some shortcomings in the representations of sound, lights, user and product interaction, usage scenario, product in context, info screens and user interfaces, and 3D fidelity. When representing sound, the presentations have been found lacking in dynamism and interactivity. The information regarding duration, pitch and volume of the sound feedback is not represented. Similarly, the representation of lights also lacks dynamism and interactivity, giving no information regarding the movement, changing intensity, blinking and glowing effects of the light feedback. Additionally, the effects of the lights surrounding the environments may be lacking, and have a washed out or unrealistic appearance.

The quality of the user and product interaction have been found to be diminished due to the stiffness and lack of variety of the users regarding height, age, gender and so on. Poorly detailed environments as well as high and unnatural viewing angles of the users are also notable shortcomings of traditional presentations. There has been noted a discrepancy between the scale and detail level of the product, the user and the environment.

Usage scenarios have been found hard to follow due to graphical and textual density, the scenario taking place separate from the usage environment and the hand being represented proportionally inaccurate. The users depicted in the user scenario may be lacking accessories related to the usage of the product, and the sequence of events taking place during use may be difficult to read.

Representations of product in context have problems of scale and detail level of the product not corresponding to the user and the environment, as well as viewing angle and placement of product being disproportionate to the environment.

The depictions of the info screens and user interfaces in the submissions have been found hard to follow due to graphical and textual density, interfaces being removed from the product, and proportionally inaccurate hand silhouettes. Moreover, it may be difficult to read a sequence of events and display more than one sequence.

The 3D fidelity analysis showed a lack of full scale mockups with audiovisual interactivity, and a lack of interactivity regarding additional components and accessories. The mockups with low material quality resulted in deformities, making it difficult to interact with the model.

Table 4.12 Shortcomings of traditional presentations

Sound	• Lack of dynamism and interactivity in representation, • Lack of duration, pitch or volume detail of the sound feedback
Lights	• Lack of dynamism and interactivity in representation, • Lack of movements, changing intensities, blinking and glowing effects of the light feedback, • Lack of the effects of lights on surrounding environments, • Washed out or unrealistic appearance
User product interaction	• Stiffness and lack of variety regarding height, age, gender and such of dummies, • Lack of environment detailing, • High and unnatural viewing angle, • Scale and detail level of the product not corresponding to the user and the environment
Usage Scenario	• Hard to follow graphical and textual density, • Scenario being removed from the real usage environment, • Proportionally inaccurate hand silhouette, • Lack of accessories in users, • Difficulty in reading sequence of events
Product in context	• Scale and detail level of the product not corresponding to the user and the environment, • Viewing angle and placement of product being disproportionate to the environment
Info screens and UI	• Hard to follow graphical and textual density, • Interfaces being removed from the product, • Proportionally inaccurate hand silhouette, • Difficulty in reading sequence of events, • Difficulty in displaying more than one sequence of events
3D fidelity	• Lack of full-scale mockups with audiovisual interactivity, • Lack of interactivity regarding additional components and accessories, • Low material quality in mockups resulting in deformities

4.6.2 MR Systems to Address the Shortcomings of Traditional Representation Tools in Industrial Design Education

From the grade averages of the categories of sound, lights, user and product representation, usage scenario representation, 3D fidelity, representation of product in context and info screens and UI, the shortcomings of traditional representation tools in presenting complex educational industrial design projects can be categorized into four tiers in order for the shortcomings to be answered with the benefits of immersion provided by MR systems (Table 4.11). The sound and lights of all the submissions from the four projects that were analyzed got the failing and poor assessment based on the grading system (Table 4.9), followed by the average rating of the representation of the user and the product, the usage scenario and 3D fidelity, whereas the representation of the product in context and the info screens and UI received the assessment of being acceptable. A three tier system for integrating MR technology into the student presentations can be suggested, namely accessible solutions with quick payoff, infrastructural investments with long term payoff, and extra development for specialized presentation purposes.

Table 4.9 Grading system for the assessment of submissions

0-0.9	Failing
1-1.9	Poor
2-2.4	Average
2.5-2.9	Acceptable
3-4	Excellent

Table 4.11 Averages of each category, ranked

0.1	Sound		
1.7	Lights		
2.4	User and product	Usage scenario	3D Fidelity
2.5	Product in context	Info screens and UI	

For the representation of sound and lights in presentations, low cost VR solutions where the students can use their own smart phones and use Unity 3D to create audiovisual interactive presentations, and improve the spatial awareness of the presentations of their designs. This accessible solution would bring quick payoff and make the biggest difference in presentations due to the low grade the assessment of sound and lights received in the design project assessment study, as the traditional ways of presenting sound and lights in design projects are almost totally lacking.

In presenting user and product, usage scenario and 3D fidelity, an infrastructural investment of a VR headset in conjunction with a PC with high computing power and additional editing software would bring long term payoff by enabling the students to present basic virtual user-product interactions and integrations with physical mock ups. Based on the results of the design project assessment study, traditional presentations do a better job representing user and product interactions, usage scenario and 3D fidelity than with sound and lights, but the VR solutions bring long term payoff.

For representing the product in context and info screens and UI, VR solutions can be more specialized spatial VR systems, additional sensors to map out the surrounding environment to enable bigger scale interactions, PC with high computing power and additional software to run the simulations, and a designated room to allow movement of the students. These more specialized high cost VR systems can help students to present the user and product interactions in large scale and in context, combined with more detailed GUI interactivity.

The following chapter is an action study of VR integration into the design process of a variety of projects developed throughout a semester to pinpoint how the results of the design project assessment study matches with the benefits of immersion brought on by the suggested VR systems.

CHAPTER 5

PARTICIPANT OBSERVATION STUDY

The claim is that a virtual reality experience displaying product designs would provide greater immersion than standard presentation tools, better meeting the communication demands in an industrial design project, particularly in large-scale and sophisticated interactive projects. According to the literature on immersion and presence, 2D visual representations are perceived at a lower level of immersion, necessitating further explanations by the design student in order to fully comprehend the design's qualities. The factors that disrupt immersion in final project presentations were addressed in the design project assessment study. The second part of the study will test the validity of the knowledge claim proposed in the first part, making transition from *tacit* information about immersion of student presentations in industrial design projects into *explicit* information about the benefits of immersion brought on by MR systems integrated in design projects.

5.1 Research Questions

The research questions for the experimental study are as follows,

- What kinds of educational strategies should be employed to teach MR to industrial design students based on their representation needs?
- What methods and strategies should be employed while teaching MR to industrial design students so that they can enrich the process and outcomes of their projects?

5.2 Introduction to the Study and Sampling

The study was conducted in the ID314 Interactive Multimedia Design course in the spring term of the 2018-2019 academic year at METU Department of Industrial Design. The Interactive Multimedia Design course aims to teach how to integrate text, graphics, animation, digital video and sound in order to create interactive multimedia applications, multimedia authoring programs and their programming languages, presentation with multimedia, and designing attractive and effective user interfaces with an emphasis on recent software. This course is an elective for 3rd and 4th year students spanning over the fall (first) and spring (second) semesters as ID313 and ID314, and the students taking this course have a variety of backgrounds, including but not limited to, industrial design. The second semester, for ID314, the students worked on industrial product presentations using new technologies. Starting from pen and paper, the students generated interactive presentations using video and touch screens, and tested the working interfaces and mechanical parts of the projects using virtual and augmented reality.

A total of 15 students worked on self-decided design projects for the course. There were three individual design projects. The students P1 and P2 carrying out these projects were 4th year industrial design students, and student P3 was a 3rd year industrial design student. Their projects were namely an infant nutrition device, playground equipment, and a self-checkout assistant. The rest of the projects were team efforts of three students each. Team T4 consisted of two 4th year architecture students and a 3rd year computer engineering student, working on a smart house ambiance device. T5 consisted of a 3rd year graphic design student, and 4th year architecture and computer engineering students, working on a tourism help center. T6 consisted of two industrial design students and a computer engineering student, all 3rd year, working on a makeup trial stand. T7 consisted of a graphic design student and two industrial design students, all 3rd year, working on a noodle vending machine (Table 5.1).

Table 5.1 Participants and projects developed during the course

Project No.	Members	Background	Year	Projects
1	Individual	Industrial design	4	Infant nutrition device
2	Individual	Industrial design	4	Playground equipment
3	Individual	Industrial design	3	Self-checkout assistant
4	Team of 3	Computer engineering	3	Smart house ambiance device
		Architecture	4	
		Architecture	4	
5	Team of 3	Graphic design	3	Tourism help center
		Computer engineering	4	
		Architecture	4	
6	Team of 3	Computer engineering	3	Makeup trial stand
		Industrial design	3	
		Industrial design	3	
7	Team of 3	Graphic design	3	Noodle vending machine
		Industrial design	3	
		Industrial design	3	

5.3 Methodology and Data Collection

In conventional research, researchers are expected to enhance their practices by utilizing propositional theory developed by other researchers. In action research, researchers are expected to enhance practices by learning from existing practices through action research, and to explain how and why the improvement occurred (McNiff, 2015). In the first part of the study, the goal was to examine the outcomes of existing practices in educational industrial design project presentations with the criteria devised from the literature review to turn tacit information about the gaps in the practice into explicit knowledge regarding the benefits of immersion brought on by MR technology. In the second part of the study, the goal was to come to conclusions about how the specified gaps in the practice would be improved as an initial cycle of improvement based on action and reflection. With the research, a cycle of analyzing, planning, acting, observing and reflecting has been completed.

The data for this study has been collected with participant observation. Marshall and Rossman (1989) define observation as "the systematic description of events, behaviors, and artifacts in the social setting chosen for study" (p.79). Dewalt and Dewalt (2002) argue that "the goal for design of research using participant observation as a method is to develop a holistic understanding of the phenomena under study that is as objective and accurate as possible given the limitations of the method" (p.92). Observing the participants in the integration of MR in industrial design in an educational setting has provided a holistic understanding. In this study, the researcher has acted in the role of observer as participant to collect data while taking a part in the group activities with the full knowledge of the researcher collecting data.

5.4 Project Calendar

The duration of the project process was 12 weeks (Table 5.2). Each class started off with the critiques of the previous week's assignment, and ended with a lecture and/or demonstration regarding the following week's assignment. The 1st week started with a project briefing, and an assignment was given for creation of initial ideas including sketches of three alternatives, as well as a mood board for product concepts. The 2nd week's class activity was narrowing down alternatives to one choice, and the assignment was creating a 3D digital model of the project, and preparing a UI screen for the most important features. The 3rd week's class activity was critiques of the previous assignment, and a demonstration on exporting 3D models to Unity. The assignment was the design of the environment, and obtaining good quality renders. The 4th week's class activity was critiques of the previous assignment, and a demonstration on GUI prototyping with Adobe XD and AE. The assignment was preparing a working UI prototype. In the 5th week, the previous assignments were critiqued, and the class activity was a demonstration for Marmoset software. The students were given the assignment of videos for advertising their projects. In the 6th week, the class activity was the presentation and critique of advertisement videos, and included a demonstration on investor presentations together with the relevant assignment. In the 7th week the students presented their assignments and attended a lecture on user testing. During the following week's national holiday, the students worked on their user testing assignment. In the 9th week, the students received feedback on their user testing and video presentations. The 10th week's class activity was a demonstration for online portfolios and interactive presentations, and the students were given the assignment of creating online portfolios. The 11th week included a demonstration on MR integration into presentations, and the students attended extra feedback and experimentation sessions in the 12th and final week as well. The course ended with in class video presentations as final submissions.

Table 5.2 Project calendar including class activities and assignments

	Class activity	Assignment
Week 1	Project briefing	Mood board for product concepts, initial idea generation: sketches of 3 alternatives
Week 2	Critiques, narrowing down 1 choice	3D model of project, UI screen of the most important features
Week 3	Critiques, exporting 3D models to Unity	Environment design and good quality renders
Week 4	Critiques, GUI prototyping with Adobe XD and AE	Working UI prototype
Week 5	Critiques, Marmoset demonstration	Video for advertising product
Week 6	Critiques, investor presentation demonstration	Investor presentation
Week 7	Critiques, user testing lecture	User testing
Week 8	National holiday	
Week 9	Critiques for user testing and video presentations	
Week 10	Demonstration for online portfolios and interactive presentations	Interactive presentations
Week 11	MR integration demonstration	
Week 12	Last critiques	VR presentation in industrial design department graduation jury

5.5 Assignments and Class Activities

The following sections will introduce the project briefing and assignments given to the participants. The assignments have been devised so that the development of the projects and the learning outcomes matched with the goal of interactive final student presentations and submissions enriched with MR. The submissions of each assignment acted as a prerequisite for moving on to the next assignment, with each completed submission acting as content for the interactive MR presentations. These assignments were mood boards and alternative concepts, 3D models of projects, environment design, working UI prototypes, advertisement videos, investor presentations, user testing, and interactive presentations (Table 5.3). The project started with a briefing, which was part of the *analysis* phase of the design process, with the learning outcomes of defining the problem, and examining of problem area/gathering of information. The creation of the mood boards and alternative concepts constituted the phases of *synthesis* and *evaluation*, and the learning outcomes were divergent problem exploration, brainstorming, and evaluating alternatives. The participants went through cycles of synthesis and evaluation in the second, third and fourth assignments by creating and developing based on feedback the 3D models of the projects, designing the environment, and the working UI prototype, to fulfill the learning outcome of converging towards the design solution. The fifth assignment of advertisement videos were a medium for design development, through design’s first iterations, and presented the embodied design. The students continued on with investor presentations and user testing to evaluate their designs and improve details, and for the last iteration cycle they created their embodied design. The participation level of the teams varied, with some of the teams completing every assignment, and some teams not completing all of the assignments (Table 5.4).

Table 5.3 Assignments

Assignments		Design activity	Learning outcomes
A0	Briefing	Analysis	Defining the problem, examining/gathering information (Cross, 2006)
A1	Mood boards and alternative concepts	Synthesis, evaluation	Divergent problem exploration, brainstorming, evaluating alternatives (Cross, 2000)
A2	3D models of projects	Synthesis, evaluation	Convergence on solution (Cross, 2000)
A3	Environment design	Synthesis, evaluation	
A4	Working UI prototype	Synthesis, evaluation	
A5	Advertisement video	Embodied design	
A6	Investor presentation	Evaluation	Improving details (Cross, 2000)
A7	User testing	Evaluation	
A8	Interactive presentations	Embodied design	Convergence on solution (Cross, 2000)

Table 5.4 Completion levels of each assignment by the teams

Teams	A1	A2	A3	A4	A5	A7	A8
P1	✓						
P2	✓	✓	✓				✓
P3	✓	✓	✓		✓		✓
T4	✓	✓	✓	✓	✓	✓	✓
T5	✓	✓	✓	✓	✓	✓	✓
T6	✓	✓	✓	✓	✓	✓	✓
T7	✓	✓	✓	✓	✓	✓	✓

5.5.1 Project Briefing

The project process started off with a briefing. The teams were explained as interdisciplinary groups of three, each member with different roles for division of labor. The projects were products with touch screens, and the emphasis was on the relations between the product and the environment, as well as GUI design. The examples given to students about product ideas were vending machines of products such as food, beverages and retail products like makeup, information kiosks for tourism purposes, navigation guides for shopping malls, interactive pavilions, unmanned cafes, and so on.

The final presentations were expected to include realistic depictions of the internal and external components to enrich the multimedia content. The UI prototyping phase included lectures and critique sessions, and discussions on user experience. The students also were expected to conduct user testing sessions to pinpoint problems in the usage scenario.

In the briefing, the importance of appealing to investors in presentations were emphasized in addition to the creative methods of visualization. Concepts such as elevator speeches, business models and customer acquisition were utilized to create the most realistic and appealing product presentation.

The goal of the course for the semester, as presented in the initial briefing, was to take part in the METU Department of Industrial Design Graduation Projects Exhibition that is held each year at the end of the spring semester, with an LCD touchscreen monitor and a VR device for viewing the projects in the exhibition space.

5.5.2 Assignment 1: Mood Boards and Alternative Concepts

Week 2 was dedicated for narrowing down the alternatives that the students prepared by critiquing their mood boards and sketches. The mood board was expected to be a visual literature research and a collection of inspirational images. The collection of images could be product examples fitting the criteria, and inspirations for the product's shape, color palette and material choices. With the inspiration from the mood boards, students were expected to sketch out three alternative concepts for their projects. The mood boards and the sketches of alternative concepts were evaluated based on the depth of exploration of the design brief, which was left vague on purpose to allow for creativity and creation of unique, futuristic concepts. The main criteria that the students had to meet were to develop large scale products with graphical user interfaces, where the considerations for the relationship between the user and the product as well as the product and the environment were to be emphasized in the following stages of development.

During class, the students presented their ideas, and interactive discussion took place for the selection of one idea. For the following week, the students were expected to complete the 3D model of their selected product concept, and submit the most important screen of their digital user interface.

5.5.3 Assignment 2: 3D Models of Projects

Week 3 started with student presentations of the previous week's assignment of creating a 3D model of the product, and one of the interface screens. The development of the 3D models continued in the following weeks. The submissions were evaluated based on the suitability of the scale of the products in relation to the human body, and the intended usage environment, as well as a basic initial drafting of the user interface to match the overall design of the product.

After critiques of the 3D models and interface screens, the students went along with a demonstration of exporting their 3D models to Unity to prepare for the next week's assignment of placing the product in its intended use environment.

