EXPLORING AUGMENTED REALITY TECHNOLOGY AS A DESIGN REPRESENTATION TOOL FOR ENHANCING THE PRODUCT DEVELOPMENT PROCESS IN INDUSTRIAL DESIGN EDUCATION

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ALPER KARADOĞANER

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submitted by **ALPER KARADOĞANER** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Industrial Design, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ____________

Prof. Dr. Gülay Hasdoğan
Head of the Department, **Industrial Design** ____________

Assoc. Prof. Dr. Naz A.G.Z. Börekçi
Supervisor, **Industrial Design, METU** ____________

Examining Committee Members:

Prof. Dr. Bahar Şener-Pedgley
Industrial Design, METU ____________

Assoc. Prof. Dr. Naz A.G.Z. Börekçi
Industrial Design, METU ____________

Assist. Prof. Dr. Gülşen Töre Yargın
Industrial Design, METU ____________

Assoc. Prof. Dr. Gazi Erkan Bostancı
Computer Engineering, Ankara University ____________

Assoc. Prof. Dr. Aykut Coşkun
Media and Visual Arts, Koç University ____________

Date: 25.09.2020

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Alper Karadoğaner

Signature :

ABSTRACT

EXPLORING AUGMENTED REALITY TECHNOLOGY AS A DESIGN REPRESENTATION TOOL FOR ENHANCING THE PRODUCT DEVELOPMENT PROCESS IN INDUSTRIAL DESIGN EDUCATION

Karadoğaner, Alper
Doctor of Philosophy, Industrial Design
Supervisor: Assoc. Prof. Dr. Naz A.G.Z. Börekçi

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Design representation tools are among the most important mediums for industrial design students in the product development process. Students use these tools to explain their products and product aspects, such as form and mechanism, during their presentations in desk crits and juries in order to get feedback from the tutors and continue with design development. Desk crits are seen as a powerful and central medium of design studio education, in which design students interact with the tutors. Design representation tools are vital for desk crits to enhance the presentations of design students and the interaction between the students and the tutors, mainly based on the progress about product aspects in their design solutions. Understanding the relationship between the product aspects and design representation tools is vital to find out how the product development process can be enhanced with the proper use of design representation tools.

Understanding this relationship is also essential for exploring how Augmented Reality (AR) as a developing technology can be integrated as a supportive design representation tool during the product development process, especially desk crits. First, a study was conducted to explore the current product development process of industrial design students. As a result of this study, the Design Representation Tool

(DRT) framework showing the relationship between the product aspects and design representation tools is developed. In addition, product aspects' requirements for AR technology are identified, and AR Interaction framework is offered to show how AR can be integrated into the design process. Based on the findings of this study, a second study was conducted to explore the potentials of AR technology and the effects of its integration into the product development process. This study revealed that AR technology has many benefits and potentials for the product development process as a supportive design representation tool.

Keywords: Design Representation Tools, Augmented Reality Technology, Product Development Process, Industrial Design Education, Desk Crits

ÖZ

ENDÜSTRİYEL TASARIM EĞİTİMİNDE ÜRÜN GELİŞTİRME SÜRECİNİ DESTEKLEMEK İÇİN TASARIM TEMSİL ARACI OLARAK ARTIRILMIŞ GERÇEKLİK TEKNOLOJİSİNİN ARAŞTIRILMASI

Karadoğaner, Alper
Doktora, Endüstri Ürünleri Tasarımı
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Tasarım temsil araçları, endüstriyel tasarım öğrencileri için ürün geliştirme sürecindeki en önemli araçlardan biridir. Öğrenciler bu araçları, masa kritikleri ve jüri sunumları sırasında geliştirdikleri form ve mekanizma gibi ürün özelliklerini açıklamak ve öğretim elemanlarından geri bildirim almak üzere kullanmaktadırlar. Tasarım öğrencilerinin öğretim elemanları ile etkileşime girdiği masa kritikleri, tasarım stüdyosu eğitiminin güçlü ve merkezi bir aracı olarak görülmektedir. Tasarım temsil araçları, öğrencilerin sunumlarını ve öğretim elemanlarıyla etkileşimini geliştirmek için masa kritiklerinde önemli bir yere sahiptir. Bu etkileşim, temel olarak, öğrencilerin ürün özelliklerini nasıl geliştirdiklerine ve ilerlettiklerine dayanmaktadır. Ürün özellikleri ve tasarım temsil araçları arasındaki ilişkiyi anlamak, öğrencilerin ürün geliştirme sürecinin tasarım temsil araçlarının doğru kullanımıyla nasıl geliştirilebileceğini anlamak için önemlidir.

Bu ilişkiyi anlamak, gelişmekte olan Artırılmış Gerçeklik (AG) teknolojisinin ürün geliştirme sürecine, özellikle masa kritiklerine, destekleyici bir tasarım temsil aracı olarak nasıl entegre edilebileceğini ortaya çıkarmak için önemlidir. İlk olarak, endüstriyel tasarım öğrencilerinin mevcut ürün geliştirme sürecinin incelendiği bir çalışma yapılmıştır. Çalışmanın sonucunda ürün özellikleri ile tasarım temsil araçları arasındaki ilişkiyi gösteren Tasarım Temsil Araçları (TTA) çerçevesi oluşturulmuştur. Ek olarak, AG teknolojisi için ürün özelliklerinin gereksinimleri tanımlanmış, ve AG'in ürün geliştirme sürecine nasıl entegre edilebileceğini gösteren AG Etkileşim çerçevesi önerilmiştir. Bu çalışmanın bulgularına dayanarak, AG teknolojisinin ürün geliştirme sürecine entegrasyonunun potansiyellerini ve etkilerini araştırmak için ikinci bir çalışma yapılmıştır. Bu çalışma, AG teknolojisinin destekleyici bir tasarım temsil aracı olarak ürün geliştirme sürecine birçok fayda ve potansiyele sahip olduğunu ortaya koymuştur.

Anahtar Kelimeler: Tasarım Temsil Araçları, Artırılmış Gerçeklik Teknolojisi, Ürün Geliştirme Süreci, Endüstriyel Tasarım Eğitimi, Masa Kritikleri

To my parents,

to my sister,

and to myself

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
AR	Augmented reality
AV	Augmented virtuality
CAD	Computer aided design
CAE	Computer aided engineering
DRT	Design representation tool
METU	Middle East Technical University
MR	Mixed reality
RV	Reality-virtuality
UX	User experience
VR	Virtual reality

CHAPTER 1

INTRODUCTION

This chapter describes the background of the problem by referring to the literature. Based on this background, it defines the problem statement and purpose of the research. To accomplish this purpose, it introduces the methodology of the research and the research questions that this thesis will answer. In addition, it describes the significance of the research, contribution to the literature and audience of the research.

1.1. Background of the problem

During the product development process, industrial designers use a variety of design representation tools, such as images, sketches, mock-ups or 3D-models, in order to support their process. With the development of technology in software and hardware, technological tools, such as computer-aided design and rapid prototyping tools, have been started to be utilized increasingly in different stages of the process, from concept development to prototyping. The 2D and 3D processes involved in the product development process have progressed with the integration of technological advancements. Digital tools used in design provide time-efficiency in product development (Wilson and Fauscette, 2008), faster product development (Chen and Owen, 1998), and efficient communication between designers and the other stakeholders (Lynn, 2006). However, the usage of physical models during the design process have decreased (Wilson and Fauscette, 2008; Bordegoni et al, 2006). Building physical models have been decreased with the generation of 3D computer models in 2D displays. 2.5D visualization approaches, 3D models in 2D screens, are being used by designers to validate their ideas with fewer physical models in their design process (Shin and Jennings, 2013). Although digital tools have several opportunities for the design process, digital modelling tools are preferred for the later phases of the design process (Aldoy and Evans, 2011). With the advancement of technology in digital tools, use of physical models have decreased and digital tools have increased to validate design concepts or to have 3D perception.

Physical prototyping can help the design process to carry out different design activities in different stages of product development process, such as prototypes that lead to ideation, fast prototypes that reduce fixation and prototypes that help user-testing (Camburn et al., 2017). However, physical prototypes are used to verify and identify design errors at the end of the product development cycle (Lanzotti et al., 2018). In addition, physical prototypes, which look like the final product, are used for user testing, to assess the final product, to test design alternatives by assessing according to user requirements (Lanzotti et al., 2018). On the other hand, a virtual prototype which is a digital model of a physical product simulated with computer can shorten product development time (Gromova, 2019). In addition, several design alternatives can be tested with virtual prototypes to find out the optimal alternative (Gromova, 2019). Digital tools that support physical and virtual prototyping are important to be used starting from earlier stages of the product development process. The adaptation and integration of the developing technologies that can be used in the product development process is required for designers to enhance their product development processes starting from earlier stages.

The product development process followed in industrial design education is rather similar to the practices in professional life. The design process follows a common and clearly identifiable process in different design areas without regarding the subject (Aspelund, 2010) with specific objectives, inputs and outputs. Aspelund (2010) identified the process in design education with different stages and each includes different objectives and requires the use of different knowledge and skills. This defined process in design education is helpful for design students in terms of development of their own skills and design approaches, and experiencing the design processes similar to professional life (Tovey, 2012).

To support the product development process of design students, design studio courses are considered as the centre of design education. These courses are supported with studio-based activities, such as desk crits to support students' work and to enhance the design studio environment. Desk crits structured in the design studio, in which design students present their progress and discuss with the tutors to get feedback, are important and helpful for the students to improve their product development process and their learning process. Despite the challenges in design education, such as new methods in teaching and the increasing number of students, the design studio and desk crits remain as a distinctive and important method for design education. Regular desk crits in design studio support communication and interaction between the student and the tutor. With this regular communication carried out in desk crits, students improve their knowledge, design skills and understanding with the guidance of tutors (Goldschmidt et al., 2010). Through tutor-student communication design knowledge is transferred; therefore, effective communication between the tutor and the design student is crucial in the design studio education.