5.5.4 Assignment 3: Environment Design

Week 4 started out with critiques of the assignment of creating a finalized scene and a realistic render where the 3D model of the product was placed in its intended use environment in Unity. Unity was selected for the integration of VR in the later stages of the project, and the students continued developing the environment design in the following weeks. The submissions were evaluated based on the level of success in achieving realism in the scene of the environment created to showcase the intended use environment of the product. The low polygon count was a necessary criterion for the future robustness of the MR scenes for the interactive presentations. HDR images were expected to be used in the environments so that the shading and reflections would be realistic in the scene. The scaling of the product in relation to the environment was another criterion in evaluating the submissions.

The important points that the students had to consider were,

- Not using Turkish characters,
- Collecting all pieces with the same material in the same layer in Rhinoceros, turning into mesh and joining, then deleting the originals of the meshes,
- Exporting as .fbx files with low polygon count,
- Placing a 1x1x1m cube in the scene on Unity to check the size accuracy of the model,
- Finding HDR images and using them by selecting the shape cube, lighting, source custom, cubemap in the inspector menu for creating realistic shading and reflections in the product, and
- Checking necessary settings for achieving realism in materials.

After the critiques, students attended a demonstration of GUI prototyping using Adobe XD and continued working on their UI prototypes for receiving feedback in Week 5.

5.5.5 Assignment 4: Working UI Prototype

Week 5 started out with a critique session on the previous week's assignment of creating a GUI for the products. The development of the UI prototypes continued in the following weeks. The assignment expected students to prepare a working user interface for their products using Adobe XD. Firstly, they were guided to place functional interface elements in XD in the Design section, then increase the number of artboards, and connect interface screens together by selecting the relevant settings in the Prototype section, where the Play button shows an interactive prototype of the interface. The submissions were evaluated based on the success level of the students in creating a detailed flowchart of the functions of the product, and adjusting steps of the interface based on the feedback received during class as well as in the user testing assignment so that the flow of the interface and the functions of the product were clear and easily understandable by the user.

After the critiques on the UI prototypes, the students attended a demonstration on Marmoset for creating realistic, high quality 3D renders for videos for the following week's assignment of advertisement videos.

5.5.6 Assignment 5: Advertisement Video

The students were expected to prepare an advertisement video for their product, such that someone who knows nothing about their product should be able to learn everything about it by watching this video. The videos were to be created using the previously submitted and further developed submissions for the assignments of 3D models of the product, realistic environment, and UI prototypes. The students were encouraged to write a script and prepare a storyboard to pinpoint exactly how they would convey the necessary information. The submissions were evaluated based on the level of information included in the video, such as the 3D animation of their product including moving mechanical parts or any other features, placing the product in a recognizable environment, completion of the user interfaces, supplementing the video with additional text or sound to give extra information about the product, enriching the video with music, using jump cuts instead of long camera movements, making sure that each scene does not linger for too long, keeping a cohesive visual style in all the scenes, making the font size and selection readable, and so on.

After the critiques on the advertisement videos, the students attended a lecture on giving investor presentations, and were given an assignment for a 20-minute presentation on their product to present in the following week.

5.5.7 Assignment 6: Investor Presentation

In Week 7 the students made their investor presentations in class and received feedback from each other acting as investors. The investor presentation was explained as a step beyond a student presentation in that it aimed to capture the interest of potential investors for the product to achieve funding. This presentation was used to potentially convince the investor that the product was worth putting into production, and that it would bring profit back to the investor. The visual identity of the product and the branding were expected to be finalized. The students were also expected to have considered the strategy of keeping the investors involved in the development and production process with regular meetings and reports, and set clear deadlines for each task so that the process could be quantifiable. The presentation was required to be a display of the design team's proficiency by mentioning their previous works, experiences of working as a team, division of labor, and so on.

The presentations were evaluated based on the success of integrating the advertisement videos into the investor presentations in a way that eliminated repetition and kept the listener's interest high. Other factors to consider were whether the product had unique features that made it stand out in the market and whether it was high end or not, as well as the matters of risk analysis, production of a prototype, distribution and marketing, profit percentage of the designer, and lastly the elevator speech, which is a 30-second version of the investor presentation.

After the critiques on the investor presentations, the students attended a lecture on conducting user testing for GUIs and were given the assignment of conducting a user test.

5.5.8 Assignment 7: User Testing

In Week 9 the students presented their user testing and advertisement videos. For the user testing the students were expected first and foremost to be as realistic as possible when completing the GUI, so that they could discover mistakes and missing pieces in their design. The students were to document their user testing process with videos and submit as a *making-of* style video at the end of the term, alongside their advertisement videos. This making-of video would include them working with paper prototypes, user testing, working on Adobe Illustrator or in Unity 3D and so on.

5.5.9 Assignment 8: Mixed Reality Presentations

The following weeks were allocated for demonstrating interactive presentation techniques based on the projects' particular needs, as well as the integration of VR into the final presentations. The students tried out several pieces of software and hardware. In the first session, the students used a bring-your-own-device method in presenting their products with interactive MR software on their mobile devices. The students went to Kreatin Studios in METU Technopolis for the second session to experiment with more complex MR systems. They used a headset to experience their MR scenarios. Their evaluation was based on how well they were able to use MR technology to present details of usage context, audiovisual feedback, and 3D fidelity. In order not to limit the students to the resources at hand regarding software and hardware, they were asked to formulate their finalized advertisement videos in a way that would depict what kind of information could be integrated into a MR system if they had full access to the technology. For both the interactive presentations and the advertisement video, the outputs of the rest of the assignments were used as digital content.

5.6 Outcomes of the Assignments in Development Stages

This section will cover a review of submissions made for these assignments with the aim of tracking the progress of the participants leading up to the interactive presentations of their projects. The review of investor presentations will be omitted, as the assignment was only a class discussion activity and the participants have not made any hard-copy submissions. The review of the user testing assignments will be presented along with the working UI prototype assignment. The interactive presentations and the finalized advertisement videos will be covered in the following section. As P1 only completed the first assignment, their participation in the study is excluded from the review. The order of the reviewed projects has been decided based on the completion level and depth of the submissions for the assignments.

The methodology of the review includes an overview of the project submissions and an analysis of their visual content. The submissions for the assignments have been reviewed in order of completion, and described along with the submissions themselves. In the analysis, the content of the design ideas and how they are represented have been investigated according to the criteria in the analysis framework developed for the first part of the study. The review is mostly descriptive with additional commentary on how the criteria in the analysis framework regarding usage context, audiovisual feedback and 3D fidelity has been met.

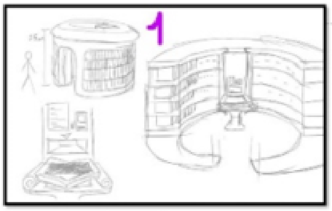
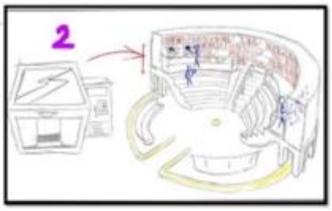
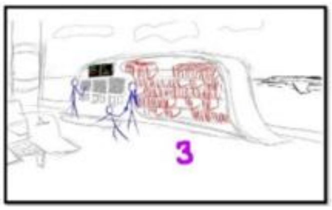
5.6.1 Team 6

Team 6 (T6) consisted of three 3rd year students; one from department of computer engineering and two from department of industrial design. Their project was a makeup trial stand for department stores.

5.6.1.1 Assignment 1

T6 created sketches and mood boards for three separate ideas (Table 5.3). Concept 1 was a futuristic make up stand inspired by the makeup stands in department stores. The concept eliminated the need for a department store worker suggesting cosmetic products to potential customers and moderating the trying on process by automating the process of selection with an interface that enabled the customers to virtually try on the products. The mood board documented inspiration sources from makeup products and fashion items for a color palette of silver and blue, and interface examples where customers try on cosmetic products on online stores from their internet browsers. The idea was to combine the makeup simulations on internet browsers with in-person shopping experiences. Concept 2 was a library capsule with seating areas. Similar to the first concept, this capsule would house a selection of books where customers would browse and select books from an integrated interface without the help of a library worker, and use the amphitheater-like seating area to relax and read. The inspiration images in the mood board showed examples of reading and relaxing capsules similar to the concept, user interfaces of online libraries and bookstores, and a warm toned color palette of orange and yellow hues. Concept 3 was a check out and relaxation area for airports where passengers can track their flight information while waiting. The inspiration came from self-checkout stands in airports, and the problem of uncomfortable waiting areas and confusing nature of airport information regarding flight status and luggage control. The aim was to make the waiting period before flights smooth and enjoyable for the passengers. The color palette was shades of blue contrasting with yellow. The concept was embodied as a one-piece structure that combined self-checkout screens, flight status information screens, duty free shopping areas, and seating areas.

Table 5.5: T6’s mood boards and sketches for three alternative concepts

		
Mood board 1	Mood board 2	Mood board 3
		
Concept 1	Concept 2	Concept 2

T6 selected their first concept to continue with their project, and experimented with 3D CAD modelling, UI design, and form giving (Figure 5.1). They worked on form giving with sketches, and simplified the body of the shopping interface to be smaller, and containing either a small selection of makeup products, or just being an interface with the products stored elsewhere. They prepared some 3D models of the makeup stand that resembles an open cabin, a standing screen resembling the top portion of a vanity table, and a unit that combines a seating area in one side, and a touchscreen on the other side. They had also worked on some preliminary user interface designs for their airport stand which allowed customization for different types of users, with a radial button dispersion around the avatar of the user. They decided to adapt this interface concept into their selected product concept of makeup trial stand.

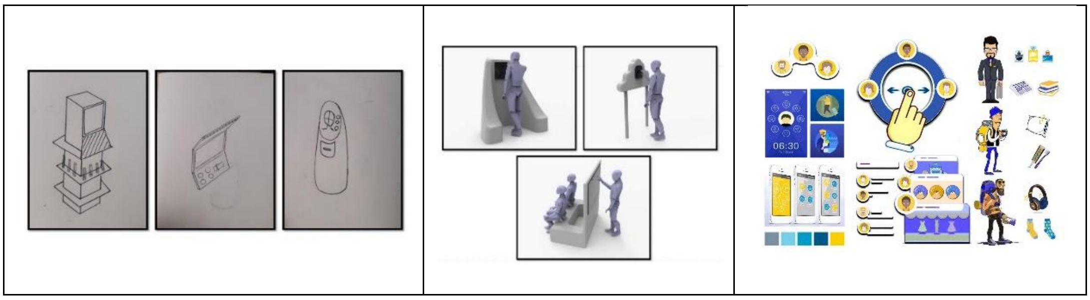


Figure 5.1. T6’s sketches of alternative forms, 3D CAD form giving trials, initial UI design iterations

T6 showed great success in exploration of concepts fitting the criteria of large-scale products with complex interactivity. By creating mood boards and sketches for each of the three alternatives they fulfilled the learning outcome of divergent problem exploration, brainstorming and evaluating alternatives. The team went above the expectations of the assignment by sketching alternative forms for their preferred design alternative, trying out 3D CAD designs and user interface details.

5.6.1.2 Assignment 2

T6’s makeup stand found form as interlocking makeup stands with reflective and transparent materials, with the upper section working as both a mirror and the user interface (Figure 5.2). The form of the makeup stand had flowing organic lines that were emphasized by the interlocked placement of two stands, and the colored sections of the body of the units that separate the touch screen interface for makeup trials. The reflective top section of the stand would act both as a mirror for the user to be able to see their face, and as an interface for simulating the makeup selection overlaid on the user’s face to color-match the products to their skin tones.

T6’s work on the assignment of creating a 3D model and an initial draft of an interface screen received positive feedback. The height of the model was designed so that the interactive reflective panel at the top half of the stand coincided with the viewing height of a user. The design of the interface matched with the flowing curvatures of the makeup stand, and a harmony in style has been achieved with the use of the blue color in the interface and the stand.

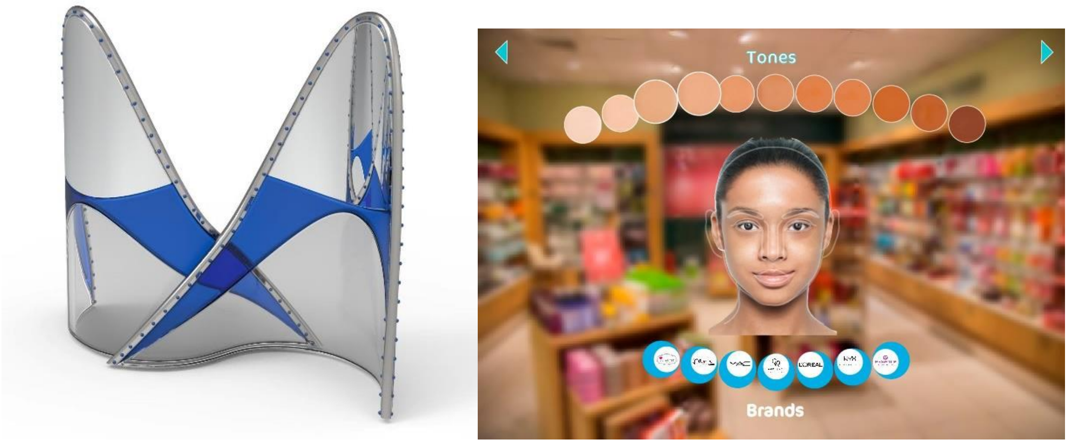


Figure 5.2. 3D model and user interface of T6’s makeup stand

5.6.1.3 Assignment 3

T6 continued on improving the 3D model of their makeup stand project. They experimented with materials, textures, lighting and interface details (Figure 5.3). Instead of using transparent material and reflective surfaces all around the stand, they decided on using a combination of brushed metal surfaces, reflective metal surfaces in blue, and a mirrored surface for the user interface that overlays makeup product application on the user’s reflection. The design showed improvement in the form of lighting around the edges to achieve better visualization of the user, and the placement of the UI elements on the screen. The product is shown in a store setting alongside display shelves.

T6 was successful in achieving realism in the scene of the environment showcasing the intended use environment of the product, namely a department store. The department store is depicted as a room with floor and wall tiles, and product shelves. The scale of the makeup stand is realistic compared to the shelves and the overall size of the room. The reflections and shading of the makeup stand did a satisfactory job in depicting the difference of materials in the different sections of the product. The environment design lacked makeup products stored in the shelves, and a checkout counter.

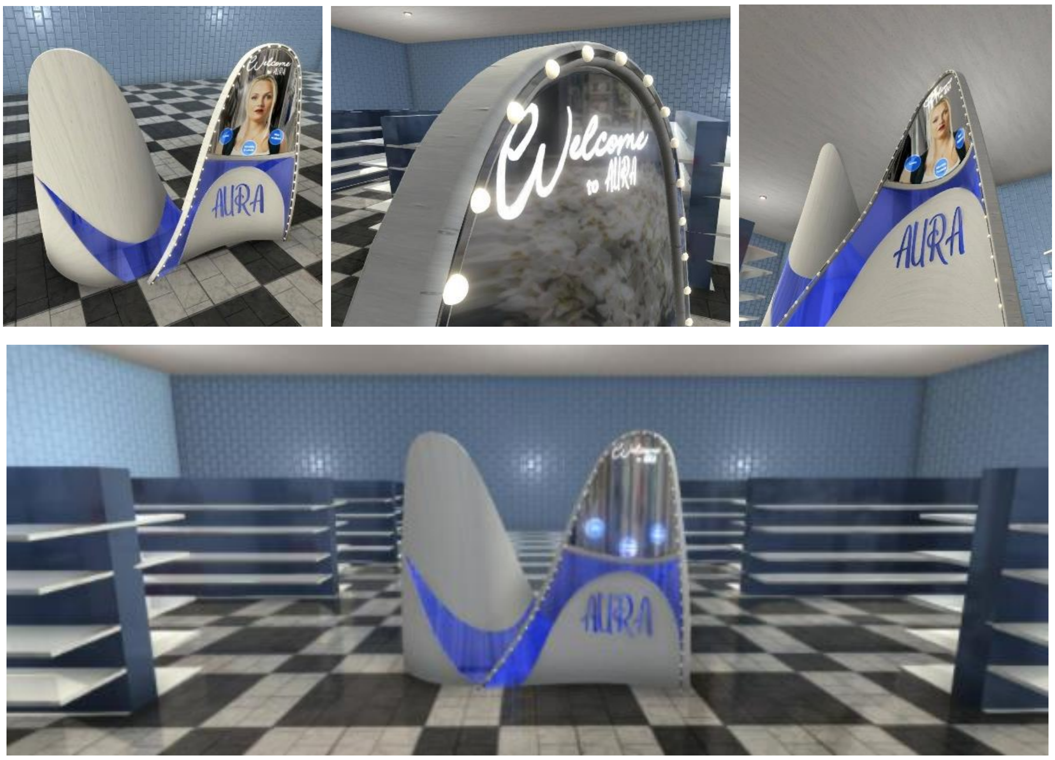


Figure 5.3. 3D model of T6's makeup stand placed in a store environment

5.6.1.4 Assignment 4

T6 decided to simplify the stand by using only one standalone product instead of two intertwining stands. They also settled on a material combination of purple and rose gold brushed metal combined with an interactive reflective screen.

The team improved the user interface overlaid on top of the mirror's reflection that allows the user to try on different types and shades of makeup products, and conducted user testing (Figure 5.4). In this iteration, the relations of size between the user and the stand is depicted in a more realistic way. The user interface was designed to show up and activate when the user comes near the stand, and the buttons on the touch screen surface show options to select different types of products with arrows that enable scrolling. The interface had buttons for selecting a product and going back to the home page. This iteration of the user interface was found to be too condensed and confusing due to including several different types of products in one screen. The team continued on developing their design for the interface in the following weeks.

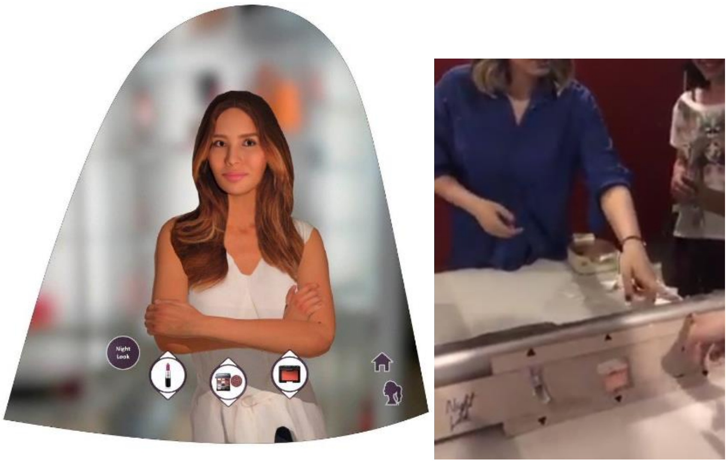


Figure 5.4. T6's makeup stand interface for selecting makeup products to try on

5.6.2 Team 5

Team 5 (T5) consisted of a 4th year student from department of computer engineering and a 4th year student from department of architecture, as well as a 3rd year exchange student from department of graphic design. Their project was a tourism help center for city squares.

5.6.2.1 Assignment 1

T5's alternative concepts were virtual real estate stalls for new construction projects, interactive pavilions relating sound waves with light games, and AR applications for revitalizing history (Figure 5.5). For the virtual estate concept, the team took inspiration from existing AR apps working on mobile devices and HUDs that display full scale and scaled down 3D models of buildings and furniture overlaid on top of real environments or on paper. Their idea was to use AR technology of viewing buildings in their intended building sites for commercial purposes in new construction projects. For the interactive pavilion concept, the team looked at examples of large-scale art installations that relate sound waves with colorful light games in shades of cool colors such as blue, purple and pink. For the tourism AR concept, the team took inspiration from AR apps that revitalize history by showing full versions of historical ruins overlaid on top of existing remains in museums or archaeological sites, and historical versions of cities. They ended up selecting the AR tourism stand concept, and developed the concept to be a stall with a white room and a screen for interaction. The customers would be able to see tourist attractions such as iconic buildings from the outside in the UI, combined with the floor number of the building as well as the ticket price and purchase options displayed on the screens. The team experimented with the form of the pavilion to be either rectangular, or rounded. (Figure 5.6).

T7 was successful in diverging into three alternative concepts, all fitting into the criteria of unique concepts with large scale embodiments with graphical user interfaces that the user can walk around and interact with. Instead of moving on to the sketches of alternative concepts, the team selected the concept of a tourism help center, and created three alternative designs for this specific type of building.

Figure 5.5. T5's alternative concepts

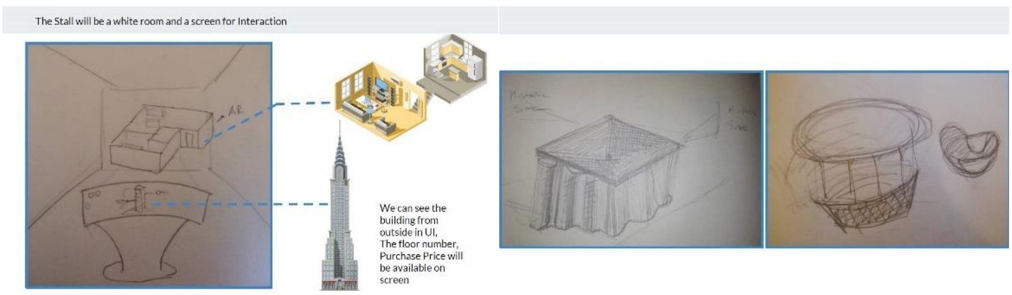


Figure 5.6. T5's sketches for the selected concept

5.6.2.2 Assignment 2

T5 developed a 3D model of their tourism center, and prepared an interface screen representing what the screens inside the building would be like during use (Figure 5.7). The team decided on a rectangular shape with rounded corners and a roof line that extends over the entrance and the walls. The emphasis on this project was the user experience of viewing a 3D rendition of the city with interaction possibilities to show different kinds of attractions as well as showing the user's placement in the city map, finding a location, extra information about the attractions, weather information and going on a virtual city tour. During the evaluation, the team's design for the tourism center building received positive feedback regarding the scale of the building and the design elements of screens and seating areas.

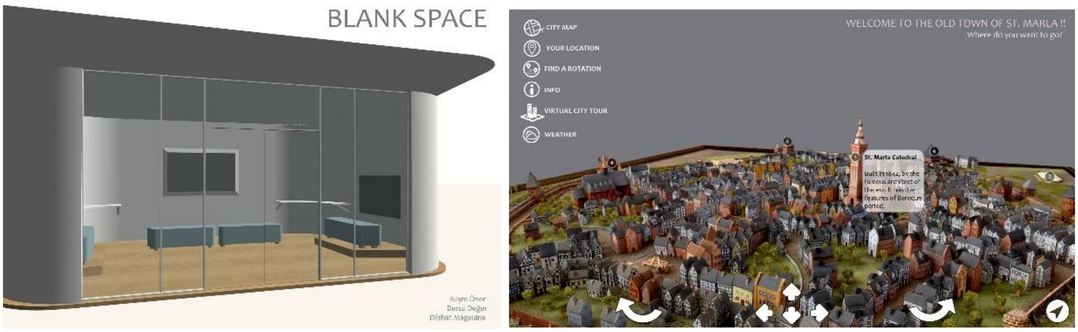


Figure 5.7. T5's tourism center design and UI

5.6.2.3 Assignment 3

T5 worked on the color and material selections in their tourism center project, and revised the size and placements of the inner screens, as well as adding a central control desk (Figure 5.8). The product is shown in a town square environment.

T5 was successful in achieving realism in the product design by improving the reflectivity, transparency and shading details in the scene where the product is shown in its intended use environment. In the background of the scene it is possible to see buildings in the distance, and the reflections of the town can be seen in the outside surfaces of the product as well as on the reflective surface of the central control desk.

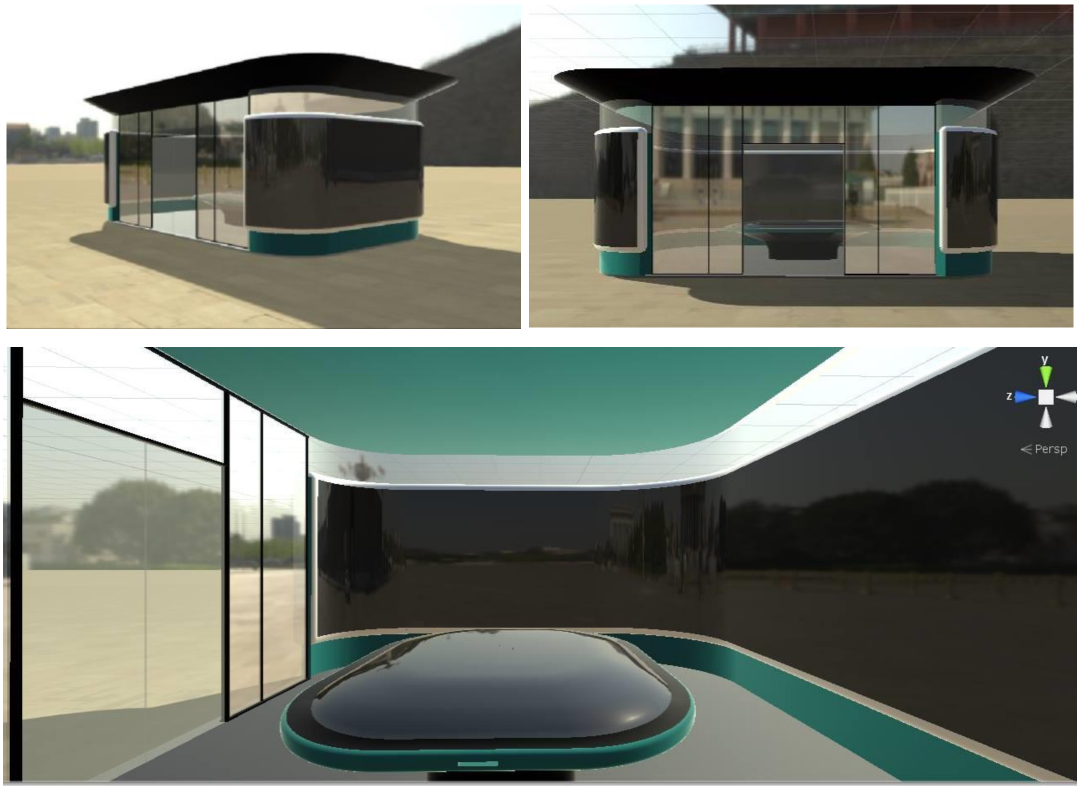


Figure 5.8. T5’s tourism center project placed in an outdoor environment

5.6.2.4 Assignment 4

T5 worked on the free-standing AR desk interface of their tourism center. On the table, the users can see tags overlaid on top of the city color coded for tourism attractions, cafés, restaurants and cultural activities (Figure 5.9). In the interface design, each blue dot represents a user situated around the control desk. When the user presses the button represented with the blue dot in the touch screen interface, a menu pops up that enables the user to select from a list of different types of attractions, and in the example depicted in the submission, select seats for an opera performance to buy tickets. The team did not prepare a full flowchart of the interface, but was able to achieve realism in creating a depiction of an information system based on AR information overlaid on a birds-eye view of the city in the central control desk.

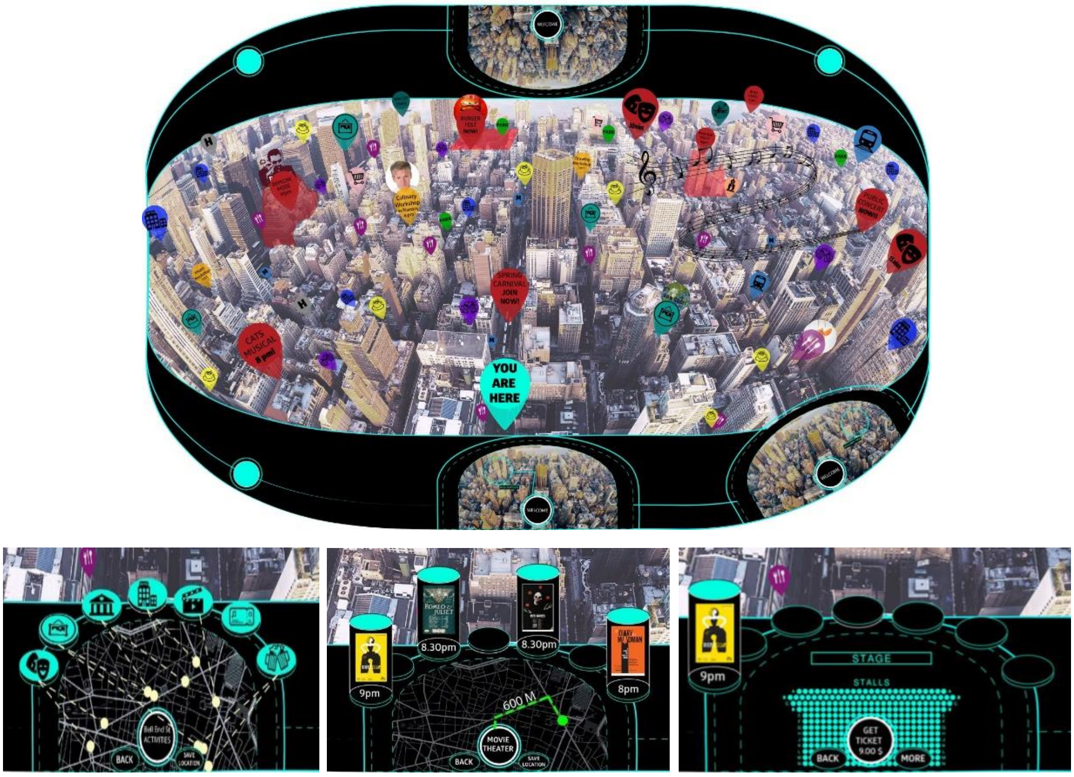


Figure 5.9. T5’s free-standing tourism center AR desk interface

5.6.3 Team 7

Team 7 (T7) consisted of two 3rd year students from department of industrial design, as well as a 3rd year exchange student from department of graphic design. Their project was a noodle vending machine for university campus buildings.

5.6.3.1 Assignment 1

For the form of the vending machine the team took inspiration from the classic Kikkoman soy sauce bottle, and the inverted truncated pyramid shaped carton container with interlocking closing tabs for ramen noodles with chopsticks sticking out; and for the interface, the team took inspiration from other high-end complex vending machines that enable customization (Figure 5.10). The team sketched out alternatives for the form and the interface, and decided on using the carton ramen noodle container as a visual metaphor to base the form of their vending machine on (Figure 5.11). The team did not fully diverge from their initial idea of a vending machine for noodles, and did not experiment with alternative concepts. Instead, they created variations of form based on visual metaphors.

Figure 5.10. T7’s mood board for the vending machine’s form and interface

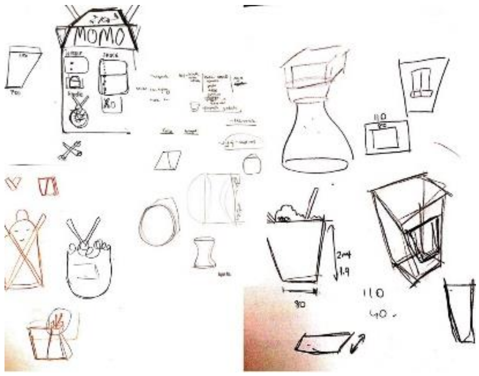


Figure 5.11. T7’s sketches of form giving ideas

5.6.3.2 Assignment 2

T7’s noodle vending machine design, after some experimentation with more traditional rectangular forms, ended up being shaped as a carton ramen noodle cup (Figure 5.12). The team used this metaphor of the carton ramen noodle cup for recognizability from a distance, and a touch of humor for getting attention. The color palette of the vending machine would be comprised of bright colors for added emphasis on visibility. The final form depicts the placement for the location where the customer's order would be placed. The team was able to translate their review of existing products into scaling the machine and placing the order output slot and the area for the screen at an appropriate height. The 3D model at this stage lacked realism due to lack of texture and material detailing, as the tabs on the top of the machine looked two dimensional.

Figure 5.12. T7's noodle vending machine design

5.6.3.3 Assignment 3

T7 continued on improving the 3D model of their noodle bending machine design. They revised the material choices of the vending machine to be more reflective, and placed the machine in an outdoor environment (Figure 5.13). The environment detailing lacked realism due to the objects in the background being too distant and zoomed out. It is not easy from the environment to discern that the machine is placed in an outdoor setting. For the user interface screen, the team submitted a full view of the front surface of the machine instead of the individual interface screens.

Figure 5.13. T7’s noodle vending machine in an outdoor environment (left), the front surface of the machine (right)

5.6.3.4 Assignment 4

T7 developed a GUI interface for their ramen noodle vending machine with actions such as selecting the type of noodles, spice mixture and sauces (Figure 5.14). They were successful in creating a working UI prototype where the user could go through the steps of selecting each choice to customize an order of noodles. The team tested their interactive prototype on a PC to get feedback from users about the flow of actions, and revised their design (Figure 5.15).

Figure 5.14. T7's ramen noodle vending machine interface

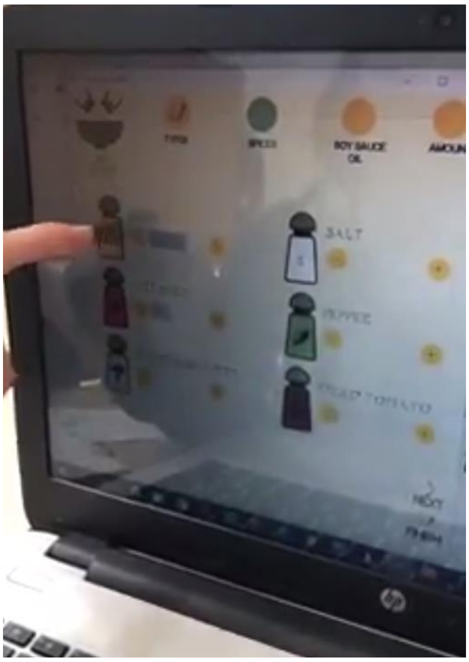


Figure 5.15. T7's user testing with working UI prototype

5.6.4 Team 4

Team 4 (T4) consisted of two 4th year students from department of architecture, as well as a 3rd year student from department of computer engineering. Their project was a smart house ambiance device.

5.6.4.1 Assignment 1

T4 created mood boards for two separate ideas. Their first concept was an interactive light installation working as a smart house system proposed to be installed in a student housing project in Ankara Bilkent Plaza (Figure 5.16). Their sources of inspiration were colorful and dynamic interior lighting controlled by mobile apps either with disguised light fixtures, or modular lights installed on the walls of a living room. They also looked at existing applications of smart house systems that control the opening and closing of curtains to adjust level of sunlight inside the house. They were planning to incorporate this concept into an existing student project they have developed for an architecture class.