During the product development process, students carry out different design activities for different stages, such as problem identification, idea generation, communication in desk crits, and evaluation. In addition to these activities, design students pay attention to multiple considerations related to product aspects in order to reach better design solutions starting from the beginning of a product development process. For instance, users of the products are one of the important primary knowledge sources for designers to understand needs and expectations for generating effective design solutions enhancing user experience (UX), also to fulfil the expectations and emotional needs of the users. Sproll et al. (2010) emphasize the importance of UX indicating that it needs to be considered starting from earlier stages of the product development process to eliminate failures in design. Similarly, with the integration of technology and digital displays into products, design students need to pay attention to the interaction between the user and the product, or user interface if any, to enhance UX provided by the product. In addition, another important design consideration is physical ergonomics that design students need take into account to reach successful design solutions. Computer aided design (CAD) systems can provide design tools that enable designers to make ergonomics evaluations starting from the conceptual design stage (Porter et al., 1995) by considering the capabilities of the users and their limitations. Högberg (2005) emphasize the importance of considering ergonomics at earlier stages of the product development process to increase the quality of the product. Moreover, aesthetics, performance, which is mainly about the components inside the product, and relatively manufacturing need to be considered starting from concept design in order to improve the product development process. Functional and aesthetic considerations are important factors for the success of product design, influencing the users' perception and satisfaction about the product (Rahman et al., 2010). Considering the manufacturing method, material selection is important to meet the functional requirements for the desired use of the product sensorial requirements for the senses of the users (Karana et al., 2008) starting from the earlier stages of design process. There are also relations between different design considerations, showing that a design consideration needs to be thought from different perspectives in different stages of the product development process. For instance, when manufacturing is taken into account, considering aesthetics, material, inner components and the assembly of the product might become important. In brief, design students need to pay attention to several design considerations at different levels in different stages of the product development process in order to reach more successful design solutions or better final products.

During the desk crit sessions, students get feedback from the tutors based on their development or progress about design considerations by making explanations. To support these sessions, design students use different representation tools, such as pictorial, physical and digital tools, while communicating with the tutors. Design representation tools, such as sketching, visual mock-ups and 3D-models, are used to support the student's explanation in order to create a common understanding between the student and the tutor, which increases communication between them.

The selection of the right tool according to both its ability and designers' ability is critical for designers to increase the productivity of their development process (Stolterman, 2008). Design representation tools used during product development process are grouped under sketches, drawing, models and prototypes by Pei et al. (2011). Chandrasegaran et al. (2013) offer a different categorization of knowledge representations including design representation tools under five categories; pictorial, linguistic, virtual, algorithmic and symbolic. Pei et al.'s categorization does not include virtual and pictorial tools such as 3D-model, AR, and photo, whereas Chandrasegaran et al.'s categorization does not include physical tools, such as physical models and prototypes. Considering this, the design representation tools are categorized as pictorial, linguistic and virtual by adding physical tools based on Chandrasegaran et al.'s categorization. Each design representation tool has advantages and challenges for different stages of the product development process. Several studies indicate benefits and challenges, and compare different design representation tools, such as Sachse et al. (2001), Won (2001) and Rahimian et al. (2008a). It has been suggested to switch between different design representation tools that support each other or to use them together for enhancing the product development process.

For industrial design education, one of the important challenges that needs to be integrated into education is that newly developing technologies lead to an increase in using digital tools, and in return, using digital tools influences the use of other design representation tools (Bakarman, 2005). With the development of digital tools, design students adapt themselves to this change and start to integrate the technology into the design studios to use during the studio sessions (Souleles, 2013). For instance, the design students use the latest software with their notebooks, which they bring in the design studios (Souleles, 2013). This integration of the current and newly developing technologies should be directed to support the product development process of design students and to enhance effective learning environments, such as desk crits, for design education. Newly developing technologies that have started to be integrated into the product development process are virtual reality (VR) and augmented reality (AR). These technologies have been studied to find out how they can be used in product design practice and also education.

Developing digital technologies, like AR, come into prominence with the rapid development of software and hardware technology. Although the most common applications of AR can be seen in entertainment, marketing and military, AR technologies are increasingly arousing both researchers' and practitioners' interest to apply new uses in different fields. Since the publication of the Horizon 2010 and 2011 reports, it has been predicted that AR as an emerging technology is likely to have growing impact on teaching and learning (Johnson et al., 2010; Johnson et al., 2011). Horizon is an annual report of experts, who discuss their experiences about technology adoption and changes in education with a review of recent literature. In addition, Horizon describes itself as "education's longest-running exploration of emerging technology trends that support teaching, learning, and creative inquiry". In the latest Horizon report published in 2019, it was reported that the integration of AR is likely to increase demand on the development and implementation of digital learning environments (Alexander et al., 2019). The demand for this integration to enrich digital learning environments will continue to rise. Furthermore, Horizon 2018 report states that universities utilize strategies including digital elements to enhance learning in the physical environments more actively regarding interest in multiple device usage including AR technology (Becker et al., 2018). AR in the Horizon 2014 and 2015 reports, and mixed reality in the Horizon 2017 report were listed among visualization technologies that have potential in the development of learning strategies and in transferring of the content in education (Becker et al., 2017; Johnson et al., 2015; Johnson et al., 2014).

The potential of AR technology has also been reported in the previous Horizon reports. The Horizon 2016 report stated that AR as interactive learning with virtual objects has the potential to enable learners to construct wider understanding and deeper cognition with a new perspective supported by this immersive technology (Johnson et al., 2016). In addition, as mentioned in the Horizon 2011 report, using AR as interactive learning and its ability to give immediate feedback to the user have potential for learners to create new understandings with the help of this interaction (Johnson et al., 2011). A study conducted by Topal and Sener (2015) with industrial design students shows the potential of utilizing AR in the presentation and prototyping stages of the product development process. In addition, AR has the potential to support other design stages and design activities during the product development process. The interest in industrial design education for creating interactive and effective learning environments with AR technology is still in its infancy. The development of AR technologies and applications can enhance the product development processes of industrial design students in a supportive way. However, this field still requires exploration through further research to develop better AR applications.

AR can be considered as an important virtual prototyping tool that can be used as a supportive design representation tool during the product development process by augmenting 3D virtual model of the design concept/product in the context as it is there. However, the utilization of AR needs to focus on the stages of the design process where the digital modelling activities start, while getting feedback from design academics. Desk crit sessions during the product development process in design education is an essential means to enhance the product development process of the students, to guide about their future progress, to improve their learning and to encourage them. Preferring digital representation tools during different stages of the product development process might have positive outcomes, such as increasing interaction between the student and tutor, and the effectiveness of the final product. Therefore, AR as a supportive design representation tool can be utilized to enhance or support the product development process and the desk crit sessions starting from the earlier stages of product development process. Although the research and development of AR in industrial design education to create interactive environments is still in its infancy, the potentials of developing a large variety of applications need to be explored through research in order to support the proper integration of AR technology into the design process. In order to find out the potentials of AR as a supportive design representation tool in the product development process, the current process of the students in industrial design education firstly needs to be explored for gaining insights on the use of different design representation tools and the relationship between these tools and design considerations including the product aspects, such as form and mechanism. It is important to understand which product aspects can be supported with AR technology and how these product aspects should be presented with AR technology. In addition, it is important to explore how AR technology can be integrated into the design stages, particularly after 3D modelling activities start, and to find out the potentials and effects of AR as a supportive tool during the product development process.

1.2. Problem statement

Several researches were conducted to understand relationships between design practice and the design representation tools, mostly based on the design stages. In these studies, the effectiveness of these tools in supporting designers' development processes were mainly related to the stages of product development, such as sketching for conceptual design stage and 3D-modelling for detailed design stage. Moreover, the relation between the design stages and these tools were studied in addition to the benefits and challenges of these tools. Design representation tools are vital for the students to explain their design considerations during desk crits and are important to support their product development process and communication with the tutors. The explanations made by the students about their design considerations, which are related to their project and developed with design representation tools during product development process, is one of the most important parts of desk crits, shaping the interaction between students and tutors. However, there is a gap in the literature about the relationship between students' design considerations that they address within their design process, and the design representation tools that they use. It is necessary to explore this relationship in order to understand how AR technology as a supportive design representation tool can be integrated into the product development process and desk crits in design education.

1.3. Purpose of the research

This research aims to explore 1) the relation between product aspects, such as form and mechanism, and design representation tools, 2) the effects of design representation tools on the product development process, 3) how these tools should be integrated into design process and desk crits in industrial design education, and 4) how AR technology as a supportive design representation tool, in addition to other tools, can be integrated into the product development process in industrial design education.

1.4. Methodology of the research

The stages of the research is defined according to the action research as stated by Stringer (2014), which is an approach to inquiry or investigate the current situations by formulating effective solutions to the situations in order to improve them. This research consists of three main phases; look, think, act including report, implement and evaluate (Stringer, 2014). Similarly, this action research is presented by Kemmis et al. (2014) in four stages; plan, act, observe and reflect.

Based on Stringer's (2014) suggestion, the methodology of the research consists of five stages; *look (collecting data), think (analyzing the data), act (formulating the findings), implement (integrating AR technology),* and *evaluate (evaluating the integration of AR)* in two different studies; one study to explore the current product development process and another study to explore the integration of AR technology into the product development process (Figure 1.1). The first study includes the *look*, *think* and *act* stages, whereas the second study includes the *implement* and *evaluate* stages.