Figure 5.16. Smart house lighting system

T4's second concept was an interactive exhibition space for a student project for Antalya Expo. Their inspiration sources were brightly colored interactive lighting applications used as art installations in the form of stands, pavilions and projections (Figure 5.18). They planned for this concept to be installed in an existing student project developed for the Antalya Expo building in an architecture class (Figure 5.18).

Figure 5.17. Interactive light installations in museums

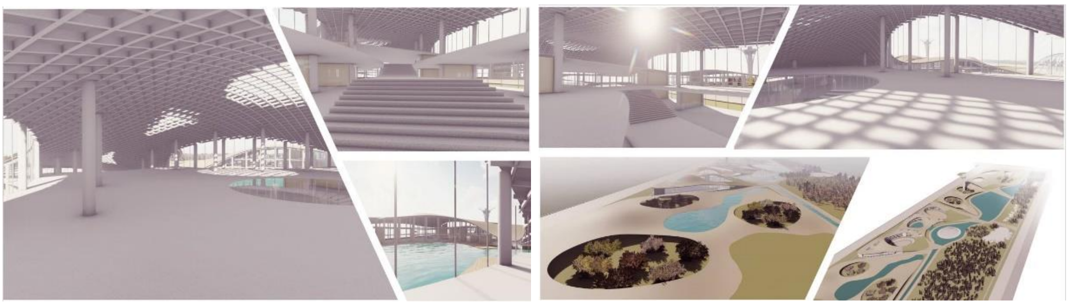


Figure 5.18. Student project for Antalya Expo building prepared for architecture class

The team was able to successfully branch out into two different ideas during the divergence design activity of creating alternative concepts, and were able to offer concrete applications for their design solutions by relating their ideas to their existing student projects. They ended up combining the two ideas to create a smart house light panel controllable with mobile devices.

5.6.4.2 Assignment 2

T4 created a 3D model for their smart house ambiance wall panel by creating an irregular network of polygons resembling a cell structure. Each cell in this design would have individual lights inside that would change color and create animations of graduating intensity of lights, controlled by a mobile app (Figure 5.19). Due to the nature of the product, the 3D design is not actually three dimensional, but is more like a relief on a wall.

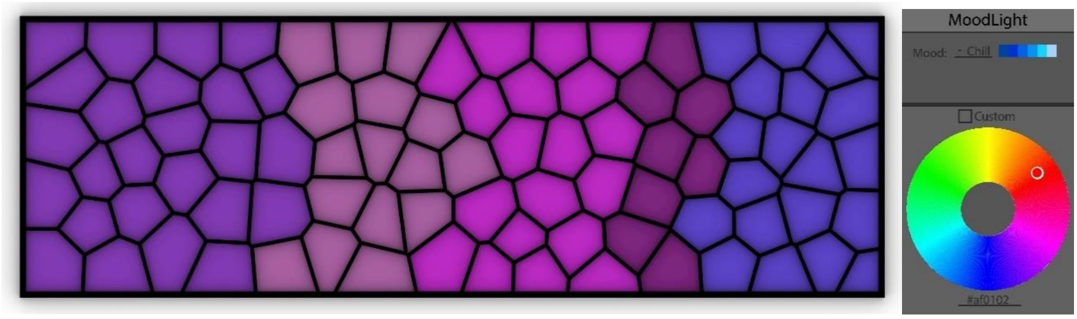


Figure 5.19. 3D model for smart house ambiance wall panel controlled with a mobile app

5.6.4.3 Assignment 3

T4 created a living room scene outfitted with furnishings such as shelving, couch, coffee table and large windows overlooking a nighttime city scene. The wall of the living room was the placement for their lighting panel project. The wall panel was shown with a color gradation glowing between purple and pink, and the light was reflected into the living room with cell-like partitions in the panel (Figure 5.20). They were able to achieve realism in the living room scene by including a variety of furnishings, having additional lighting above the seating area of the living room, and large windows that show reflections of the light panel as well as the environment outside with landscaping. The modular nature of the design allowed T7 to scale their product to fit the full height and width of the living room wall, achieving realism in size.

Figure 5.20. T4’s smart house ambiance wall panel placed in a living room environment

5.6.4.4 Assignment 4

T4’s smart house ambiance wall panel was controlled by a mobile app, and had predetermined color palettes to choose from, as well as a custom palette maker, and settings for animation (Figure 5.21). T4’s mobile app for controlling the light panel was fully developed and of professional quality. The layout of the buttons in the app and the variety of interactions were similar to existing app designs for controlling smart house devices.

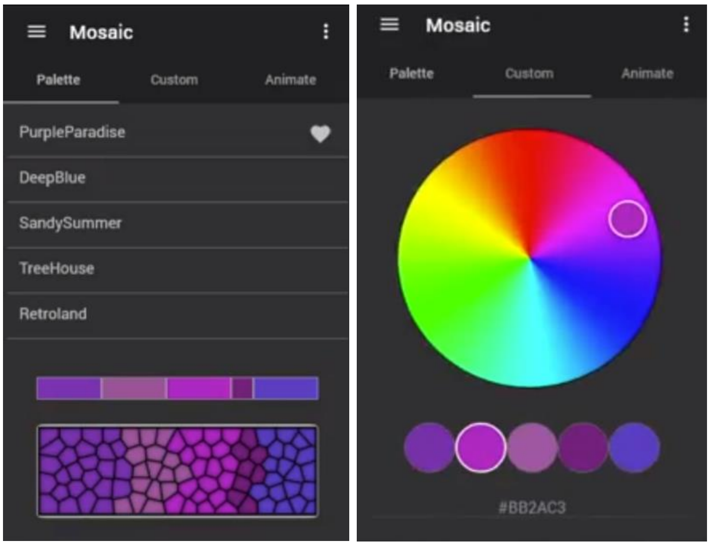


Figure 5.21. T4’s smart house ambiance mobile app interface

5.6.5 Participant 3

Participant 3 (P3) was a 3rd year industrial design student. Their project was a self-checkout assistant robot.

5.6.5.1 Assignment 1

P3's inspiration for the functionality came from self-checkout counters that are in use in some grocery stores, where the user can scan the items they want to buy one by one on the scanner, and place them in the bags themselves; and the inspiration for the form of the product came from décor objects with organic shapes (Figure 5.22). P3 was inspired by the digitization process of Amazon stores where the customers only have to have the store's app installed on their phones, simply scanning the items on their phones, and walking out of the store without even checking out; as the app would register the items as bought and charged the customer's payment cards that are saved in the app. The idea P3 developed was a personal shopping assistant robot that served this purpose with a touch of humor and animism, to combine the functionality of a self-checkout stand with a shopping cart to carry the items (Figure 5.23). P3 decided on their concept without diverging into alternative concepts for their design.

Figure 5.22: P3's functionality and form mood board for a self-checkout assistant

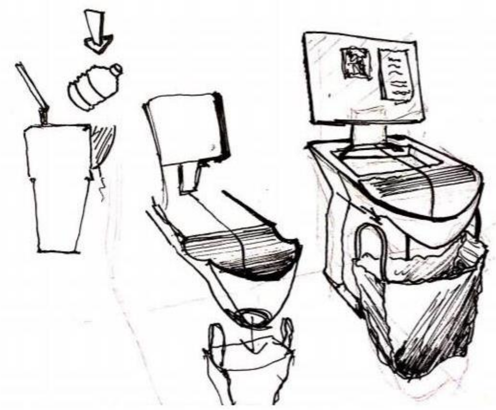


Figure 5.23. P3's sketches for a self-checkout assistant robot

5.6.5.2 Assignment 2

P3's 3D model for the self-checkout robot was initially a highly futuristic design resembling a UFO (Figure 5.24). This robot would follow the customers in a store by flying behind them, and the internal volume where the customer would place the products in was made visible with transparent areas cut out from the reflective metal body. In this submission, P3 focused on artistic depictions of their 3D model.

Figure 5.24. P3's initial 3D model for self-checkout robot concept

5.6.5.3 Assignment 3

P3 adjusted their 3D model by turning the robot into an enclosed egg-like shape with an opening to act as a receptor for the customer's shopping items. They also added lighting strips along the body as a form of visual feedback, and decided that the robot would work with voice activation. For the submission of environment design, P3 placed the robot next to shelving units stacked with products to simulate a grocery store environment. The scaling of the robot matched with the size of the shelving and the products stacked on the shelves. The environment lacked realism otherwise due to the lack of a wide angle shot, as the robot is pictured as backed up into a corner (Figure 5.25).

Figure 5.25. P3's self-checkout assistant robot in a grocery store environment

5.6.6 Participant 2

Participant 2 (P2) was a 4th year industrial design student. Their project was playground equipment for city parks.

5.6.6.1 Assignment 1

P2's mood boards included themes of bright colors and organic lines, modularity and visibility at night (Figure 5.26). The inspiration sources were collaborative playground equipment that exists in children's parks, gaming arcades, water parks and climbing courses for children. The color palettes P2 prepared had bright colors that resembled rainbows. In the mood boards, there were examples of playground equipment that glow in the night as well, in the same bright color schemes. P2 has sketched three different alternative playground sets for three different kinds of games: hide and seek, freeze tag and shadow tag (Figure 5.27). The hide and seek game was played with design elements that provided half-covered rotating concave shapes children can hide behind and promoted strategic thinking from the children to figure out the safest hiding places, and tagging units with LED lighting and buttons. The freeze tag game was a tagging experience set where children would pass through standing circles with sensors and LED lighting. The sensors would detect when someone passes inside the circle, and the LED lighting would change its color to red or blue. The circular units would also be used as outdoor furniture. The shadow tag game included playground equipment that teaches the concept of shadows to children with sensors detecting the density of shadows and buttons for tagging each other and climbing.

Figure 5.26. P2's mood board with themes of bright colors and organic lines, modularity and visibility at night

Figure 5.27. P2's sketches for three different alternative playground sets for three different kinds of games: hide and seek, freeze tag and shadow tag

P2 was successful in their development of three alternative concepts by diverging into different modes of play with differently shaped playground units. They were able to translate their inspirations of bright colors, organic shapes and interactive lighting at night into their alternative concepts.

5.6.6.2 Assignment 2

P2's initial design for the playground equipment were for the second concept of freeze tag where the children would pass through circular units with LED lighting and sensors that changed colors (Figure 5.28). The submission for the 3D model of the design made it difficult to understand scale in relation to a child, and the sensors and lights were not easily discernible. P2 decided to change their concept and continue working on their first idea of hide and seek.

Figure 5.28. P2's 3D model for freeze tag playground equipment

5.6.6.3 Assignment 3

P2 created models for the hide and seek concept consisting of arches and seating units acting as hiding spots (Figure 5.29). They created an outdoor playground environment with trees and silhouettes of children playing amongst the playground equipment. The scale of the equipment was consistent with the children and the trees that surround them.

Figure 5.29. P2’s playground equipment in an outdoor environment

5.7 Outcomes of the Mixed Reality Presentations and Videos

The students experimented with a variety of VR software and hardware for their mixed reality presentations. In the earlier stages, the students took on a bring-your-own-device approach and presented their products in interactive VR software on their smartphones. In the second session for experimenting with more complex MR systems, the students visited Kreatin Studios’ office in METU Technopolis to experience their AR scenes in an Oculus Rift VR headset. Kreatin Studios is the course instructor Emrecan Çubukçu’s firm creating interactive experiences for museums and exhibitions ranging from large scale projections to hand-held devices, and touch screen kiosks to VR systems. The visit took place on 23.05.2019.

The students were asked to finalize their videos to show what they have not been able to achieve with the computing power of the MR systems available to them, by using scenes created and rendered in Unity, parts of which were used in their interactive presentations.

5.7.1 Team 6

T6's makeup trial stand model was placed, rotated and scaled to size in the class environment to achieve the integration of computer-generated graphics into the real environment to complete an immersive and interactive AR presentation for and with the other students and the instructors. The team was able to incorporate their 3D models developed into their interactive experience. The AR presentation provided benefits of experiencing and communicating the user and product interaction, as well as seeing the product in a real-world environment (Figure 5.30). In this interactive presentation, the 3D fidelity characteristics of scale, material quality and component detailing can also be seen.

Figure 5.30. T6's makeup trial stand 3D model placed in a real environment

5.7.1.1 Video

T6's video started out with rotated views of the makeup stand in a store environment, with extra information texts added. Then the user walks up to the stand and operates the interface to try on makeup products. The video also shows detail shots and the exploded views of the product. (Figure 5.31). The environment is presented just as a background photo, but the level of realism in presenting the usage scenario, the interaction of the user and the product, and the 3D fidelity attributes of material qualities and component detailing are well presented.

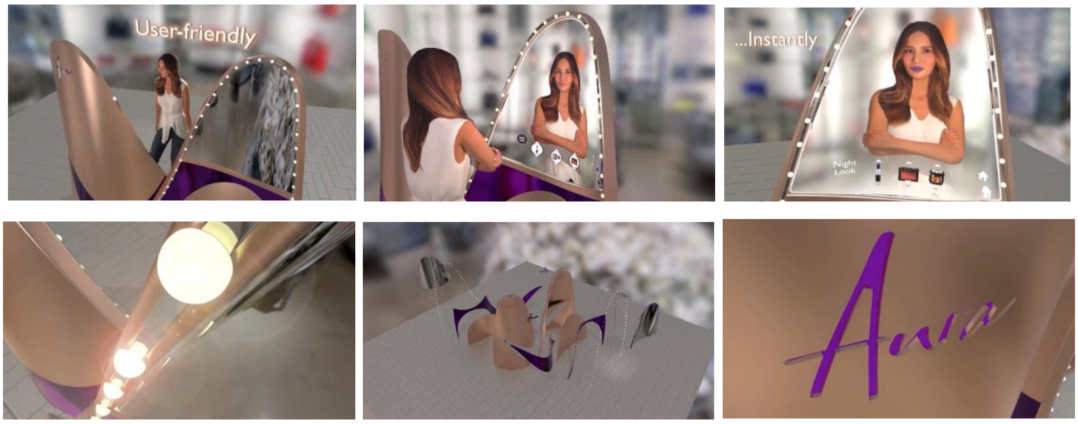


Figure 5.31. Screenshots from T6's video of the user trying on the makeup products via the screen

5.7.2 Team 5

For their interactive presentation, T5 placed the 3D model of the tourism stand with its completed see-through interactive windows and the control desk firstly in the classroom, then went outside to demonstrate the full size of the building in a parking lot so that the viewer could walk around and see all of the features of the design from the inside and the outside (Figure 5.32). The use of the parking lot area as a background created a very realistic feel in terms of environment and user product interaction, as well as providing a full-scale product simulation. The user interface details are also visible in the AR scene. In the later sessions with the HUD, T5 experimented with navigating the tourism help center's control desk interface (Figure 5.33).

Figure 5.32. T5's interactive AR presentation inside the classroom and the parking lot

Figure 5.33. T5 navigating the tourism help center control desk interface with Oculus Rift headset

5.7.2.1 Video

In their video, T5 placed their tourism center in a city square at night setting with surrounding users looking at the outside screens, and showed the building from all angles on the exterior and the interior, supported by text annotations for extra information (Figure 5.34). In the video, the usage scenario is carried out by a user as they search for tickets through the interface. The internal components of the tourism center are shown in exploded view, and the outside screen interface is also explained through annotations. The lighting of the nighttime environment depicted in the background matches with the glowing lights of the center as it would be seen during nighttime.

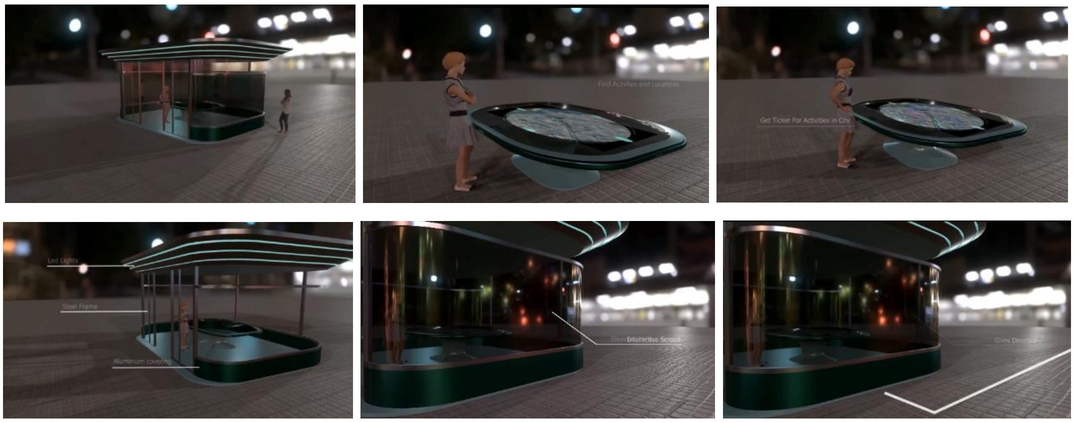


Figure 5.34. Screenshot of T5’s video showing tourism center in a city square with text annotations

5.7.3 Team 7

T7 observed the noodle vending machine at a distance, as well as up close (Figure 5.35). They were able to place their 3D model in their AR presentation, but had technical difficulties with the orientation of the 3D model (Figure 5.36). With their presentation, they were able to show the true scale of the product in relation to the user and the environment.

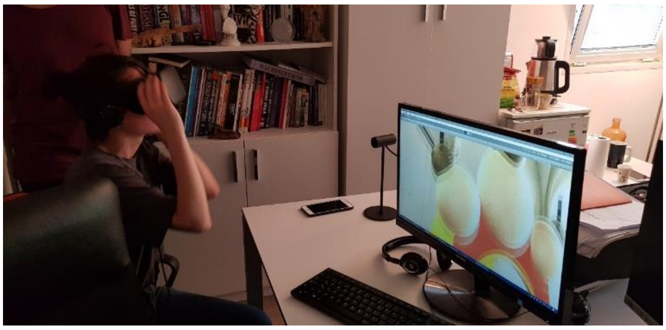


Figure 5.35. T7 viewing the noodle vending machine up close

Figure 5.36. T7's AR scene with the vending machine model placed in a real environment

5.7.3.1 Video

T7 started their video with a studio view of their vending product with text for additional information. Then a classroom scene is depicted, where the user takes a break from studying, and goes up to the vending machine for noodles. The user interface is shown as a separated scene where the user selects customization options of their noodles. Then the user is shown receiving the cup of noodles from the slot (Figure 3.37). The team adopted a cartoonish visual style in their video to match their cartoonish metaphor of using a noodle carton as the inspiration for the body of their vending machine. They were able to communicate details such as the usage scenario, user and product interaction, environment detailing, and user interface detailing.

Figure 5.37. Screenshots from T7's video

5.7.4 Team 4

T4 overlaid the panel on top of a wall in the classroom environment using a VR app (Figure 5.38). They were able to present details relating to how the product relates to the users and the environment in matters of scale and component detailing. They were able to see animations of light as well.

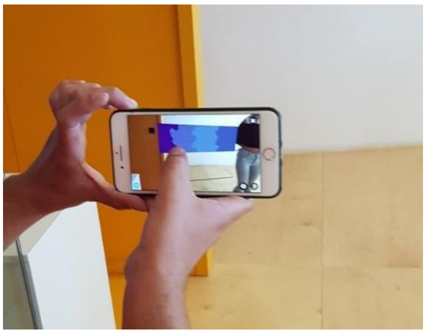


Figure 5.38. T4’s interactive AR presentation for the smart house ambiance panel

5.7.4.1 Video

T4’s video started with the user entering a living room where the smart house ambiance panel installed on the wall, and going through the mobile app to change the color of the lights in the smart house ambiance panel. The glowing animation of the light panel is shown with additional text information, as well as different color alternatives (Figure 5.39). Their video also showed an exploded view of the panel, depicted additional users as silhouettes, and a furnished living room scene illuminated by the glowing color gradations of the smart house ambiance panel (Figure 4.40)

Figure 5.39. Screenshots from T4’s video of smart house ambiance panel being controlled by the user via the mobile app, and the color options

Figure 5.40. Screenshots from T4's video showing the users around the panel, and color gradation effects in a furnished living room

5.7.5 Participant 3

P3 used augmented reality on smartphones to present a self-checkout assistant in a real environment, firstly as an interactive presentation for and with the other teams and the instructors (Figure 5.41). He placed the 3D model of his design and scaled it to actual size, and created an engaging AR presentation to capture images where the robot is actualized in the real environment and with users. P3 then presented their robot in the cafeteria environment following a user towards the payment stalls (Figure 5.42), for capturing maximum realism in terms of environment and usage scenario.

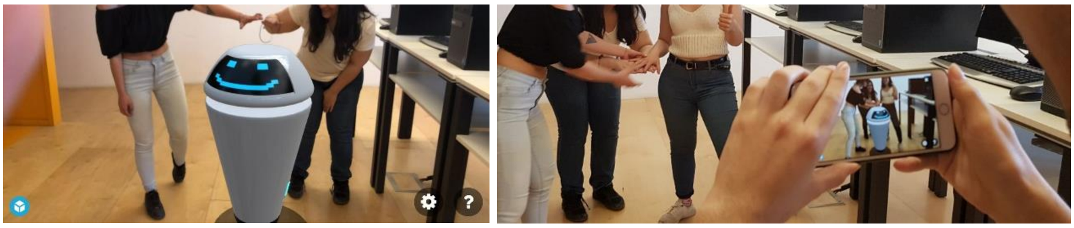


Figure 5.41. P3's interactive AR presentation of self-checkout assistant for the other teams and instructors

Figure 5.42. P3's interactive AR presentation of self-checkout assistant in a store-like crowded environment

5.7.5.1 Video

P3's video showcased the component detailing, material quality, voice activation and the movement of the device, with minimal text explanations (Figure 5.43). The voice activation detail was given as textual information, and not audiovisual feedback.

Figure 5.43. Screenshots of P3's self-checkout assistant video showing voice interaction and movement

5.7.6 Participant 2

In their interactive presentation, P2 has placed their playground equipment in full scale on a park environment (Figure 5.44) so that the viewer could walk around the elements of the design. P2 had problems with the usage of a platform in the 3D model, as it blocked the view of the realistic environment. P2 also had problems with placement of the model in terms of height.

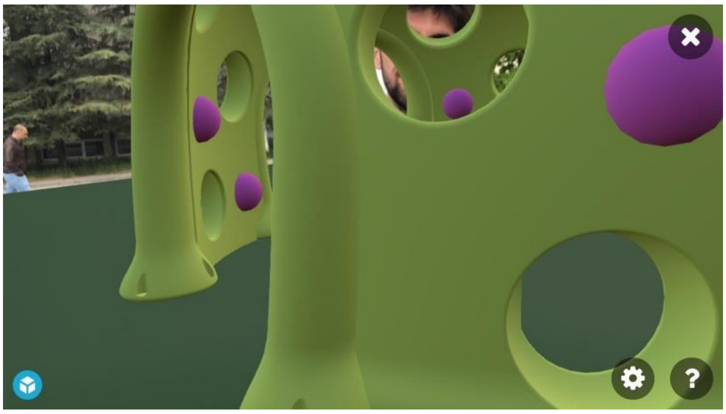


Figure 5.44. Interactive presentation of P2’s playground equipment placed in a real park environment

The students were also expected to present their projects in which the experience of using the product would be presented using MR technology. P2 was able to achieve this goal by including an interactive VR experience in their graduation project jury.

P2’s outdoor playground equipment providing safe hide and seek experiences for primary school age children encouraged players to hide in ways encouraged by the shape and function of modules in the playground (Figure 5.45). Technologically supported equipment enables children to think strategically while increasing their social interaction and physical development. The multifunctional modules provide safe hiding experiences during day and night.

As announced in the initial briefing of the project regarding integrating an interactive VR presentation into the METU Industrial Design Graduation Project jury, P2’s playground equipment project was presented with the VR headset Oculus Rift (Figure 5.46). The device was obtained from the course instructor Emrecan Çubukçu from Kreatin Studios in METU Technopolis. The viewers experienced the VR scene consisting of a full playground set with a variety of play modules in a studio setting, as depicted in the presentation board.

Figure 5.45. P2’s playground equipment presented in the VR experience

Figure 5.46. Interactive VR experience presenting P2’s playground equipment project to the members of the graduation jury

5.8 Findings of the Participant Observation Study

The submissions for the mixed reality presentations and the videos have been analyzed separately based on the visual analysis framework developed from the literature review findings introduced in Chapter 4. The first analysis criterion is representation of *usage context*, in which the submissions were analyzed based on their success in transcending the shortcomings of traditional presentation methods with regards to representing the product in context, the user and the product, and the usage scenario. Second criterion is *audiovisual feedback*, in which the submissions were analyzed on the representation of lights, sound, and info screens and GUI. Lastly, the submissions were analyzed under the *3D fidelity* criterion of scale representation, material quality and component detailing. The instances where the participants have used MR related technology and content to answer the shortcomings of traditional representation methods have been analyzed. The findings will be interpreted based on the criteria for which MR technologies have been found the most helpful. The outcomes have been thematized into six categories that will provide strategies on how MR could be integrated into industrial design education.

5.8.1 How could MR affect the project briefing, outcome expectations and class structure?

Briefing: In the project briefing, the specifications of projects regarding scale and GUIs have been characterized by how MR could bring the most benefits. The type of product to be developed by the students are their own selections to arrive at a product that is unique in concept and execution. The students were given guidance in the form of product examples that fit the criteria of large scale and complex interactivity. Among these were customizable vending machines, information kiosks, etc.

Course conduct: The class structure was relatively casual, depending on in-class collaboration and hands-on demonstration of the steps leading up to the MR presentations. From the feedback they received on the first week, the students decided on the concept for their designs, and from the second week on they had already developed a 3D model. The early initial drafting of the digital content such as the 3D model, the environment design and the UI prototype allowed the students to move on through the steps rapidly, revising their design in each step. The casual and collaborative nature of the course conduct was deliberate to make the adjustment of using a new technology for the first time.

Outcomes: The end goal for outcomes were the MR presentations and video submissions. The setup for the MR presentations were Unity for developing scenes, 3D model of the product, and the Oculus Rift VR headset. One of the participants included an MR presentation of their graduation project during the graduation projects jury. The video deliverable for the final submissions were prepared in order to supplement the MR presentations and include details in the presentation that could not be sufficiently explored in MR.

5.8.2 How could MR affect the phasing of the process and the development of design ideas?

The participants attended demonstrations of each assignment to develop the MR scene. The participants' success in the MR presentations and videos show a correlation between the content expectations in each assignment and the final assessment criteria of *usage context*, *audiovisual feedback* and *3D fidelity*.

Usage context and 3D fidelity: In matching the assignments to fit the assessment criteria, the development of the assignment of environment design made sure that the representation of the product in context and scale in the MR presentations and videos were sufficiently developed. Similarly, the early development of 3D models in the second assignment made sure that the students had digital content to use in their MR scenes. With each new assignment the participants developed another aspect of their presentation, and improved the previous iterations through feedback and user testing. The participants excelled in the integration of MR into their final presentations in the aspects of product in context, user and product, scale, material quality and component detailing.

Audiovisual feedback: T4 and T6 were able to represent lights in their MR presentations as well, although not in the form of audiovisual feedback that is interactive. None of the participants integrated sound feedback in their MR presentations. The fact that the participants were more successful in representing the aforementioned product aspects than in representing lights and sounds points to a need of allocating specific assignments, demonstration and feedback sessions on audiovisual interactivity.

5.8.3 How would MR contribute to teamwork, distribution of labor and decision-making?

Out of all of the participants, the difference in performance between the team participants and the individual participants are striking.

Individual participants: P1 dropped out of the course after the first assignment, and P2 and P3 did not complete all of the assignments (Table 5.1). P2 and P3 also changed their design significantly between the assignments, which meant that design developments did not have time to accumulate towards the end. This is particularly evident in P3's video, which could be likened to a teaser trailer instead of a full product reveal as has been the case in teams 4, 5, 6, and 7.

Teams: In contrast, the teams were able to complete all of the assignments (Table 5.4). T4, T5 and T6 had exceptional success in the MR presentations and the videos. This was arguably due to division of labor and the intense workload distributed among more than one person, the familiarity of the team members with each other due to having worked on projects together prior to this course, as well as the multidisciplinary nature of the teams, specifically the computer engineering students, giving the chance to each member to contribute with different sets of skills. The success of the teams in regards to the teamwork, decision making and problem solving regarding the UI prototypes, digital content management and use of MR technology have elevated their teams' outcomes in comparison to the participants who worked on their own. It should be noted that the graphic design students in teams 5 and 7 have also dropped out early in the project, teams 5 and 7 completed the course as two-person teams.

Table 5.6 Participants and projects developed during the course

Project No.	Members	Background	Year	Projects
1	Individual	Industrial design	4	Infant nutrition device
2	Individual	Industrial design	4	Playground equipment
3	Individual	Industrial design	3	Self-checkout assistant
4	Team of 3	Computer engineering	3	Smart house ambiance device
		Architecture	4	
		Architecture	4	
5	Team of 3	Graphic design	3	Tourism help center
		Computer engineering	4	
		Architecture	4	
6	Team of 3	Computer engineering	3	Makeup trial stand
		Industrial design	3	
		Industrial design	3	
7	Team of 3	Graphic design	3	Noodle vending machine
		Industrial design	3	
		Industrial design	3	

Table 5.7 Completion levels of each assignment by the teams

Teams	A1	A2	A3	A4	A5	A7	A8
P1	✓						
P2	✓	✓	✓				✓
P3	✓	✓	✓		✓		✓
T4	✓	✓	✓	✓	✓	✓	✓
T5	✓	✓	✓	✓	✓	✓	✓
T6	✓	✓	✓	✓	✓	✓	✓
T7	✓	✓	✓	✓	✓	✓	✓

5.8.4 How would MR support project presentations by increasing immersion?

Spatial awareness: The MR presentations increased immersion in the representation of environment, correct scaling of the product, and the relation between the user and product. T5 achieved very realistic results by using AR to overlay their tourism stand on an open space so that the viewer can walk around the building. The success of their interactive presentation also came from a correctly scaled and positioned 3D model in the real environment. The VR presentations with the Oculus Rift HUD enabled the teams to present their designs in an immersive way by being able to show the true scale of the products in relation to the viewer and the environment developed in their scenes.

Contextualization: In their AR presentations, T6 was able to present the user and product in a realistic setting by placing the makeup stand in the classroom environment and overlay the 3D model of their product to look like a real person was interacting with the product. Their 3D model had good component detailing and material accuracy, which contributed to the sense of the product really being there. P3's AR presentation was also a good example of immersion in showing the self-checkout assistant robot near the entry stalls in the cafeteria, which closely mimics the environment of a crowded store. The other participants also had successful AR presentations.

Real time interactivity: T7, T5 and P2 had some problems with positioning and scaling, which were eventually solved due to the interactive nature of the AR software enabling them to make on site changes to the size and position of the 3D models.

The observations regarding MR supporting student practices echo the affordances of virtual learning environments Scavarelli, Arya and Teather (2021) have cited based on learning theory perspective: enhanced spatial knowledge (Dalgarno and Lee, 2010), improved contextualization of learning (Steffen et al., 2019), multiple frames of reference for seeing objects and environments from different perspectives (Erickson, 1993; Bertrand et al., 2018) and immersive 3D presentations (Heeter, 1992; Witmer and Singer 1998).

5.8.5 How could MR be helpful in providing interactivity for the presentations?

Embodiment and empathy: The interactivity provided by the MR presentations had the benefit of not only representing the user and product relations, but also simulating the basic attributes of the products and creating a sense of being right next to the design. In the sense that the viewer can place the product and scale it to size, walk around the 3D model of the product and get a closer look on the component detailing and material qualities of the design; the use of MR upgraded the presentations into an interactive experience. The observations of student work regarding MR providing interactivity echo the aforementioned affordances of virtual learning environments that Scavarelli, Arya and Teather (2021) have cited based on learning theory perspective, as well as the affordances of embodiment and empathy: the virtual body interacting with a virtual environment is an essential part of presence (Biocca 1997; Slater 2009) and learning (Johnson-Glenberg, 2018), and embodied cognition allows the viewer to empathize with another person's experience (Bertrand et al., 2018).

Usage scenario: The MR presentations were lacking in interactivity in regards to the GUIs of the products. The viewer can perform the basic acts of walking around and observing the product, but they are not able to actually interact with the products' interfaces. The audiovisual feedback of lights and sounds were also lacking in the presentations. The reason for the staticity of the MR presentations is limited software and hardware access, as professional MR scenes have the option of displaying animations and videos. Teams 4 and 7 tried to negate this problem by including the full usage scenarios and the GUIs in their videos. The takeaway is that in this study MR has increased interactivity in student presentations in regards to basic representation of the user and the product by simulating a use environment, but the lack of access to better hardware and software meant that the usage scenario could not be represented, and usage testing could not be conducted in detail in the MR presentations. Guiding students in more concrete ways such as adding an interactivity step to the assignments would be helpful in this regard in future studies.

5.8.6 How could MR setups be scalable in an educational context?

Hardware and software setup: The teams used two kinds of MR setups. The first was an AR setup consisting of mobile phones and 3D models created in Unity. The second setup was Oculus Rift HUD with the same 3D models. The AR setup depended on the participants' own devices and each team could make simultaneous presentations, whereas they only had access to one HUD and had to take turns.

Perspective of the viewer: The VR presentations were individual experiences where the viewer was isolated, and the rest of the group were not able to see what the viewer was experiencing. Because the AR presentations included the real environment and were not affixed to the viewer's immediate field of vision, the presentations took on a more collaborative nature where in addition to the person holding the mobile phone to show the AR scene, other people could act as models to simulate the user product interaction.

Mobility of the viewer: Another difference between the AR presentations and the VR presentations were the matter of location. Because the AR presentations were done with mobile phones, the teams were able to change location to improve their presentations. However, due to the casual setting of the Kreatin office visit for the VR presentations and there being only one HUD device permanently connected to the computer to access Unity, the viewers had to sit next to the computer and could not achieve full embodiment in the virtual environment. Experimentation with software native to the Oculus Rift such as Tilt Brush and Gravity Sketch enabled the participants to design 3D surfaces and shapes in real time and experience a higher level of interactivity also by having the freedom of using a bigger space and walking around without being connected to a computer. Based on Dalgarno and Lee’s (2010) research, scaling up the MR setup could grant richer/more effective collaborative learning and greater opportunities for experiential learning.