The *look* stage includes data collection from industrial design students and academics during the product development process of their graduation projects carried out in the Department of Industrial Design at METU. Data collection consists of observations of desk crits and surveys evaluated after each desk crit. After the students completed their product development process and submitted their projects, they were invited to participate in focus group sessions that were conducted to ask them to evaluate their product development process in order to support the data collected from the observation sessions.

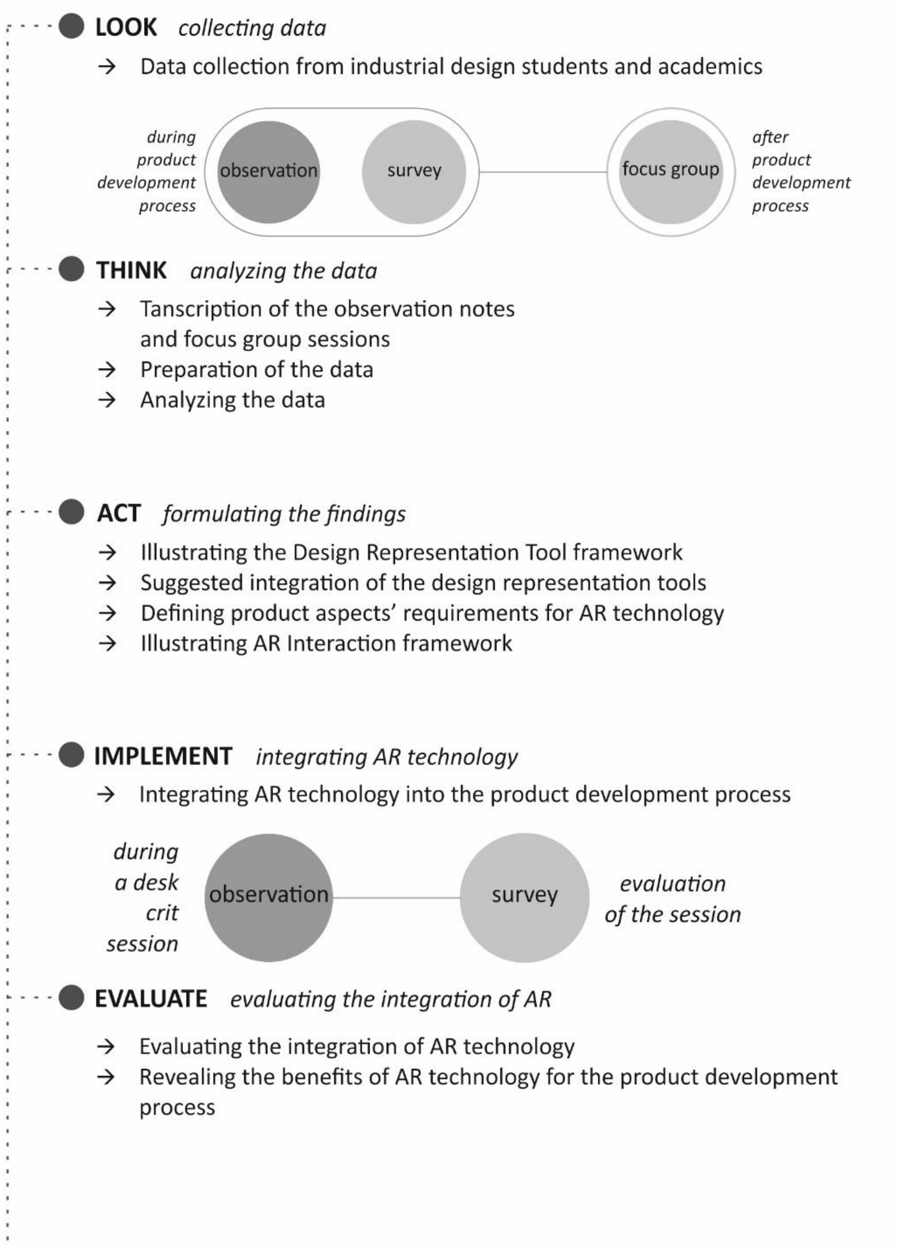

Figure 1.1. Methodology of the research

The *think* stage includes transcription of the observation notes and focus group sessions, preparation of the data by reviewing them multiple times and analysis of them. In the *act* stage the findings were formulated. This stage includes illustrating a model, the Design Representation Tool (DRT) framework that shows the relations between the product aspects and the design representation tools. It also includes the suggested integration of design representation tools into the product development process. In addition, the *act* stage defines the product aspects' requirements for AR technology and illustrates a second model, the AR Interaction framework for product aspects.

The *implement* stage includes data collection for a study in which AR was integrated into the product development process of a project given to the students in an elective course based on the findings of the first study. This stage includes the observation of the students during a desk crit session and a survey for the evaluation of the integration of AR technology into the product development process.

In the *evaluate* stage, analysis is carried out on the data for evaluating the integration of AR technology into the design process. Transcription of the observation notes and surveys evaluated by the students and the guest tutor were analyzed to reveal the benefits of AR for the product development process of industrial design students.

1.5. Significance of the research

With the development of technology, newly developing representation tools, such as AR as a supportive design representation tool, have started to being developed and can be integrated into the product development process in addition to the current design representation tools. Aiming at the integration of AR technology into the product development process in industrial design education, this research investigates the relations between the product aspects and design representation tools by exploring the current process of industrial design students in order to understand how AR technology can be integrated into design studio sessions. The difference of this research from other studies described in the literature is its focus on this relation in order to suggest the integration of AR technology and to guide the integration of developing technologies.

1.6. Contribution to the literature

This thesis will mainly contribute to the literature in industrial design education with the following outputs. First, it illustrates the Design Representation Tool (DRT) framework for enhancing the use of the tools in order to improve the product development process. This model shows the relations between product aspects and design representation tools. Secondly, the thesis defines product aspects requirements for AR technology and offers an AR Interaction framework. These outputs can be beneficial for AR researchers and developers to better develop potential applications. They can also be helpful for academics to make decisions about whether an AR application can be integrated into the process. Another output is the benefits of AR technology as a supportive design representation tool for the product development process of the students.

1.7. Research questions

Based on the relation between product aspects and design representation tools, this thesis aims to provide guidance on how AR can be integrated into the product development process. To achieve this aim, it mainly offers three investigations; exploring the current product development process, exploring how AR technology can be integrated into this process and understanding the benefits of this integration. The research questions that are addressed are:

- How can design representation tools be used for enhancing the product development process in industrial design education?
- How can augmented reality technology be integrated into the product development process in industrial design education?
- How can augmented reality technology as a supportive design representation tool affect the product development process?

1.8. Audience of the research

This research may arouse interest for the following audience:

- Academics in industrial design education who want to improve the use of design representation tools during the product development process.
- Academics who aim to employ AR technology as a supportive design representation tool during the product development process.
- Design researchers who are interested in AR technology as a design representation tool within industrial design education and profession.
- AR researchers and developers who want to develop AR applications for the product development process.

1.9. Structure of the thesis

This thesis consists of six chapters and an overview of the chapters can be seen in Figure 1.2.

Chapter 1 describes the background of the problem, problem statement, purpose of the research, methodology of the research, significance of the research, contribution to the literature, research questions and audience of the research.

Chapter 2 provides a literature review on the product development process in industrial design practice and education. It describes the stages, design activities and design considerations in the product development process. In addition, this chapter explains design studio education in terms of design critiques, tutor-student relationship and communication models in design studio. Furthermore, it presents how knowledge is represented and the design representation tools used during the product development process.

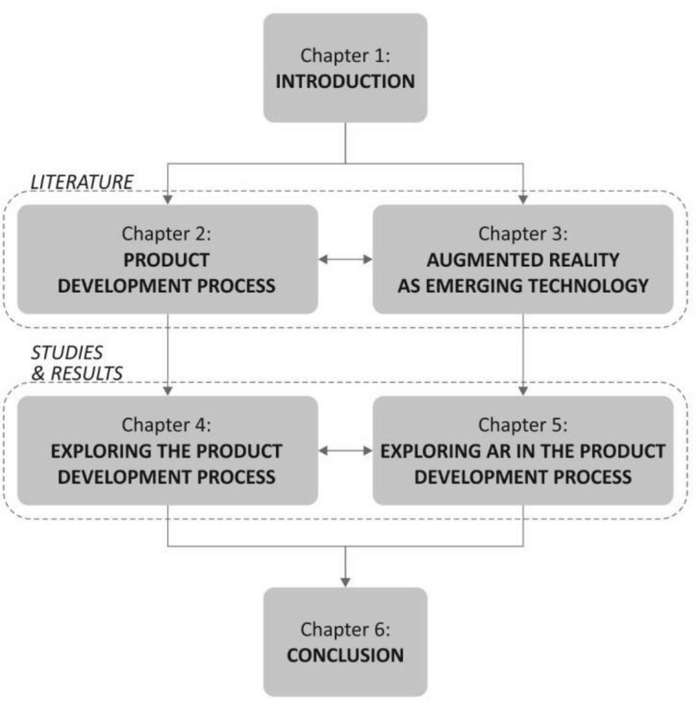

Figure 1.2. Structure of the thesis

Chapter 3 reviews AR as a developing technology in education and in industrial design. It briefly summarizes the AR technology to provide a background for its terminology, developments and working principle. This chapter explain AR researches conducted in education with its advantages, disadvantages and learning gains. It also presents the current and developing AR tools used in industrial design education and practice. In addition, it discusses the significance of AR, and its benefits and drawbacks for the product development process.

Chapter 4 introduces the proposed methodology for exploring the product development process of industrial design students and the studies conducted for this exploration. Based on these studies, it presents the Design Representation Tool framework, showing the relationship between design representation tools and product aspects, for enhancing the development of product aspects. It also presents how these tools are used to support each other considering product aspects. In addition, this chapter presents product aspects' requirements for AR technology and the AR Interaction framework to guide how AR can be integrated into the product development process.