5.8.7 How could MR integration in an educational industrial design setting be documented for later reference?

Documentation: In the AR presentations, the ability to take screenshots and videos on the mobile phones solved the problem of gathering static visuals of the interactive experiences for further reflection and documentation. This has not been possible with the VR presentations beyond seeing the viewer’s point of view in the computer monitor connected to the headset. The fleeting and isolated experience of observing the VR presentations was an unforeseen drawback over traditional tools and methods of presentation, where the documentation is part of the presentation itself, in the form of presentation boards and mock ups. This problem could be solved by better strategizing how to document the experience, such as setting up a monitor so that the rest of the viewers can see what the HUD wearer is seeing, or recording videos of the VR walkthroughs.

Supplementation: The teams were made aware of the access to MR software and hardware and negated the disadvantages of limited access by supporting their MR presentations with an additional assignment/final deliverable of videos. T5, T6, and T7 showed in their videos product design characteristics of usage scenario, lights, info screens and GUI, component detailing and material quality, which were not sufficiently presented in the MR presentations.

5.9 Discussion

This chapter concludes the empirical study consisting of two parts. The first part of the study aimed at assessing presentations of design projects to find out the shortcomings of traditional design representation tools in presenting industrial design projects of large scale and complex interactivity. A total of 45 projects' presentation materials have been assessed based on a visual analysis framework with the criteria of the effectiveness in representing usage context, audiovisual feedback and 3D fidelity.

In the second part of the study, an interactive multimedia course has been devised around this visual analysis framework and the assessment of presentation materials to integrate MR in the design process to overcome the shortcomings of traditional design representation tools. In this course, the participants worked on unique design projects with large scale and complex interactivity as individual participants as well as teams. Throughout the course, they were given assignments to develop their MR presentations as they develop their designs. The participant observation has provided findings about how MR could affect the project briefing, outcome expectations and class structure, how MR could contribute to teamwork, distribution of labor and decision-making, how MR could support project presentations by increasing immersion, how MR could be helpful in providing interactivity for the presentations, how MR could be scalable in an educational context, and how MR integration could be documented in an educational industrial design setting for later reference. These findings have been presented as strategies on how MR could be integrated in the design process to enrich student presentations and overcome the shortcomings of traditional design representation tools.

CHAPTER 6

CONCLUSIONS

This thesis looks into the product development process and final presentations of industrial design students, as well as the use of MR technology as a supporting design representation tool in this process to improve the students' presentations. This chapter outlines the findings of the research by revisiting the research questions, describing the limitations of the study, and offering recommendations for future research.

6.1 Revisiting the Research Questions

The following sections will be outlining the answers to the research questions based on the findings from the literature review and the two-part empirical study.

6.1.1 How do educational industrial design projects typically progress, and what kinds of prototypes are created in the design process?

In the field of industrial design, the product development process can be summarized as a three-step cyclical activity that includes analysis, synthesis, and assessment in each cycle, with the finished product as the end result. The designer uses the design brief or any other information about the product in the analysis stage, then continues on to the synthesis stage to apply creative ways for developing a prototype of the product, and finally conducts user testing and collects feedback in the evaluation step. This three-step process occurs in cycles, with the product evolving from a rough drawing to a completely finished product. As a result, as the development progresses, the prototypes that emerge from the synthesis step become more and more high fidelity. Designers assess the data they have, synthesize by producing ideas and engaging in creative activities, then evaluate the results of their synthesis to obtain new data to analyze in order to better their ideas.

Prototypes are always used for synthesis and evaluation. Anything that results from the synthesizing processes can be called a prototype, and the idea is evaluated using that prototype. Prototypes can be anything from hasty sketches to fully established physical models. Physical models are typically low quality at first, but as the design progresses through review processes and the designer refines the design, the fidelity of the model rises. However, it may be impossible to illustrate all details of a product in a physical model unless a functioning prototype has been created for user testing.

6.1.2 What are the shortcomings of traditional design representation tools in presenting complex educational industrial design projects?

In both professional and educational industrial design practice, 2D, 3D, and digital design prototypes are created to demonstrate design details. It has been discovered that as design projects become more complicated in terms of scale and interactivity, representations become more problematic. Multimedia representations, which offer a higher resolution result, have been shown to overcome these challenges. New representational technologies can mitigate the limitations of high-fidelity prototypes, allowing designers to collaborate more effectively.

Difficulties that may develop while expressing audiovisual interaction and large-scale projects with presentation boards and mock ups are examples of complexity factors in educational industrial design projects. When evaluating the efficacy of traditional presentation methods, the information relating to usage context, audiovisual feedback, and 3D fidelity should be prioritized. Findings of the design project assessment study (Table 4.12) outline the shortcomings of traditional design representation tools.

The presentations were considered to be weak in dynamism and interaction when it came to expressing sound. There is no information about the length, pitch, or volume of the sound feedback. Similarly, the portrayal of lights lacks dynamism and engagement, providing no information about the light feedback's movement, changing intensity, blinking, or glowing effects. Furthermore, the lighting effects around the environments may be inadequate, giving them a washed-out or unnatural appearance. Because of the stiffness and lack of variety of users in terms of height, age, gender, and other factors, the quality of the user and product interaction has been observed to be degraded. Traditional presentations have a number of flaws, including poorly detailed settings and users' viewing angles that are too high and unnatural. There is a misalignment between the product's scale and detail level, the user, and the environment.

Due to graphical and textual density, the scenario taking place outside of the usage environment, and the hand being proportionally inaccurately depicted, following usage scenarios have been found to be difficult. The consumers portrayed in the usage scenario may be missing product-related accessories, and the sequence of actions occurring during use may be difficult to follow.

The magnitude and amount of complexity of product representations in context do not correlate to the user or the environment, and the viewing angle and positioning of the product are disproportionate to the environment.

Due to graphical and textual density, interfaces being detached from the product, and proportionately inaccurate hand silhouettes, the submissions’ renderings of info panels and user interfaces have been judged difficult to understand. Furthermore, reading a sequence of events and displaying many sequences may be difficult.

A lack of full-scale mockups with audiovisual interactivity, as well as interactivity related extra components and accessories, was discovered during the 3D fidelity examination. Deformities came from low-quality mockups, making it impossible to engage with the model.

Table 4.12 Shortcomings of traditional presentations

Sound	• Lack of dynamism and interactivity in representation, • Lack of duration, pitch or volume detail of the sound feedback
Lights	• Lack of dynamism and interactivity in representation, • Lack of movements, changing intensities, blinking and glowing effects of the light feedback, • Lack of the effects of lights on surrounding environments, • Washed out or unrealistic appearance
User product interaction	• Stiffness and lack of variety regarding height, age, gender and such of dummies, • Lack of environment detailing, • High and unnatural viewing angle, • Scale and detail level of the product not corresponding to the user and the environment
Usage Scenario	• Hard to follow graphical and textual density, • Scenario being removed from the real usage environment, • Proportionally inaccurate hand silhouette, • Lack of accessories in users, • Difficulty in reading sequence of events
Product in context	• Scale and detail level of the product not corresponding to the user and the environment, • Viewing angle and placement of product being disproportionate to the environment
Info screens and UI	• Hard to follow graphical and textual density, • Interfaces being removed from the product, • Proportionally inaccurate hand silhouette, • Difficulty in reading sequence of events, • Difficulty in displaying more than one sequence of events
3D fidelity	• Lack of full-scale mockups with audiovisual interactivity, • Lack of interactivity regarding additional components and accessories, • Low material quality in mockups resulting in deformities

6.1.3 What are mixed reality technologies and what are the current uses and benefits of the technology?

Following a period of silence, since it originally gained traction in the 1990s, MR has reawakened in the tech industry, and is now finally being available to the general public, with major businesses such as Oculus Rift and HTC releasing cutting-edge gadgets. VR is a type of mixed reality in which humans perceive digitally manufactured settings as if they were physically present in them. An MR system is made up of hardware and software components. Headsets that display pictures and play sounds, projectors that can modify a physical location, and sensors that detect the users' movements and sounds and provide multimodal feedback, are examples of hardware components. Software components are the programs that compile data from sensors, generate and operate virtual environments on hardware components, and save everything on a server or in the cloud. These hardware and software components are combined in various combinations and specifications to create an MR system that may be used for whatever purpose the user desires. Entertainment and video games, as well as automotive, healthcare, education, tourism, and space studies, have all employed MR.

6.1.4 What are the uses of MR in current design practices?

Because a three-dimensional model or even a working prototype is the most realistic representation of a product, designers are expected to create high-fidelity physical prototypes. A high-fidelity physical model is not only preferred by project stakeholders, but it also allows for more detailed and accurate user testing. Producing high-fidelity physical models, on the other hand, can be costly and time-consuming. Designers can avoid these issues by generating virtual prototypes and testing them in a virtual reality environment.

Studies have been carried out to see if virtual reality can be used in the product development process. Virtual prototyping and user testing are two of the most noticeable examples of using MR for design tasks. The fidelity of conventional approaches that involve physical prototypes ranges from rapid hand sketches to comprehensive drawings, and from rough mockups to operational prototypes. Prototype quality and attention to detail are critical for obtaining accurate data from user testing. Working physical prototypes, on the other hand, can be time consuming and costly. Virtual prototypes can help solve this difficulty, and they have been used in a number of studies with no evidence that they are less effective than real prototypes.

MR has also been used for concept formulation and freeform modeling, in addition to prototyping and user testing. Although the research on concept design and surface creation are outdated, the new MR technology's improved precision and ease of operation may be useful for such tasks in the design process. It is also feasible to draw ideas for industrial design practice from the usage of MR in other industries. For example, an MR system's capacity to tell a story and take the user on a trip while engaging with the system's pieces might be valuable for visualizing product usage scenarios, which could enhance design ideation, user testing, and presentation activities. MR's visualization capabilities are not restricted to images and videos; they can also be applied to text to present any type of design data. Furthermore, the ability to check out a product in any setting can be a powerful tool for selling a new product design or encouraging people.

6.1.5 How can the benefits of immersion provided by MR systems strengthen the shortcomings of traditional representation tools in presenting complex educational industrial design projects?

By filling in gaps in human perception, MR creates immersion by providing realistic simulations. Previous research has shown that MR in learning contexts provides benefits such as a greater sense of presence, overcoming real-world limits by providing physical, environmental, and social awareness, contextualizing learning, and reproducing existing real-world components. The findings suggest that spatial awareness and increased interactivity are two advantages of immersion in MR systems, and that multimedia stimuli boost immersion. These advantages could be beneficial in displaying information such as usage context, audiovisual feedback, and 3D quality in instructional industrial design projects, potentially filling a gap in traditional presentation approaches by increasing spatial awareness in large scale projects and using multimedia stimuli to convey audiovisual interactivity. The findings from the participant observation study show the ways industrial design students used MR systems to strengthen the shortcomings of traditional representation tools in design.

Usage context and 3D fidelity: The development of the environment design assignment ensured that the product's portrayal in context and scale in MR presentations and videos was appropriately developed. Similarly, the students have digital content to use in their MR sceneries thanks to the early construction of 3D models in the second assignment. In the areas of product in context, user and product, scale, material quality, and component detailing, the participants excelled in incorporating MR into their final presentations.

Audiovisual feedback: Some participants were able to depict lights in their MR presentations, but not in the form of interactive audiovisual feedback. Sound feedback was not included in any of the participants' MR presentations. The fact that the participants were more successful in conveying the aforementioned product elements than lights and sounds suggests that audiovisual interactivity should be assigned specific assignments, demonstrations, and feedback sessions.

Spatial awareness: The MR presentations boosted immersion in the environment's depiction, the product's accurate scaling, and the user-product relationship. The teams were able to display their designs in an immersive fashion by using the Oculus Rift HUD to demonstrate the true scale of the products in relation to the viewer and the environment created in their scenes.

Contextualization: Participants were able to present the product in realistic settings that mimicked the intended use environment of the products, as well as show consumers engaging with the products to mimic a complete contextualization of usage, in their AR presentations. The sensation of the product actually being there was aided by good component details and material accuracy.

Real time interactivity: Some participants faced issues with placement and scaling, which were finally resolved thanks to the AR software's interactive nature, which allowed them to modify the size and position of the 3D models in real time.

Embodiment: The MR presentations' interactivity had the benefit of not just illustrating user and product relationships, but also mimicking the basic features of the items and generating a sense of being right next to the design. The usage of MR elevated the presentations into an interactive experience by allowing the audience to position the product and scale it to size, walk around the 3D model of the product, and have a closer look at the component detailing and material quality of the design.

Usage scenario: In terms of the product interfaces, the MR presentations lacked interaction. The spectator is allowed to walk around and observe the product, but they are unable to engage with its interfaces. The lack of access to better hardware and software meant that the usage scenario could not be represented, and user testing could not be conducted in detail in the MR presentations. MR has increased interactivity in student presentations in terms of basic representation of the user and the product by simulating a use environment, but the lack of access to better hardware and software meant that the usage scenario could not be represented, and usage testing could not be conducted in detail in the MR presentations. In future studies, it might be beneficial to guide students in more tangible ways, such as adding an interaction phase to the tasks.

6.1.6 What methods and strategies should be employed while teaching MR to industrial design students so that they can enrich the process and outcomes of their projects?

The findings of the participant observation study regarding briefing, course conduct, outcome expectations, teamwork, hardware and software setup, perspective and mobility of the viewer, documentation and supplementation can be used as strategies to teach MR to industrial design students so that they can enrich the process and outcomes of their projects.

Prior skills: It was found that previous experience of 2D sketching, 3D modeling, basic video and sound editing were helpful for participants to overcome the learning curve of MR integration. Since the tech scene is ever-changing, and since content creation and management software skills are interchangeable, specific software knowledge to integrate MR has not been necessary. The instructors are advised to find the balance between the software most widely used among the students, and the most up to date options.

Briefing: In the project briefing, it is suggested that the scale and GUI specs of projects be described in terms of how MR could provide the maximum benefits. It has been found helpful that the type of product that the students will create is based on their personal preferences in order to create a product that is both unique in concept and execution. Students were given examples of products that met the criteria of large scale and complicated interactivity as guidance.

Course conduct: It has been found beneficial to fragment the intermediary steps and assignments of the project so that each step builds up to the MR presentations. The students were able to move quickly through the processes, modifying their design as they went, thanks to the early initial drafting of digital content such as the 3D model, environment design, and UI prototype, which enriched the final presentations. The course hours were interactive so that students could acclimate to utilizing new technology for the first time, and it was helpful to rely on in-class cooperation and demonstrations of the phases leading up to the MR presentations.

Outcome expectations: It has been helpful to set the end goals for outcomes as the MR presentations and video submissions. The previous assignments' outcomes accumulated to create fully realized MR presentations, and additional video submissions to supplement the MR experiences where features of the design could not be explored fully in MR. Another outcome goal was to transfer the outcomes of this course into the industrial design graduation projects exhibition and jury. Unity was used to create scenes for the MR presentations, as well as a 3D model of the product and the Oculus Rift VR headset.

Teamwork: The study shows that teams were more successful than the individual participants due to the layered nature of the development steps and the overall labor intensity. It would be better to integrate MR presentations into design projects that are developed as teams as opposed to individual work. Individual participants struggled to complete all of the assignments leading up to the MR presentations, and large design changes between assignments meant that design developments were not accumulated in time for the MR presentations. In contrast, the teams were able to complete all of the assignments. This was arguably due to the division of labor and the heavy workload distributed among multiple people, the familiarity of the team members with one another due to prior project work together, and the multidisciplinary nature of the teams, which allowed each member to contribute with different sets of skills. In comparison to the participants who worked on their own, the teams' performance in terms of teamwork, decision making, and problem-solving involving UI prototypes, digital content management, and usage of MR technology has improved their teams' outcomes.

Hardware and software setup: The MR setup regarding hardware and software should be decided based on the needs of the design projects. There were two types of MR sets employed by the teams. The first was an AR setup made up of mobile phones and Unity-created 3D models. The Oculus Rift HUD with the same 3D models was the second arrangement. The AR setup was dependent on the players' own devices, and each team may present at the same time, whereas they only had one HUD and had to take turns.

Perspective of the viewer: The differences in AR and VR regarding the experience of the viewer and the rest of the class and instructors should be considered. The VR presentations were one-on-one experiences in which the viewer was separated and the rest of the group could not see what he or she was going through. Because the AR presentations included the real environment and were not affixed to the viewer's immediate field of vision, they became more collaborative, with other people acting as models to simulate the user product interaction in addition to the person holding the mobile phone to show the AR scene.

Mobility of the viewer: The location in which the MR presentations would take place, and whether the presentations would be tethered to a computer or not should be considered so that the real time immersion could be explored to full capacity by the viewers. The teams were free to shift locations to improve their presentations because the AR presentations were done on mobile phones. Due to the fact that there was only one HUD device permanently linked to the computer in order to access Unity, viewers were forced to sit close to the computer and were unable to fully immerse themselves in the virtual environment. Participants were able to construct 3D surfaces and shapes in real time using software unique to the Oculus Rift, such as Tilt Brush and Gravity Sketch, and experience a higher degree of involvement by having the ability to use a larger space and wander around without being connected to a computer.

Documentation: Recording of the MR experiences should be planned in accordance with the number of participants, the ordering of the presentations, and the audience’s involvement in the presentations. The ability to take screenshots and movies on mobile phones during AR presentations addresses the challenge of collecting static visuals of interactive experiences for future reflection and recording. With VR presentations, this hasn't been achievable beyond seeing the viewer's point of view on a computer monitor attached to the headgear. A good option for VR presentations would be setting up a monitor so that the rest of the audience can see what the HUD user is seeing, or filming recordings of VR walkthroughs.

Supplementation: To negate drawbacks regarding access to technology and the possibility of technical difficulties, it has been found helpful that the MR presentations be supplemented with the final deliverable of a video explaining full characteristics of the designs. The teams were informed about the availability of MR software and hardware, and they were able to overcome the drawbacks of limited access by supplementing their MR presentations with a video assignment/final delivery.

6.2 Limitations of the Research

The limitations for the first study were firstly that the researcher was able to attend the development and final presentations of only the electric oven and the vitroceramic cooktop projects, whereas the researcher assessed the apron bus and the city bus projects only based on the submissions for the final presentations.

Secondly, not all presentation material was documented to the same degree. For the apron bus and city bus projects, not all of the mock ups were documented well. Some mock ups were not photographed, and the photographs of the mock ups that were documented were not all in the same quality regarding angles, moving parts and close ups of the detailing.

The limitations for the second study were firstly that the Interactive Multimedia Design course is an elective course that was conducted four hours every week, as opposed to mandatory studio courses that take twelve hours every week. Due to the fact that the Interactive Multimedia Design course was not mandatory, some of the participants did not make it a priority to finish all the assignments. Three out of all of the participants did not complete the course to the end. Another limitation of this study was limited access to HUD VR hardware and software. The participants had the chance to experiment with native software to the Oculus Rift only at the end of the project, which meant that the full capabilities of the setup were not explored.

As for data collection of the second study, the analysis was done by looking at the interim submissions, final presentations, and observing the participants throughout the process. The participants or the second instructor involved in the course were not surveyed for further elaboration of the research questions. The objectivity of future research will be supported with methods such as questionnaires and inter-rater reliability.

6.3 Recommendations for Further Research

At this point in the investigation for MR integration, considering the general findings and limitations of the study, it is possible to offer recommendations for future research. Directions for future research might include further inspection firstly by improving aspects of interactivity by adding more developmental steps in the project design process like the design of audiovisual feedback in the form of lights and sound. By putting emphasis on the criteria of lighting and sound interactions, another level of complexity can be added to the presentations regarding interactivity and provide the advantage of the MR characteristic of displaying a sequence of events. This way the improvement possibilities in the representation of the usage scenario can be further studied.

Another future research direction could be specifying separate criteria and assessment strategies for AR and VR integration. The research shows that the possibilities of AR and VR show differences especially in the way of the software and hardware setup. Each student being able to have AR presentations with their own mobile devices was a big advantage over the VR presentations due to the lack of access to individual devices. One on one demonstrations of VR HUDs prior to the presentations and scaling up the VR setup by involving native design software for the HUD could bring possibilities for further investigation on how presentations could be improved.

The research has been focused on final presentations of design projects. Future research could also be conducted regarding using MR in the iterative steps of the design process for synthesis activities. Design activities such as form creation, user testing and presentations for intermediary critique sessions could also benefit from MR integration, especially with HUD native software like Gravity Sketch, which is specifically developed for product design. Additionally, instead of focusing on the complete product design process, specific tasks can be pinpointed for MR integration, such as the selection of color for testing color preferences. Since the studies on this dissertation have been focused around complex projects, this narrowing of use area of MR could bring insights from simpler projects.

Future studies might also benefit from a shift from a technology dominated perspective to a more pedagogical perspective. It has been found that while there are some shortcomings of traditional design representation tools that can be answered by MR technology, MR presentations also benefited from the supplement of other forms of media. Indeed, the question was always about how the new can add to the old, not how the new is here to get rid of the old. Therefore, a holistic approach that covers 2D, 3D, MR and other multimedia in industrial design education can be the next step in research. This multiplicity of presentation can be transformative for students, who are diverse learners with different mindsets, approaches, interests and backgrounds.

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APPENDICES

A. Project Brief for Electric Oven in Collaboration with TEKA

Middle East Technical University Faculty of Architecture Department of Industrial Design
Spring 2016-17 ID 302 Industrial Design IV

Asst. Prof. Dr. Harun Kaygan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Dr. Senem Turhan, Res. Asst. Itır Güngör Boncukçu, Res. Asst. Mert Kulaksız, Res. Asst. Başak Topal

03 April 2017

Rethinking the Built-in Electric Oven for Sustainability in collaboration with Teka

In this project we will rethink the standard, 60x60cm built-in electric oven for local small households from lower-middle income level, focusing on small portion food, energy efficiency and local needs and preferences. Focal points of the project are the oven's internal organization, interface, and baking and serving accessories, taking into consideration the whole product lifespan.

Target user group

Local small households from lower-middle class, including housewives, students and bachelors, working single parents, elderly couples, etc.

Project dimensions

Energy efficient
Enabling small-portion baking, reheating, etc.; enabling users to keep track of, and personalize their energy consumption

Easy to clean, maintain, upgrade and repair
Prolonging the product lifespan with product details that ease cleaning, maintenance, and repair; enabling technical or aesthetic upgrading

Local
Responsive to local needs, concerns, preferences and habits

Project Phases

Research
1. Baking festival
2. Literature search
3. User observations (Experience Chart) and interviews
4. Assembly-disassembly session

Idea generation
1. Brainstorming
2. Task exercise

Product detailing
1. User testing
2. Expert feedback
3. Design detailing and technical details

Assessment

Teamwork (75%)

15% Research

Including literature search, user observations

25% Preliminary jury

35% Final jury and exhibition

Individual work (25%)

15% Individual submissions

Including Assignment zero, insight memos, task exercise

10% Individual reports for team performance (Whatsapp)

B. Project Calendar for Electric Oven in Collaboration with TEKA

METU DEPARTMENT OF INDUSTRIAL DESIGN 2016-17 SPRING SEMESTER - CALENDAR

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
Project starts Assignment #0 Research brief delivered 3/Apr	Research phase 4/Apr	5/Apr	Baking Festival 6/Apr	7/Apr	8/Apr	9/Apr
Literature Search presentations 10/Apr	*Research phase* 11/Apr	12/Apr	**User Obs. interviews presentations** **Assembly-disassembly Session** 13/Apr	14/Apr	15/Apr	16/Apr
Brainstorming session 17/Apr	*Idea generation phase* 18/Apr	19/Apr	Task exercise 20/Apr	21/Apr	22/Apr	23/Apr
24/Apr	*Idea generation phase* 25/Apr	26/Apr	**Preliminary jury** 27/Apr	28/Apr	29/Apr	30/Apr
1/May	*Product detailing phase* 2/May	3/May	**User testing** 4/May	5/May	6/May	7/May
8/May	*Product detailing phase* 9/May	10/May	**Expert Feedback** 11/May	12/May	13/May	14/May
15/May	*Product detailing phase* 16/May	17/May	**Design detailing and technical drawings** **Expert Feedback** 18/May	19/May	20/May	21/May
22/May	23/May	24/May	**Final Evaluation** 25/May	**Last day of classes** 26/May	27/May	28/May
Finals > 29/May	30/May	31/May	1/Jun	2/Jun	3/Jun	4/Jun
Graduation 5/Jun	*METU graduation exhibition* 6/Jun	7/Jun	8/Jun	9/Jun	**<Finals** 10/Jun	11/Jun

ID 302 weekly course schedule: Monday afternoon (13:40-17:30) and Thursday whole day (08:40-12:30, 13:40-17:30) version: 28 Mar 2017

C. Project Brief for Autonomous Apron Bus for Airports in Collaboration with OTOKAR

METU DEPARTMENT OF INDUSTRIAL DESIGN
Fall 2017-2018 / ID 401 Industrial Design V

Prof. Dr Gülay Hasdoğan, Assoc. Prof. Dr Owain Pedgley, Assoc. Prof. Dr Bahar Şener-Pedgley
Part-Time Inst. Sezgin Akan, Part-Time Inst. Mine Hoşgün Soylu, Part-Time Inst. Ece Yalım
Res. Asst. Emre Çağlar, Res. Asst. Dilruba Oğur, Res. Asst. M. Erdi Özgürlük

27 November 2017, Monday

PROJECT 2

'Autonomous Apron Bus for Airports' in Collaboration with OTOKAR

For the second project this semester, you will work in groups to design an '**autonomous (driverless) apron bus for airports**' in collaboration with Otokar. Otokar Otomotiv ve Savunma Sanayi A.Ş. is a Turkish manufacturer of buses for public transportation, semi-trailers for the transportation and logistics industries, and tracked and tactical armoured vehicles for the defence industry.

An **apron bus** is a vehicle used to transfer airline passengers between an airport arrival / departure gate and a parked aircraft. It is frequently used as an alternative to a **jet bridge**✈ for various reasons, e.g. lack of airport infrastructure (particularly at small airports), especially busy airports servicing many aircraft simultaneously, long distance transfers, or ferrying smaller numbers of CIP (business class) or VIP (first class) passengers to aircraft from private lounges. An apron bus operates only on the **airside (security controlled side)** of an airport, also known as the **apron area** of the airport.

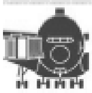
Numerous apron bus designs exist. Some are modifications of buses originally intended for the public highway. Others are purpose-built as extra-wide and long, to hold a larger number of passengers. For economy class passengers, apron buses are usually fitted with minimal or no seating, with most of the passengers standing for the journey. CIP and VIP passengers usually have dedicated apron buses that include a sufficient number of seats for passengers to travel in comfort.

In this project, you must consider deeply how the needs of users can be best met through the design of a new apron bus. This will inevitably focus on interior layout, visibility, accessibility, comfort etc., but attention to the overall vehicle identity and exterior styling is also crucial. Furthermore, you are required to integrate the technological advancements of **autonomy** (driverless vehicle technology) and **non fossil-fuel power sources** (e.g. hybrid, plug-in electric, biofuel, electric) into your designs.

Due to their short distance standardised routes, apron buses usually lack information displays about destinations, airlines, terminal gates, etc. Considering that some passengers will be taking long international journeys, turning off their smart devices, without Internet connectivity, and generally disoriented regarding place, time and destination, there are many opportunities to provide quality guidance and an improved user experience for passengers. As a starting point, you may want to pay attention to some of the points listed below, but you are expected to add to this list based on your group's research:

- Size (e.g., number of passengers to be accommodated)
- Layout (e.g., number of passengers sitting or standing?)
- Space dedicated for personal belongings (e.g., hand luggage, baby buggies)
- Accessibility (e.g., for baby buggies, small children, less abled passengers)
- Information provided (e.g., local information, travel information)
- Internationalization (e.g., local and international languages, common signage)
- Connectivity (e.g., information by providing Internet access)

OTOKAR: www.otokar.com/en-us/



✈ A **jet bridge** (also called *airbridge*, *skybridge* or *passenger boarding bridge* is an enclosed, movable walkway which extends from an airport terminal gate to an airplane door, allowing passengers to board and disembark on foot without going outdoors.

D. Project Calendar for Autonomous Apron Bus for Airports in Collaboration with OTOKAR

Week	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
1	27 Nov **INTRODUCTION TO THE PROJECT II** Distribution of the brief; formation of groups. Guests from Otokar	28	29	30 **Assignment I: Literature search group presentations**	1 Dec	2	3
2	4 **Problem Statement Workshop**	5	6	7 **Assignment II: User Research Poster Presentation / Idea Generation Workshop 1** (development of scenarios)	8	9	10
3	11 **Idea Generation Workshop 2** (development of product identity)	12	13	14 **Initial ideas presentation** (3 concepts with system scenarios)	15	16	17
4	18 **Initial ideas critiques**	19	20	21 **Sketch Problem I / Critiques**	22	23	24
5	25 **Mock-up day / Critiques**	26	27	28 **Preliminary Jury**	29	30	31
6	**HAPPY NEW YEAR**	2	3	4 **Sketch Problem II / Critiques**	5	6	7
7	8 **Final Screening**	9	10 **Submission**	11 **Final Jury**	12	13	14

E. Project Brief for Vitroceramic Cooktop in Collaboration with TEKA

METU Department of Industrial Design / Spring 2017-2018

Middle East Technical University Faculty of Architecture, Department of Industrial Design, Spring 2017-18, ID 302 Industrial Design IV
Asst. Prof. Dr. Naz A.G.Z. Börekçi, Asst. Prof. Dr. Fatma Korkut, Asst. Prof. Dr. Senem Turhan, Inst. Aernout Kruithof,
Res. Assist. Itır Güngör Boncukçu, Res. Assist. Başak Topal, Res. Assist. Mert Kulaksız

9 April 2018

Project II: Rethinking the Built-in Vitroceramic Cooktop and Interface for Sustainability in Collaboration with Teka

In this project we will rethink the built-in vitroceramic hob for households from middle income level, focusing on energy efficiency, and local needs and preferences for cooking. Focal points of the project are the cooktop's layout, its user interface, cooking and serving accessories, also taking into consideration the whole product lifespan.

Target user group

Local and global households from middle class working families.

Project dimensions

- Resource efficient (reducing amount of water, heat, number of pots, pans and dishes used in the process of cooking and serving)
- Responsive to local needs, concerns, preferences and habits
- Easy to clean cooktop; easy to clean and store accessories
- Prolonging the product lifespan with product details that ease cleaning, maintenance, and repair
- Enabling technical or aesthetic upgrading
- Enhancing user experience and user attachment through user interface
- Enabling users to keep track of, and personalize their energy consumption

Project Phases

Research	Idea generation	Product detailing
1. Assembly-disassembly session	1. Brainstorming	1. User testing
2. Cooking festival	2. Task exercise	2. Expert feedback
3. Literature search	3. Role playing for scenario building and process analysis	3. Design detailing and technical details
4. User observations and interviews		

Assessment

Teamwork (75%)
15% Research (including literature search, user observations)
25% Ideation portfolio (scenarios, model trials, etc.)
35% Final jury and exhibition

Individual work (25%)
15% Individual submissions (including Assignment zero, insight memos, task exercise)
10% Individual reports for team performance (Whatsapp)

F. Project Calendar for Vitroceramic Cooktop in Collaboration with TEKA

METU Department of Industrial Design / Spring 2017-2018

Project II: Rethinking the Built-in Vitroceramic Cooktop and Interface for Sustainability in Collaboration with Teka
Calendar

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
9. Apr Distribution of brief. Visit from TEKA, "product dissection session".	10. Apr	11. Apr	12. Apr Literature search presentations. Cooking festival and presentations.	13. Apr	14. Apr	15. Apr
16. Apr User observation presentations.	17. Apr	18. Apr	19. Apr Brainstorming. Task exercise (individual). Scenario building (team).	20. Apr	21. Apr	22. Apr
23. Apr Mock-up trials	24. Apr	25. Apr	26. Apr. Interface design seminar User Interface Designs	27. Apr	28. Apr	29. Apr
30. Apr Desk critiques	1. May	2. May	3. May Desk critiques	4. May	5. May	6. May
7. May User Testing	8. May	9. May	10. May Open table critique session (experts from TEKA)	11. May	12. May	13. May
14. May Desk critiques	15. May	16. May	17. May Desk critiques	18. May	19. May	20. May
21. May Desk critiques	22. May Last day of classes	23. May	24. May Final screening and technical drawings	25. May		
			31. May FINAL JURY			

G. Project Brief for City Bus in Collaboration with MAN

INDUSTRIAL DESIGN STUDIO④

ID401 Industrial Design V
2018-19 Fall Semester

PROJECT 2 – DESIGN BRIEF

'CITY BUS OF THE FUTURE'
in collaboration with **MAN TURKEY**

Buses are a lifeline for public transportation around cities. They make connections throughout the suburbs and inner-city regions, creating a network that is far more extensive than provided by metros, trams or trains. To get an idea of the scale of city bus travel, consider the statistics for London[1]: 675 bus routes, 9000 buses, 19000 bus stops, 2 billion passenger journeys per year.

Your task, working mostly **in groups,** is to design a **city bus of the future** targeted at **5-10 years from now.** The emphasis in this project is on creating a final bus design that communicates a **'wow factor' for its passengers** whilst delivering a high level of **functionality** and **technical viability**.

The bus will be a **'low-entry'** type, allowing easy entry and disembarkation especially for the elderly, pushchairs, wheel chair users, etc. It must be suitable for use in Europe (including Turkey). It will be electric-powered (using rechargeable cells) and should follow stylistic cues of current MAN buses, interpreted for the future. Groups are free to decide if the bus should have a driver or not (or what level of autonomy the bus should operate with).

PROJECT DIMENSIONS

The project has multiple dimensions that must be explored:

- **Passenger Comfort & Convenience:** e.g. coping with changing passenger numbers (busy/quiet periods); seating and standing passengers; physical and emotional comfort; location and capacity of baggage/luggage areas
- **Meeting the Needs of Special User Groups:** e.g. children, disabled, elderly, luggage-laden
- **E-Mobility & Digital Services:** e.g. smart urban transportation, integrated transportation systems, on-the-go pushed information
- **Local Customization:** single body but with specialized interiors/exteriors, e.g. for Turkey vs. Spain vs. Denmark; or for touristic vs. non-touristic city)
- **Technical Design:** service sets (ventilation, air conditioning and lighting) to better serve all passengers; light-weighting (materials, manufacture, assembly) to reduce energy consumption whilst moving

[1] 2017 data (https://www.london.gov.uk/sites/default/files/bus_network_report_final.pdf)

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A dossier of information will be provided to you in the early weeks of the project, giving you a **'helping hand'** for design thinking and ideation.

HINT:

For success in this project, you should consider **changes in the next 5-10 years that will have an impact on bus design and bus journeys.** Scenario-building and future-forecasting, taking into account predicted needs and desires of passengers, transportation infrastructure, and trends in vehicle design, will be essential to developing strong design concepts.