Chapter 5 introduces the proposed methodology for exploring the integration of AR as a supportive representation tool in product development and the study conducted for this exploration. Based on this study, this chapter presents the effects and potentials of AR technology and the benefits of its integration into the product development process.

Chapter 6 summarizes the findings, and discusses the outputs of this thesis based on the research questions. In addition, it mentions the limitations of the studies and puts forth potential directions for further studies.

CHAPTER 2

PRODUCT DEVELOPMENT PROCESS

Industrial designers follow similar product development process in which they conduct several design activies and pat attention to different design considerations in order to find better solutions for their projects. In design education, design studio and desk crits in studio sessions are considered as the most important medium for the students to improve their process. Therefore, the relationship and communication between the students and the tutors during studio sessions becomes important for desk crits. In these crits, the students make knowledge representation about their projects' progress with different design representation tools, such as physical and digital tools. In this chapter, a literature review on these topics will be presented under three sections, product develpoment process, design studio education and design representation tools.

2.1. Product development process in industrial design

The product development process has been defined by several researchers. The product development process, namely design process, is mainly defined as an iterative process including several stages to reach a design solution for a design brief. This process was outlined around several stages. Wright (2002, p. 113) described the design process with seven stages, which are;

1. *Identification of the problem.*
2. *Gathering needed information.*
3. *Search for creative solutions.*
4. *Step from ideation to preliminary designs (including modeling).*
5. *Evaluation and selection of preferred solution.*
6. *Preparation of reports, plans, and specifications.*

7. *Implementation of the design*.

Although Wright (2002) explained the design process with seven stages, he strongly emphasized that one or more stages may not appear in different design processes and the stages may be repeated multiple times iteratively in order to reach a desired design solution. As defined by Baxter (1995), the development process goes through the main stages of *business opportunity, design specification, embodiment design, detail design,* and *design for manufacture*, with iterations if necessary. Each stage includes several design activities to move on to the next stage of the design process, illustrated in Figure 2.1 by simplifying the development process. Although the process seems directional, iterations are suggested at the necessary stages of the product development process.

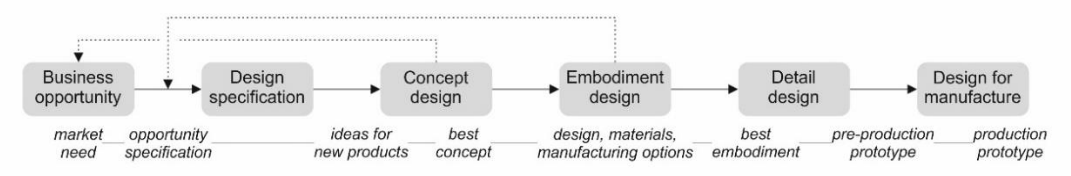

Figure 2.1. Design activities at different stages of product development
(Baxter, 1995, p. 19)

Similarly, the product development process was described from planning stage to production ramp-up stage (Ulrich and Eppinger, 2011). The industrial design process takes place between these stages based on the product type, which may be technology-driven or user-driven. The stages for user-driven product development process, are *concept development (identification of customer needs, concept generation and selection, concept testing), system-level design in which industrial design refines the most promising concepts*, and lastly *detail design, testing, and refinement*. Figure 2.2 presents the development process described by Ulrich and Eppinger (2011).

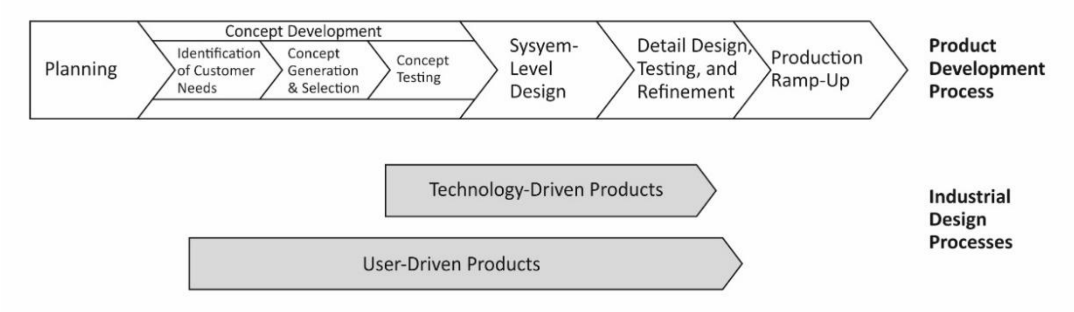

Figure 2.2. The product development process and industrial design process for technology and user-driven products (Ulrich and Eppinger, 2011, p. 223)

The product development process is generally defined as an iterative process of the stages. The industrial design process defined by Gotzsch (1999) suggests going forth and back considering the function, emotion and aesthetics of design based on the type of product. Modelling to test and make modifications is an iterative stage of a design process (Cross, 1990). The design process is defined by Billet as a dynamic process (Figure 2.3), in which the feedbacks provide information to support the next phase of the development process (as cited in Charlesworth, 2007).

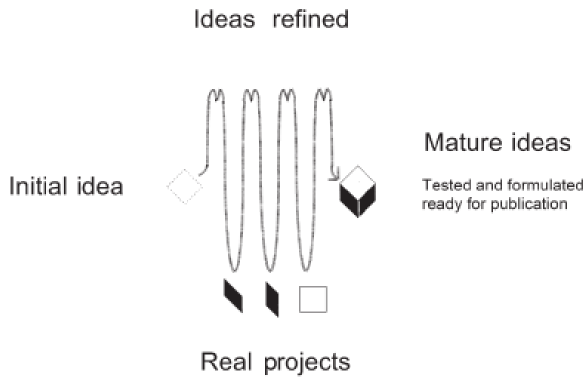

Figure 2.3. Design process defined by Billet (1995) (as cited in Charlesworth, 2007, p. 36)

For this research, it is important to explore the design activities that are related to design representation tools and the design activities that can be supported by AR technology. Although virtual tools used in the design process are viewed as presentation tools that can be employed after the development phase (Charlesworth, 2007), the design phases in which digital methods are employed, are; *concept* *generation, preliminary refinement, further refinement, final concept selection* and *specification* (Aldoy and Evans, 2011).

2.1.1. Product development process in industrial design education

Industrial design education has shown a historical development. Knowledge and skills developed with the design projects have been transferred from the workplace to the design studio environment (Lawson, 2000; Souleles, 2013). In this respect, it can be seen that the project development processes followed in industrial design education have a similar structure to the practices carried out in professional life. Aspelund (2010) states that the design process follows a common and clearly identifiable process in different design areas without regarding the subject. This design process includes stages with specific objectives, input and output. When the design student progresses in the process by reaching the goals set for each stage, s/he can better understand the dynamics of the design process, determine his/her design solution path more accurately, make important decisions about his/her project on time and evaluate his/her own product development process.

In addition, it is essential to define the stages of the design project, to manage the process, to document it, to evaluate it retrospectively, to carry out teamwork, and to organize the communication between collaborating parties (Aspelund, 2010). Aspelund (2010) identifies the process followed in design education in seven stages; *inspiration, identification, conceptualization, exploration/refinement, definition/modeling, communication* and *production*. Each stage includes different objectives for education and requires use of different knowledge and skills relatively. A defined process with stages in design education is beneficial for design students to understand design as an action, a process and a solution, to develop their own skills, to create their own design approaches and to experience the processes they will encounter in professional life (Tovey, 2012).

To support the progress of the design students, different instructional approaches are applied and larger part of this approach is project-based work individually or in group (Souleles, 2013), especially in studio courses. Studio courses are supported with studio-based activities, such as workshops, sharing experiences and critiques to support individual or team work and to enhance effective studio environments. The critique sessions are beneficial for the design students to present their progress and to discuss with the tutors in order to get feedback. The informal critiques take place during studio sessions and these studio sessions include the individual presentation of each student to get feedback from tutors and sometimes industry experts and to be evaluated (Souleles, 2013). Despite the challenges in design education, such as new methods in teaching and increasing number of students, the design critiques and project-based works remain a distinctive and important method for design education.

Design studio is seen as an important learning environment for design education, where the learning-by-doing model takes place in, and communication between the design students and tutors support the product development process.

The development of digital technologies and tools contributes to adapt and use them during design studios and desk crits, which might affect the use of other design representation tools. The younger generation of design students has adapted themselves to this change. The current generation of design students, who are more computer literate, show up in the design studios with their notebooks installed with the latest software (Souleles, 2013). This adaptation of the technologies should be directed to support the product development process of design students and to enhance the learning environment, such as desk crits, for design education.

2.1.2. Design activities under the stages of the product development process

A study conducted with engineering students by Atman and Bursic (1996) to define the activities in the design process found that the stages that the students followed were; *identification of need, problem definition, information gathering, idea generation, modeling, feasibility analysis, evaluation, decision, communication, implementation* and *other*. The student carried out the activities in these stages while solving the design problems in order to reach design solutions. The detailed explanation of these activities can be seen in Table 2.1.

Table 2.1. The stages of the design process defined by Atman and Bursic (1996, p. 244)

The stages	**Activities carried out in the stages**
Identification of need	Identify basic needs (purpose, reason for design)
Problem definition	Define what the problem really is, identify constraints, identify criteria, reread problem statement, question the problem statement
Information gathering	Searching for and collecting needed information
Generate ideas	Develop possible ideas for a solution, come up with ideas, list different alternatives
Modeling	Modeling, describe how to build the idea, how to make it, measurements, dimensions, calculations
Feasibility analysis	Determining workability, verification of workability, does it meet constraints, criteria, does it make sense, etc.
Evaluation	Comparing alternatives, judgement about various options, is one better, cheaper, more accurate
Decision	Select one idea or solution among alternatives
Communication	Define the design to others, write down a solution or instructions
Implementation	Produce or construct a physical device, product, or system (note that in the experiment, subjects can only discuss implementation, they cannot actually do it)
Other	This code is used when none of the above codes can be applied. For example, the subject may be transitioning between two steps ('OK, let's see.). It also may be used when the subject says something not relevant to the problem being solved

Although these stages and activities were defined for the engineering design process, it can be seen that there are similar stages and activities during the project development processes followed in industrial design education. Studio-based activities in industrial design education are important to support the students' design process. Workshops, design critiques with tutors and group critiques or evaluation critiques, in which the design students present to their concepts/product to discuss with a group of tutor and consultant(s), are included in studio learning environment to support the stages that students follow in their product development processes. These design activities take place in the design stages of studio-based education.

2.1.3. Design considerations of the product development process

Starting from the beginning of a product development process, designers pay attention to multiple considerations related to product aspects in order to reach better design solutions. Some of these considerations are generally common for all design solutions, such as ease of use and safety. On the other hand, industrial designers need to pay more attention to specific aspects for specific products. For instance, with the development of the digital technology, interactive products including digital user interfaces are increasing and designers need to develop better solutions for these product interactions in order to meet the expectations of users.

Users are one of the important sources of information providing designers an understanding of their needs and expectations for effective design solutions. Bruseberg and McDonagh-Philp (2001, p. 435) state "industrial design training is embracing the need for designers to elicit user needs in order to support the development of successful new products". To do so, product design education included user centered design methodologies by reflecting the professional practice (McDonald-Philp and Lebbon, 2000). Understanding the users is essential to fulfil the expectations and needs of the users, such as emotional needs. Empathizing with a certain user group is crucial for designers to reach effective solutions that respond to the emotional needs of the user (McDonald-Philp and Lebbon, 2000). In addition, the exploration of user needs could eliminate the risk of failures in design solutions and could provide better user experience (Wu and Pillan, 2017).

User experience (UX) can be considered as interaction with the product, usability, desire towards a product or emotional relationship. Hassenzahl (2008, p. 12) defines UX as "momentary, primarily evaluative feeling (good-bad) while interacting with a product or service" by emphasizing the user and feelings through function, interaction and presentation. Sproll et al. (2010) emphasize the importance of UX indicating that it needs to be considered starting from earlier stages of product development to eliminate failures in design. In addition, industrial designers need to apply different approaches in order to evaluate the UX qualities of their concepts in order to reach better design solutions providing better experiences. Users, their needs and expectations, their emotions, and user experience are important factors that industrial designers need to consider during product development.

In addition to these factors, industrial designers need to focus more on interaction or user interfaces with the changes in user-product interaction and relatively user behavior towards the smart products that have been changed and developed in time. With the integration of technology and digital displays into the products connected and controlled through interaction, industrial designers need to explore the interaction of tangible products (Vitali et al., 2017). Interaction is also an important factor that needs to be taken as another design consideration. As stated by Yang and Chen (2009), the core of interaction design is to make a balance between the user and technology by improving emotional enjoyment and user experience, which needs to be sustained by industrial designers. Similarly, user interface is a design consideration that industrial designers need to take into account, in order to fulfil the expectations and needs of users for physical products including a user interface, by providing better user experience through better usability.

Physical ergonomics is an important design consideration that industrial designers need to take into account during product development to reach successful design solutions. Industrial designers need to access ergonomics information through research or access to necessary information from ergonomists. CAD systems provide design tools that enable industrial designers make ergonomics evaluations, such as posture, reach and clearances, on the design concepts starting from the conceptual design stage (Porter et al., 1995). Physical ergonomics during the product development process for industrial designers is also to consider the capabilities of the users and their limitations to reach an appropriate posture for comfort, usability and safety. Hogberg (2005) emphasizes the importance of considering ergonomics at earlier stages of the product development process to increase the quality of the product, and mentions that product designers need to use methods supporting ergonomic consideration together with the other design considerations. For instance, Suri and Marsh (2000) suggest the scenario building method for user profiling and task analysis to get information about user characteristics, tasks, activities and goals that product designers need to consider by making user research, such as field observation or interviews.

In addition to physical ergonomics, aesthetics and relatively manufacturing need to be considered by industrial designers from users' perspectives starting from concept design in order to improve the product development process (Wallace and Jakiela, 1993). Moreover, industrial designers need to focus both on aesthetics and performance, which is about the components inside the product for successful products, and computer tools support industrial designers in deciding on component alternatives during product development in addition to considerations of aesthetics (Wallace and Jakiela, 1993). Although a relation between functionality, referring to the performance, and aesthetics was not found in a study conducted by Han et al. (2019), these design considerations were seen to play important roles in product design. However, when functionality is considered as the inner component of a product, it might most likely be in relation with aesthetics. Similarly, functional and aesthetic considerations are important factors for the success of the product design, which influences the users' perception and satisfaction about the product (Rahman et al., 2010). From users' perspective, aesthetics is considered as emotions, feelings and perceptions that users experience through product design (Lam et al., 2016; Venkatesh and Meamber, 2008). In brief, aesthetics and functionality are vital factors that might be related with each other in addition to the users' perception and satisfaction.

Considering aesthetics in product design, other related design considerations are manufacturing and materials. During the product development process, decision making about manufacturing method and material selection is done according to several factors; technical aspects, aesthetic requirements, or demand of company (Souza et al., 2017). Materials should meet the functional requirements for the desired use of the product and sensorial requirements for the senses of the user; thus, industrial designers need to select proper materials for the product they are developing by considering the technical and sensorial aspects of materials (Karana et al., 2008). Although material consideration predominantly takes part in the detailing stage, in which industrial designers need more specific information according to the details with the technical specifications, designers need different information about material aspects to consider material in different stages of the product development process, such as intangible aspects in the conceptual stage that can respond to users' perception and emotions (Karana et al., 2008). Relations between different design considerations show that a consideration needs to be thought from different perspectives in the different stages of the product development process. When manufacturing is taken into account, considering the assembly of the product also becomes important to optimize the cost and time to assemble the parts. Boothroyd (1994) emphasizes the importance of considering assembly and manufacturing starting from the earlier stages of the product development process. The importance of considering maintenance of a product is to improve user satisfaction and sustainable consumption (Zhang and Chu, 2010). In addition, maintenance has a vital role for the product life cycle and is seen as the most efficient way to sustain functionality of a product during its lifecycle (Takata et al., 2004).

In brief, as mentioned in this section, industrial designers deal with many different design considerations during the product development process in order to reach successful design solutions or better products. Design considerations are mostly related to each other and cannot be considered separately. Industrial designers need to consider these all together during their product development process. For instance, industrial designers need to consider aesthetics, usability, technology, interfaces and similar product aspects for an interactive smart product (Wu and Pillan 2017). Industrial designers take into account these considerations at different levels in different stages of the product development process by considering their relations.

2.2. Design studio education

The design studio is seen as the center of design education and design critiques are considered as the major medium in which design students present their progress to discuss with the tutors and to get feedback. Considering design studio and critiques, tutor-student relationship and the communication between them are important for tutors to transfer design knowledge to the students and are vital for the students to make knowledge representation externalized with design representation tools in order to improve the students' progress, enhancing their product development process.

2.2.1. Design critiques in studio education

The design critiques structured in the design studio are crucial for the design students both to enhance their product development process and to improve their learning processes. A study conducted by Cross (1997) showed that better qualified concepts were emerged through team discussions. Even crits by students, namely peer crits, on design concepts with their peers support the importance of the design critiques. Studio education is defined as reflection on action by Schön (1991), in which design students follow a design project under the tutors of the design studio. During their project in the design studio, students get feedback from the tutors based on their actions, namely the design activities and steps carried out during the design development process. Studio education through project-based learning consists of "learning through applying analysis, synthesis, judgement, and arguing ideas" to develop the students' design and tacit thinking skills (Hokanson, 2012, p. 73). These ideas focus on the communication between the design students and the tutors in the studio learning environment unlike a classroom experience.

Design critiques are mainly used to define a broader range of design activities including reflections, discussions, juries, and presentations, and are described in different forms. When the term *critique* is shortened to the term *crit* in design, *crit* generally refers to individual or small group activities (Hokanson, 2012). Blythman et al. (2007) report several types of crits; desk crits, formative crits, summative crits, industry project crits, group crits, reviews, seminars, peer crits, and online crits (Table 2.2).

Table 2.2. Different types of crits (Blythman et al, 2007)

The types of crit	**Explanation of the crits**
Desk crits	One to one discussions tutor and student
Formative crits	Crits which usually take place at some interim stage during a project/module before work is submitted for summative assessment.
Summative crits	Crits where a mark or grade is given for the work. This can be as part of the crit where the presentation may be taken into account as part of the mark or by staff looking at the work after feedback has been given to students.
Industry project crits	Often used by architecture and design courses, where an invited professional from industry is part of the crit panel.
Group crits	These are the most common form of crits, where a group of students take part in a crit run by one or more tutors.
Reviews	A name used by some architecture courses for a group crit.
Seminars	These sessions can be crits usually in a more intimate setting with a smaller group of students and staff.
Peer crits	These are crits run by the student group with the tutor acting as a facilitator.
Online crits	Students place their work for critique online and students send comments to the individual student.