CRITIQUES

Sketch books, mock-ups, workshop outcomes and CAD models are the main means of communicating design ideas with instructors during studio critiques. They should be brought to critiques. Instructors' feedback and advice will be based on seeing what has been done since the previous critique.

CONFIDENTIALITY

This project will run under confidentiality with MAN. Therefore, do not disclose details of the work to people outside of the ID4 studio. Do not post on-going work, ideas, research findings, images, concepts, etc. onto social media and do not share confidential MAN information.

GRADED PROJECT STAGES

The project will run for seven weeks including the final jury. It will be managed through in-class exercises, workshops, design critiques and juries – as detailed in the course calendar. The following components are graded, individually or as a group.

Research Task 1	Individual	**2.5%**
Sketch Task 1	Individual	**2.5%**
Sketch Task 2	Individual	**2.5%**
Research Task 2	Group	**2.5%**
Initial Ideas Jury	Group	**5%**
Preliminary Jury	Group	**10%**
Final Jury	Group	**15%**
TOTAL		**40%**

At juries, grades will be awarded not only for the quality of design ideas but also the justification of those ideas based on research. Therefore, throughout the project you are expected to be pro-active about making research and gathering information, using the results to justify and strengthen your design decisions.

At the end of the project, a peer review system will be used to convert group grades into individual student grades. Students will be asked to rate the contribution of their group members. The ratings will be used to calculate a personalized grade for individuals, based on the group grade. Further details will be provided later.

H. Project Calendar for City Bus in Collaboration with MAN

COURSE CALENDAR

PROJECT 2: MAN

INDUSTRIAL DESIGN STUDIO④

ID401 Industrial Design V

2018-19 Fall Semester

W	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
9	26 November PROJECT 2 BRIEF MAN FACTORY VISIT	27	18	29 ✧ Research Task 1: Transportation Design IN-CLASS EXERCISE: ROLES & VISIONS	30	1 December	2
10	3 ✧ Research Task 2: Bus Journey Scenarios CRITIQUES	4	5	6 WORKSHOP: SCENARIO-BASED IDEA GENERATION	7	8	9
11	10 CRITIQUES	11	12	13 INITIAL IDEAS JURY	14	15	16
12	17 CRITIQUES Mock-Up Advice	18	19	20 WORKSHOP: STYLING & IDENTITY CRITIQUES ✧ Sketch Task 1: MAN Styling	21	22	23
13	24 CRITIQUES	25	26	27 PRELIMINARY JURY	28	29	30
14	31 CRITIQUES ✧ Sketch Task 2: Design Detail	HAPPY NEW YEAR!	2	3 FINAL SCREENING	4 *Last day of classes*	5	6 *Exams* →
15	7	8	9	10 FINAL JURY**	11	12	13

I. Project Brief for ID314 Interactive Multimedia Course

PROJECT 02: Dijital arayüzlü ürün tasarımı ve sunumu

- Projemizde, derste öğrendiğimiz kavramların ışığında dokunmatik ekranlı bir ürün tasarlayacağız. Tasarlarken en önemli iki faktör ürünün mekanla ilişkisi ve arayüz tasarımı olacak.
- Kriterlere uygun ürün örnekleri otomatlar(makarna, çay, kahve, noodle, pizza, cupcake, makyaj malzemesi, vs), turizm bilgilendirme kiosku, avm yol bulma rehberi, durak ve durak bilgilendirme sistemi, pavillion, interaktif mekanlar, insansız büfeler gibi ürünler olabilir. Final sunumunda exploded view yapabilmek için ürünün iç aksamlarının ve oynar mekanik parçaların olabildiğince detaylı çalışılması gerekiyor.
- UI ve UX tasarımının farklarını tartıştığımız dersimize uygun olarak UX bakış açısıyla, ürünün çalışabilen bir UI prototiplemesini yapacağız.
- Kullanıcı testleri yaparak ürününüzün kullanım senaryosundaki problemleri tespit edip çözeceğiz.
- Yatırımcı sunumlarının püf noktalarını öğrenip olabilecek en gerçekçi ve en alımlı ürün sunumu tekniklerini uygulayacağız. Amaç ürününüz için yatırım yapacak müşterileri ikna etmek. Bu aşamada üretim maliyeti, elevator speech, business model, customer acquisition gibi konularda araştırma yapmanız gerekecek. Aynı zamanda portfolyonuzda şık duracak bir çalışma olacak.
- 28-30 Mayıs tarihlerinde KKM’de gerçekleşecek Endüstri Ürünleri Tasarımı Mezuniyet Projeleri sergisinde yer almayı hedefliyoruz. Sergi alanında LCD dokunmatik ekranda sunum ve VR sunumu da olacak.

- 3er kişilik gruplar halinde çalışacağız. Proje kadar grup üyeleri arasında iş bölümü yapılabilmesi için roller belirlenmeli. İlk aşamada bir proje müdürü seçeceksiniz. İlerleyen aşamalarda kişisel ilgi alanları ve yeteneklere göre görevleri üyelere bölüştürmek(kendisi dahil) ve ödev hazırlanması sürecinin sorunsuz ilerlemesini sağlamak müdürün görevi olacak.
- Grupları ilk projedeki gruplar bölünmeden ve multidisipliner gruplar yaratabilmek adına bu şekilde belirledik, değişiklik talebiniz varsa yorumlarda kendi aranızda anlaşıp linkteki dökümanda not edebilirsiniz. Grup ismi ve müdür kısımlarını da doldurun.

https://docs.google.com/spreadsheets/d/1OwwP2w_hKv_2SeSRLGF5irgE9oWXG7BSE65CIc3Opws/edit#gid=0

J. Project Calendar for ID314 Interactive Multimedia Course

mon	tue	wed	thur	fri	sat	sun
4		Assignment 1: Moodboard Initial idea generation		8	9	10
11	Critiques for initial idea generation, selection of one concept	Assignment 2: 3D model of project, UI screen of the most important features	14	15	16	17
18	Exporting of 3D models from Rhino to Unity	Assignment 3: Environment finalization and good quality renders	21	22	23	24
25	Adobe XD lecture, UI prototyping in AE	Assignment 4: Working UI prototype	28	29	31	31
april 1	Critiques, reminder lecture for Marmoset	Assignment 5: Video for advertising product	4	5	6	7
8	Critiques, investor presentation lecture	Assignment 6: Investor presentation	11	12	13	14
15	Critiques for investor presentations	Assignment 7: User testing	18	19	20	21
22	23 National Holiday	24	25	26	27	28
29	Critiques for user testing videos	1	2	3	4	5
6	Online portfolio and interactive presentation lecture		9	10	11	12
13	VR/AR integration lecture	Assignment 8: Bringing everything together	16	17	18	19
CLAS SES	Final screening	22	23	SUBMI SSION	25	26

END 20	(compulsory)			FOR FINAL PROJE CTS		
27	GRADUATION PROJECTS EXHIBITION	GRADUATION PROJECTS EXHIBITION	GRADUATION PROJECTS EXHIBITION	31	june 1	2

K. Assignment Briefs for ID314 Interactive Multimedia Course

Assignment 1:

Moodboard

Bu aşama literatür taraması ve ilham için imaj toplanması gibi düşünebiliriz. Ürünün fiziksel özellikleri için kriterlere uyan ürünlere dair ilginizi çeken örnekleri, ürünün şekli, renk paleti, malzeme seçimleri için ilham olabilecek görselleri toplayabilirsiniz. Aynı şeyi kullanıcı arayüzü için de yapmalısınız ki tasarımınızın ortak bir dili olsun. Moodboard hakkında tüyolar için bu kaynaklara göz atabilirsiniz:

https://designmodo.com/moodboards/

https://www.canva.com/learn/make-a-mood-board/

Üç alternatif konseptin skeçleri

Moodboarddan aldığınız ilhamla en az 3 adet ürün alternatifi için skeçler hazırlayacaksınız. Skeçlerde eksik kaldığını düşündüğünüz noktalarda moodboardunuza referans verebilirsiniz. Bu aşamada yüksek kalitede bir teslim beklemiyoruz, amaç kısa sürede çok sayıda alternatif geliştirebilmek. Sınıfta bu alternatifleri tartışıp aralarından bir tane seçeceğiz.

Teslim: Powerpoint slaytlarınızın ilkini imaj olarak albüme ekleyin, kalanını aynı imajın altına yorum olarak atın.

Assignment 2: Ürünün modellenmesi, tek ekran arayüz tasarımı

Seçtiğiniz ve geliştirmekte olduğunuz ürün fikrini modelleyecek ve kullanıcı arayüzünün en önemli ekranının tasarımını yapacaksınız.

Assignment 2: 3D modeling of the product, single user interface screen

You are expected to complete the 3D model of your selected product idea, and submit the most important screen of your digital user interface.

Assignment 3: Mekan ve ürün modellerinin hazırlanması, şık renderlar
Ürününüzü bir mekan içine yerleştirip yüksek kalitede etkileyici renderlar alacaksınız.
Teslim: ürünün kullanılacağı mekan içerisinde finalize edilmiş 3D modelinin yüksek kalite renderı

Assignment 3: Finishing of the 3D models of the environment and the product, good quality renders
You are expected to get a good quality render of your product in its intended environment of use.

Assignment 4: Çalışır UI prototipi hazırlanması
2 Nisan dersimizde kritik aldığınız görselleri bu albümde paylaşalım arkadaşlar. Onun dışında UI hakkında geliştirdiğiniz görselleri de koyabilirsiniz.
Bu ödevde Adobe XD kullanarak ürününüz için çalışır bir kullanıcı arayüzü tasarlayacaksınız. XD'de design modunda önce fonksiyonel elemanları yerleştiriyoruz. Sonra artboardları çoğaltıyoruz ve farklı ekranları Prototype sekmesinde ayarlarını seçerek birbirine bağlıyoruz. Play tuşu ile deniyoruz.
İlk olarak önemli olan şey flowchart şeklinde fonksiyonlarımızı belirlemek, kullanım aşamalarında kullanıcının kayıp hissetmeyeceği şekilde ayarlamaları yapmak. Daha sonra grafik dil ve markalaşma uygulamalarını yapabilirsiniz.

Assignment 5: Ürünün reklam videosunun hazırlanması
Ürününüzü her özelliğiyle anlatan bir video hazırlayacaksınız. Ürününüz hakkında hiçbir şey bilmeyen birisi bu videodan her şeyi öğrenebilmeli. Sahne sahne ne tür bilgi verileceğini belirlemek ve bilgi akışını mantıklı bir şekilde yapabilmek için bir script ve storyboard hazırlayarak videonuzu yapmaya başlayabilirsiniz.
Videonuzda ürününüzün 3D animasyonunu, kullanıcı arayüzü akışını, hareketli mekanik parçalarını, ya da önemli olan diğer özellikleri floating textler vs. kullanarak gösterebilirsiniz. Örnek reklam videoları görmek için Yanko Design’a

bakabilirsiniz. Önümüzdeki ders (9 nisan) kritik vereceğiz, teslim tarihi Cuma günü olacak.

You are expected to prepare an advertisement video for your product. Someone who knows nothing about your product should be able to learn everything about it by watching this video. You can start by writing a script and preparing a storyboard to pinpoint exactly how you'll convey the necessary information. You can use 3D animation of your product, the user interface, moving mechanical parts or any other features, and enhance with floating texts and such. Check out Yanko Design for examples of such videos. On the next class (9th of april) we will give feedback, and you'll submit your videos on Friday.

Assignment 6: Yatırımcı sunumu hazırlanması

Ürünümüz bizim aklımıza yattı ama bakalım başka insanların da aklına yatacak mı? En zoru para verecek kişiyi ikna etmek. Bunun için bir sunum hazırlayacaksınız. Sunum 20 dakikalık, maksimum 20 slayttan oluşan bir powerpoint sunumu olacak. Haftaya derste konuşacağız.

- Yatırımcı sunumlarında projenizi hayata geçirecek insanı projenizin üretime değer ve ona para getirecek bir proje olduğuna ikna etmelisiniz.
- Sunumunuzda ürününüzün görsel tasarım dili tamamen oturmuş olmalı. Marka tasarımı açısından düşünmelisiniz.
- Yatırımcıyı işe dahil etmeyi unutmayın. Her ay raporlama yaparak toplantılar üzerinden yatırımcının işi takip etmesini önerebilirsiniz.
- Hangi aşamada neyi tamamlayacağınıza dair net bilgi alışverişinde bulunmalısınız. Ölçülebilir tanımlarla ilerlenmeli.
- Ekibin kendi içindeki özgüveni sunumu daha etkili kılar. Ekip üyelerinin daha önce beraber çalışmış
- olması, başarıları gibi detaylar tanıtılmalı. Kimin görevi nedir? İş bölümünü nasıl yaptınız?
- Önceki hafta hazırladığınız reklam videolarını sunumunuza nasıl entegre edeceksiniz? Ne en başında, ne en sonunda olmamalı, ama söylediğiniz

şeyleri tekrar etmemeli. Yatırımcıyı ne kadar uzun süre ilgili tutabilirseniz o kadar iyi.

- Ürününüz kolayca kopyalanabilecek bir ürün mü, yoksa benzer ürünler arasında öne çıkaran özellikleri var mı? Ucuz mu, kaliteli mi? Patentli mi?
- Risk analizi yapılmalı.
- Prototip üretilecek mi?
- Dağıtım ve pazarlama nasıl yapılacak?
- Üründen elde edilecek gelirin yüzde kaçı tasarımcıya gidecek?
- Yönetici özeti(elevator speech) nasıl olacak?

Assignment 7: Tanıtım videosu teslimi ve kullanıcı testi

Önümüzdeki salı günü için öncelikle ürünün tanıtım videosunu olabilecek en profesyonel şekilde editleyip tamamlamanızı istiyoruz. En önemli kriter bu video ile derdinizi anlatabilmek. Dikkat etmeniz gereken şeyler ürününüzün kullanıcı arayüzünün tamamlanmış olması, renderlarda ürünün bir yüzey üzerinde durması hissini vermek, ürün ile ilgili gerekli tüm bilgiler verilecek şekilde metin ya da seslendirme, müzik ile videoyu zenginleştirmek, uzuuun kamera hareketleri izletmektense jump cutlar kullanmak, kestiğimiz her sahnenin uzunluğuna dikkat etmek(fazla uzun süre aynı sahnede takılı kalmamalıyız), metin kullanacaksak büyüklüğü ve fontu, kullandığınız bütün sahnelerin görsel dil olarak aynı tarzda olması, gibi detaylar. Bu videoyu bahsi geçen konuları düşünerek bir izleyin, kafanızda oturacak.
https://www.youtube.com/watch?v=PqDBsyviU2o

Buna ek olarak kullanıcı testi yapmanızı istiyoruz. Kullanıcı arayüzünü ne kadar gerçekçi prototiplerseniz kullanıcı testinizden o kadar güzel sonuç alırsınız. Amaç sizin farkına varmadığınız hata ve eksiklikleri gidermek. Kullanıcı testi süreci ve çıkardığınız sonuçlarla ilgili bir video yapmanızı istiyoruz. Dönem sonunda projenin tümü ile ilgili making of tarzında bir video da teslim edeceksiniz. Mesela paper prototype yapılması, kullanıcı testi, illustratorda ya da unityde çalışırken ya da modelleme yaparken görüntüleriniz olmalı. Yani çalışırken uygun videolar çekmeyi unutmayın.

Assignment 8: Final screening

Ürün tanıtıcı video

- Reklam kısmı: girişte kısa, yanko design tarzı bir reklam olacak. ürünün markalaşması önemli. çarpıcı bir giriş olmalı.
- AR/VR kullanımı: ürününüzün big reveal'i bu olacak. AR/VR ile kullanım senaryosunu baştan sona gösteren bir video çekeceksiniz. arkadaş çeker gibi değil, gerçekten ürün çekiliyor gibi sahnenin kompozisyonuna özen göstererek, profesyonel kalitede, öğrencinin yaptığı anlaşılmayacak şekilde çekilmesi lazım.
- Teknik detaylar: ölçüler yazılmalı. üretim şekli, kullanılan malzemeler, exploded view, Adobe XD üzerinden arayüz detayları olacak.

Making of videosu

30 saniyelik bir video olacak. ürünün arkasındaki ekibi görmeliyiz. fikir geliştirme süreci, alternatif fikirlerin elenmesi, modelleme, paper prototype, kullanıcı testi...

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

Degree	Institution	Year of Graduation
MS	Middle East Technical University	2015
BS	Middle East Technical University	2011
High School	Gazi Anadolu Lisesi	2006

WORK EXPERIENCE

Year	Place	Enrollment
2019-	Eskişehir Technical University	Research Assistant
2014-2019	Middle East Technical University	Research Assistant
2013	Simsoft Computer Technology	3D Designer
2012	Albert Genau Glass Balcony & Frameless Glazing	Industrial Designer

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

1.

Topal, B., & Sener, B. (2015, August). Appraisal of Augmented Reality Technologies for Supporting Industrial Design Practices. In *International Conference on Virtual, Augmented and Mixed Reality* (pp. 513-523). Springer International Publishing.

2.

Topal, B., & Sener, B. (2015). Augmented Reality for Enhanced Student Industrial Design Presentations. In *DS82: Proceedings of the 17th International Conference on Engineering and Product Design Education (E&PDE15).* Great Expectations: Design Teaching, Research & Enterprise, Loughborough, UK.