Crits are considered as a powerful medium in the learning process of the students (Percy, 2004) and the centre medium of design studio education (Schön, 1991; Goldschmidt et al., 2010; Hokanson, 2012). On the other hand, there also are counter opinions. Percy (2004, p. 152) argues in her study that crits “fails to serve as a vehicle for students to express their learning through design”. Similarly, Blythman et al. (2007) report about summative crits that they can often be found as frustrating because the students may not progress through reflections to continue their development process. On the other hand, tutor expectation about summative crits is to teach the students how to make reflections and evaluations about their progress and develop their own judgement.

Hokanson (2012) defines the peer crits, desk crits and summative crits or final critiques as central of the design critiques. However, he also pointed out that summative crits are most likely to be less effective for idea development and students' learning. Similarly, final presentation experience was seen as less effective than the other crits in design studio learning experience (Anthony, 1987). Generative critiques, such as desk crits and group crits are seen as very successful and effective to engage students in the explanation and discussion of their design in an informal studio environment, which aims at the improvement of the students' product development process by coaching and guiding the students about their progress (Blythman et al., 2007; Hokanson, 2012). Generative critiques are considered as coaching or guiding the students (Schön, 1991; Hokanson, 2012) to improve problem solving skills, find better solutions and make better judgements (Hokanson, 2012). Desk crit, as a generative critique, is one of the most important medium of design studio education. Design students can benefit from the critiques of the tutors in order to improve their product development process (Shaffer, 2003). Therefore, it is important to support desk crits and enhance the interaction between the students and the tutors by using proper design representation tools and by integrating developing tools that can be used for industrial design education.

2.2.2. Tutor–student relationship and the role of tutors in design studio

Although there are also formal discussions, such as evaluation juries, the most common sessions in design studio is the desk crit, which can take place either at the tutor's desk or the student's desk. As also described by Schön (1985), the student presents and explain their process whereas the tutor tries to understand the problems of the students, their needs about the knowledge and also tries to observe their process. In addition, the tutor tries to intervene during the students' presentation and explanation, and respond to the students' problems, needs and understanding. This is one of the most important tutor-student communication means to improve the student's progress on a regular desk crit. With this regular communication in desk crits, students improve their knowledge, design skills and understanding with the guidance of the tutors (Goldschmidt et al., 2010; Goldschmidt, 2002).

Goldschmidt et al. (2010) define the desk crits as the most prevalent format in design studio. In addition, they describe desk ‘crits as a medium in which students present the current state of their projects in addition to the development since the last crit and the tutor discusses about their process to help them continue with their development in the right direction by asking questions, giving examples, suggesting alternatives, indicating problem areas and so on (Goldschmidt et al., 2010; Goldschmidt, 2002). During these desk crits, tutors’ role becomes important because they put their knowledge and professional skills into design studio in addition to their personalities, understanding of their role and values (Goldschmidt et al., 2010). Based on Quayle’s (1985) six teacher profiles by focusing on desk crits, Goldschmidt (2002; p. 432) lists three instructor profiles:

> “Instructor as source of expertise/authority: The instructor knows something that the student is trying to learn; he or she is expected to transmit this knowledge and know-how to the student who, in turn, is expected to know how to extract it from the instructor.
>
> Instructor as coach/facilitator: The student has potential abilities and tacit knowledge and the instructor is expected to help develop and maximize this potential through guidance and opportunities for the acquisition of experience. Schön (e.g., 1987), among others, insists on describing the design instructor as a coach.
>
> Instructor as ‘buddy’: The instructor provides positive reinforcement and encouragement and helps in the socialization process into the professional community and its culture” (p. 432).

Although there might be intersections of these profiles in a tutor’s role in design studio, the tutor can rarely perform these profiles equally (Goldschmidt, 2002). In a study conducted by Goldschmidt et al. (2010) coaching, which was defined as somewhere between dominating the crit and being facilitator with minimal impact, seemed to be the most beneficial strategy in which the students felt as equal partners.

The technology starts to take place in the studio and students use technology to present their progress (Goldschmidt, 2002). In addition, newly developing technologies lead to an increase in using digital tools in industrial design education (Bakarman, 2005), in which design students adapt themselves and bring the technology into the design studios to use during studio sessions (Souleles, 2013). Therefore, the integration of the technologies into tutor student communication needs to be directed in order to improve better communication between them by enhancing the learning environment and to support the product development process of the design students.

2.2.3. Communication model in the design studio

During design studio sessions, especially desk crits, design knowledge is communicated to the design student. Through communication or interaction between the tutor and the students, design knowledge is transferred with tutor's personal profile to provide the design students with self- conscious experiences in a meaningful way by supporting them with design knowledge to the specific case solutions (Uluoğlu, 2000). Teaching through communication in desk crits mainly depends on the tutor student communication. A model for tutor student interaction in the design studio suggested by Uluoğlu (2000) tries to define general and personal aspects of design knowledge (Figure 2.4). She also stated that "*Representation of knowledge with a communicative intent will be different from one's own internal representations. What happens within an individual's mind and what happens between two people may lead to different results*" (Uluoğlu, 2000, p.36). Thus, effective communication between the tutor and the design student is crucial in design studio education to transfer design knowledge in the intended way.

In this model, the communication or interaction is mainly provided in studio critiques through design knowledge representation. The tutor's educational role is defined by educational choices and communication style, in other words, knowledge gained through tutor guidance and experiences through tutor demonstrations. Furthermore, the tutor's architectural role is defined by architectural knowledge and design knowledge which refers to personal knowledge and might differ from other tutors based on the approach to the design process and control mechanism to handle the design process in the design studio. In addition, the tutors specifically adapt this knowledge according to the semester of the design studio, in which they define the objectives of the projects and characteristics of the studio. On the other hand, the student's role is defined by architectural and design knowledge as an architect and is defined by learning style and communication style as novice designer. Although this tutor-student interaction model in the studio is based on architecture, interaction in the industrial design studio is similar. In addition, this model is valid for the design fields including similar studio education, like industrial design and architecture.

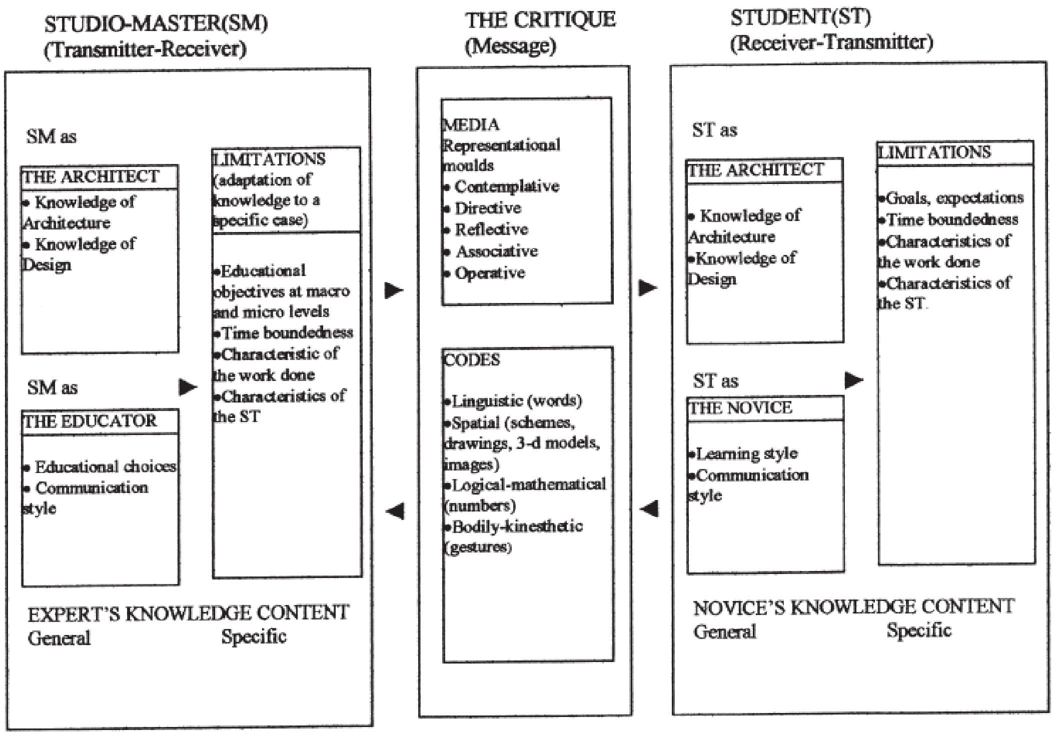

Figure 2.4. A modal for interaction between studio-master as tutor and the design students in the studio (Uluoğlu, 2000, p. 38)

Uluoğlu (2000) defined fourteen representational forms of design knowledge that the tutors use to communicate with the students during the studio critiques based on the purpose of the message to be given to the students. These are; *interpretation, coaching, questions, demonstration, description, completions, examples, reminders, positive evaluation, analogies, problem statement, scenarios, conflict statement, negative evaluation* and *others (informal conversation)* (Uluoğlu, 2000). These different representational forms depend on the purpose; these may include to understand the content, guide about how to do, enlighten the students to broaden their thinking, evaluate to move the student to next stage, and help students fill the gaps between their ideas and the products. The representational forms of design knowledge mainly define the communication and interaction between the tutor and the student during critiques in the design studio.

2.2.4. Knowledge representation in design

Owen and Horváth (2002) categorize the product realization knowledge into four levels; product development knowledge, product representation knowledge, product assessment knowledge, and product making knowledge. While development and representation knowledge is more related to the product development process, assessment and making knowledge mostly include knowledge about assessment and manufacturing. Product development knowledge includes specifications for design or product, user requirements, material selection, product technology, cost, and other knowledge related to the development process. Conceptual ideas and solutions, decisions through solutions, product optimization for solutions, experiences with a similar product that the designer develops and similar types of knowledge are related to development knowledge. This knowledge needs to be externalized with representations. Product representation knowledge is represented in several forms; definitive drawings of product or parts, physical models of concept, integration of standard or existing parts, 3D or CAD modelling, CAE analysis models, development of prototypes and similar (Owen and Horváth, 2002).

These design representation tools can be classified. Based on Owen and Horváth's (2002) classification, there are mainly five classes of knowledge representations, which are pictorial, symbolic, linguistic, virtual, and algorithmic. Product knowledge representations can be in the form of drawings (pictorial), production rules (symbolic), user requirements (linguistic), CAD modelling and virtual prototypes (virtual), or operational procedures (algorithmic). Representative examples of knowledge representations from product design for different classes are given in Table 2.3 and knowledge representations used in different stages of product design are seen in Figure 2.5.

When looking at the classes of knowledge representations, *pictorial, linguistic* and *virtual* representations are the ones that are used by industrial designers during the product development process. In addition to these knowledge representations, *physical* representation can also be considered as mock-ups, physical models, and prototypes, either of low fidelity or working ones, and such similar tools. Therefore, there are mainly four classes of product design knowledge representations used in design education, namely, pictorial, linguistic, physical, and virtual.

As stated by Chandrasegaran et al. (2013), some representations can be included in different classes and this classification of knowledge representation does not show a strict distinction between different representations. This indicates the relationship between different knowledge representation tools used in the design process. An effective product design as a supportive tool during the product development process is defined as the ability to capture the knowledge, the ability to present knowledge relevant to the context, and the ability to reuse the knowledge (Chandrasegaran et al., 2013). Considering the iterative process of product design, different knowledge representation tools need to support each other and allow the designers to enhance their process in terms of better exploration of design ideas and solutions, better decisions and evaluations, and better representations that increase communication in collaborative settings.

Table 2.3. Examples of knowledge representations for different classes (Chandrasegaran et al., 2013)

Classes of knowledge representations	**Examples of knowledge representations from product design**
Pictorial representations	Sketches, detailed drawings, charts, photographs, CAD model views
Symbolic representations	Decision tables, production rules, flow charts, assembly tree, fishbone diagram, ontologies,
Linguistic representations	Customer requirements, design rules, constraints, analogies, customer feedback, verbal communication,
Virtual representations	CAD models, CAE simulation, virtual reality simulations, virtual prototypes, animations, multimedia,
Algorithmic representations	Mathematical equations, parametrizations, constraint solvers, computer algorithms, design/operational procedures

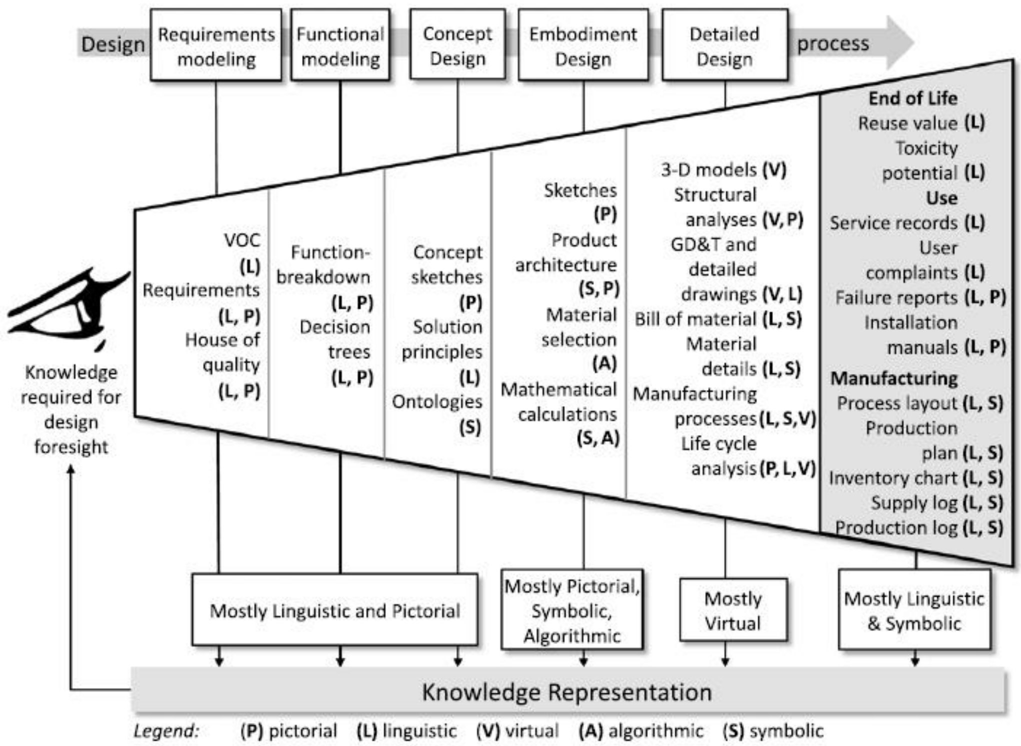

Figure 2.5. Knowledge representations in different stages of product design. Design process based on Pahl and Beitz (1996) and classification of knowledge representation based on Owen and Horváth (2002) (Chandrasegaran et al., 2013, p. 208)

2.3. Design representation tools in the product development process

Industrial designers utilize multiple design representation tools during their development process to communicate with the stakeholders or the tutors, develop their ideas, and model their concept for digital fabrication and visualization. With the development of digital tools, designers have started to integrate these tools to benefit from the advantages. On the other hand, improper use of design representation tools might lead to critical issues, like bounded ideation, which decrease the effectiveness of the development process. Without considering the power of a design representation tool and how it supports the process, idea fixation, lack of communication and inappropriate representation might emerge. The selection of the right tool according to both its ability and designers' ability is critical for designers to increase the productivity of their development process (Stolterman, 2008). The effectiveness of the design representation tools in supporting the design process enables designers to make better decisions about tool selection (Self et al., 2009). Several researches have been conducted to understand relationships between design practice and the design representation tools. The effectiveness of the tools in supporting designers' development processes were found to be mainly related to the stages of product development, such as conceptual design and detailed design.

2.3.1. Pictorial tools used in the product development process

The use of pictorial tools starting from earlier stages of the product development process is undisputedly important for idea generation, communication, conceptualization and so on. A study conducted by Menezes and Lawson (2006) showed that sketching has a strong relation with the conceptual stages of the product development process. In addition, designers' interaction with conceptual sketches is important for designers both for their productivity and for communicating with others. The importance of interacting through conceptual sketches to support productivity was also reported on several researches (Goldschmidt, 1991; Suwa and Tversky, 1997; Tovey et al., 2003). The interaction of design students with their drawings during the conceptual phase seemed to be stronger and more relevant to students than their skills (Menezes and Lawson, 2006). The vital role of sketching is to initiate and develop creative ideas starting from earlier stages of the design process, and generation, revision, and refinement of the ideas can easily be done with sketching (Shih et al., 2017).

A study conducted by Cardella et al. (2006) showed that sketching also had an important role in problem solving activities and supported communication during the design process. In addition, McGown et al. (1998) found in their study that the use of sketching is more common in the conceptual stage, with the highest use during the beginning of the product development process, having the advantages of speed and ease of use. Different types of sketching were also identified, depending on the purpose of the designers. For instance, thinking, talking and prescriptive sketches were identified by Ferguson (1992); realization, learning and designer sketching profiles were identified by Bar-Eli (2013); and other types, such as working sketch, preliminary sketch, conceptual sketch and detailed sketch, were defined in different studies (Goel, 1995; Do and Gross, 1996). Thinking sketches can be considered as the interaction of design students with their drawings during their individual processes, whereas talking sketches are those that support the discussions within a group. Prescriptive sketches are those used for communicating with people from outside of the product development process. Conceptual sketching is considered as the centre of the emergence of new ideas that were not planned, as well as the centre of the transformation, development and generation of new ideas (Menezes and Lawson, 2006; Sun et al., 2014). In a study conducted by Pei et al. (2011), sketching is grouped under four categories; *personal sketches* including idea, study, referential and memory sketch, *shared sketches* including coded and info sketch, *persuasive sketches* including sketch rendering and *handover sketches* including prescriptive sketches. Each group has different purpose, personal sketches for externalization of thoughts, shared sketches for conveying information, persuasive sketches for evaluation of the design concept with realistic representations and handover sketches for conveying required information to other member in the team.

2.3.2. Physical tools used in the product development process

Physical tools are integrated into the design process by designers for various purposes during different activities within different stages of the product development process, used for solving problems, supporting idea generation, evaluating ideas and concepts, and effective communication. As stated in Robin (1993), James Dyson, a popular designer with his inventions, reaches creative designs by experiencing and observing physical objects. His approach to solve the problems depends on working with physical objects in the workshop. Although some studies point to the risks of using prototypes in the earlier stages of the development process such as time constraints (Dow et al., 2010) and idea fixation (Christensen and Schunn, 2007), opposite results have been indicated in other studies. When physical prototypes are integrated into the design process rather than only sketching, more beneficial ideas emerge with the assistance of the physical models in design reasoning (Viswanathan and Linsey, 2009).

The results of a study conducted by Salwa et al. (2015) show that participants that integrate prototypes in early stages of the design process increase the number of ideas when compared to others who do not, resulting in more creative ideas with the help of prototypes. Thus, using low fidelity models and prototypes iteratively as early as possible is suggested to underline critical problems and to widen the creative design solutions more effectively. Using low fidelity models and prototypes properly in early stages of the development process enables designers to make evaluation and verify critical requirements, resulting in better final design solutions. A research carried out by Yang and Epstein (2005) indicated that less detailed prototypes result in better final designs. These studies intensify the idea that low fidelity models and prototypes with less details can also support the designers in solving problems with improved idea generation and better design solutions starting from earlier stages of the product development process. Pei et al. (2011) defines the physical models used in industrial design as sketch models, design development models, operational models and appearance models. Sketch models are used to capture the key characteristics of the design concept whereas design development models are used to explore the relations between different parts. Operational models are used to understand how the product is used and to evaluate physical ergonomics whereas appearance models are for physical representation of the product. They also define appearance prototypes used in industrial design for detailed representation of the product with its final form, functional aspects and ergonomics.

Designers are encouraged to use physical models in the design process as a tool for evaluating and stimulating ideas (Charlesworth, 2007). In addition, prototypes in the later stages of the design process are important to evaluate design concepts for the continuation of the development process, and prototypes of design concepts made in the early stages are known to lead to mature outcomes (Sanders and Stappers, 2015). The other significant roles of the prototypes are to trigger effective communication in collaborative settings (Stappers, 2009) and to act as innovation catalyst in group environments in the early stages of the design process (Mahtani et al., 2019).

As stated by Mahtani et al. (2019), prototyping tools need to be cost effective to evaluate ideas or concept(s) by using prototypes and these prototypes need to provide the right feedback to designers. In addition, effective communication through prototypes needs to be supported with prototyping tools. Prototypes should be dynamic, enabling designers to make quick changes or iterations. In this sense, the use of 3D modelling allows designers to turn their prototyping into a quick and clean process. However, integrating CAD and rapid prototyping instead physical modelling needs to be managed carefully by design educators (Charlesworth, 2007).

2.3.3. Digital and virtual tools used in the product development process

The integration of digital tools into the product development process allows the support of different design activities carried out within the stages of the design process; namely visualization, generating new ideas, creativity in groups, communication, and fabrication. One of the potentials of CAD is the support that it provides for enhanced visualization and communication through digital models (Robertson and Radcliffe, 2009). In addition, it supports the creative process with the implementation of new ideas as well as the communication between the partners. Computer based tools can also be used to record ideas, which makes communication and sharing of ideas easier within groups (Dennis and Williams, 2003).

CAD models have the potential of enhancing the cognitive activities of designers starting from the early stages of the design process, as well as sketching (Shih et al., 2017). In a study conducted by Robin (1993), CAD was seen as a tool that helps designer explore and present the design ideas effectively after the conceptual phase. Oxman (2006) states that CAD technology is used for graphical representation, advanced modelling and evaluation during different stages of the product development process. In addition, CAD has the ability to support detailed design in the later stages of the design process when compared to sketching (Self et al., 2009). Shih et al. (2017) stated several advantages of CAD models and indicates a major advantage as the information precision of the product, such as layout and scale, which allows the designer focus more on their process. Moreover, CAD models support interactive and visual environments that support the exploration of the ideas. Salman et al. (2014) state that CAD tools can be used to generate conceptual designs, to inform about the design, and to present the design.

It can be easily seen from these studies that the use of digital tools, especially CAD tools for designers, has increased starting from the early stages of the product development process through to the later stages. This increase has roots in the advantages of digital tools, such as enhancing cognitive activities of designers, supporting the exploration and presentation of ideas, and supporting enhanced visualization and communication through digital models. On the other hand, there may be critical disadvantages of the use of CAD tools. Shih et al. (2017) state that using CAD tools may influence circumscribed thinking negatively, which leads to decrease in creativity. In addition, these tools may cause bounded ideation and therefore may not be always helpful for idea generation. When the design idea becomes more detailed, design fixation may emerge resulting in the resistance of further development of the product. However, when CAD tools are used properly during the product development process starting from the earlier stages, they may support and enhance designers' processes from different points. Switching between different design representation tools or using them together will be more effective, supportive and helpful for designers.

2.3.4. Approach towards design representation tools

As mentioned in previous sections, each design representation tool has advantages for different phases of the product development process. Several studies indicate the advantages and disadvantages or benefits and challenges of design representation tools. In addition, some of these studies compare different design representation tools, especially sketching versus CAD modelling, such as Sachse et al. (2001), Won (2001), and Rahimian et al. (2008a). Regarding the benefits and challenges of design representation tools as discussed in the literature, switching between different design representation tools that support each other or using them together to enhance the product development process has been suggested. The characteristics of design representation tools that the designers utilize during the product development process fulfil several needs of designers (Rahimian et al., 2008b).

In a study conducted by Ibrahim and Rahimian (2010), there seemed a preference of the designers to switch between different design representation tools, namely sketching and CAD modelling. Won (2001) found that conventional tools and computer systems had different benefits for designers' visual thinking in the conceptual stage of the design process. As stated by Shih et al. (2017), design environments need to be provided with different tools instead of being limited to a specific design representation tool. This points to the importance of using different design representation tools that support each other. Chen (2007, pp. 580-581) stated that;

> "The experimental results demonstrate that using conventional and digital media simultaneously, as comparing with using only one media, helps arouse creative thinking and cognitive activity and improves the design outcome in the stage of conceptual sketches design. Particularly, the interaction between two media

> promotes cognitive thinking to the broader field and find more complex mode of design thinking. The combination of conventional and digital design media not only provides diverse experiential association, but also has more opportunities than individual media to generate creative results" (pp. 580-581).

In addition, Ibrahim and Rahimian's (2010) study showed that mixed media environment including conventional sketching and CAD tools resulted in higher solution quality when compared to single use of either sketching or CAD modelling, and mixed media environment was the most effective among these three settings. Based on Rahimian et al.'s (2008a) study showing the benefits and challenges of sketching and CAD modelling, Shih et al. (2017) stated that these two design representation tools have a complementary relationship and suggested a switching behavior model for mixed design environments including sketching and CAD modelling. Their study showed that switching between different representation tools was considered as an ideal approach for the conceptual stage by all participants with several advantages; helping designers make proper decisions about their design, enhancing co-evaluation and the natural workflow of the design process. In addition, integration of these tools into each other helped designers during problem exploration and solution refinement with iterative switches supporting the design process.

The main approach towards design representation tools is to switch between them or to use them together by supporting each other. However, most of the studies are conducted to find out the relationship between sketching and CAD modelling. For the product development process, other tools also have the potential to enhance the product development process as well as sketching and CAD modelling. Therefore, it is also important to explore the relationship between other design representation tools, not only sketching and CAD modelling.

2.4. Summary and discussion

In industrial design education, the product development process includes several stages with different objectives and requirements to transfer design knowledge, develop the student's skills, and enable the students to develop their own design process with the design projects conducted during their education. Design studio is seen as the most important medium and considered as the centre of design education, supported with studio-based activities, such as design critiques and workshops, to transfer design knowledge and develop students' skills through communication and interaction between tutors and students. Desk crits are beneficial for design students to present their progress and discuss with the tutors and get feedback from them in order to enhance their product development process and improve their learning process.

During their product development process in the design studio, design students carry out different design activities, such as problem identification, idea generation, evaluation, preparation, and communication. In addition, design students pay attention to several considerations related to product aspects in order to reach better design solutions starting from the beginning of a product development process, such as user experience, ergonomics, aesthetics related to form, manufacturing and material.

They explain these considerations during desk crits to transfer design knowledge by using different design representation tools in order to discuss and get feedback from the tutors. Design students utilize different design representation tools, such as sketching, visual mock-ups and 3D models, to externalize design considerations developed during the product development process. Integration of newly developing technologies into design education is increasing and this integration can influence the use of other design representation tools. The adaptation of the younger generation to the technology lead to an increase in the use of technology in the design studio such as the use of personal notebooks with latest software in design studio.

Design representation tools are critical for the desk crits to enhance the communication and interaction between design students and tutors. Several studies were conducted to find out the relations between the stages of the product development process and design representation tools. Moreover, the relation between design activities and these tools were studied in addition to the benefits and challenges of these tools. One of the most important parts of desk crits is the explanation made by the students about their design considerations that develop during the product development process. Communication and interaction with the tutor during desk crits is mainly based on design considerations and how students have handled them in their design solutions. However, there is a lack of studies exploring the relations between design considerations and design representation tools. Exploring this relationship is vital to find out how communication and interaction between design students and tutors during desk crits can be enhanced with the proper use of the design representation tools. In addition, it is important to find out how developing technologies, which will be adapted into design education with further developments, can be integrated into desk crits in terms of the relationship between design considerations and developing technology, such as the use of AR during desk crits. For this purpose, it is important to firstly identify the relationship between design considerations and design representation tools by exploring the product development process. By this way, it is also important to explore how and in which ways AR can be integrated into the product development process, especially into desk crits.

CHAPTER 3

AUGMENTED REALITY
AS A DEVELOPING TECHNOLOGY

Augmented reality (AR) is a developing technology and has potentials for education as stated in Horizon reports, which are mentioned in Section 1.1. Many researches have been done to explore this technology in education in order to find out its advantages and disadvantages. Researches were also conducted in product design with the development of AR applications for different stages of the design process. However, creating effective environments with AR technology in industrial design education is still infant. Aiming at the integration of AR technology into design education, literature review about AR in industrial design will be presented in this chapter by mentioning developed applications for product design, its benefits and drawbacks for product development process. In addition, literature review about AR in education will be presented to have a better understanding about AR in education, which might have a reflection for industrial design. Before presenting these topics, AR technology will be presented.

3.1. Augmented reality technology

In this section, definition of AR, its terminology, brief history and developments, and basically how it works will be presented to understand AR technology.

3.1.1. Definition of augmented reality

Augmented reality, in simple terms, refers to the creation of enhanced or AR by adding computer assisted information over the real world. The terms *blended reality* and *mixed reality* are also used to define AR. Carmigniani and Furth (2011) define AR as a real-time direct or indirect view of an enhanced or augmented physical real-world environment by adding computer generated virtual information to the real world. The information added to the real world should be seamlessly integrated into users' perception of real-world environments (Yuen et al., 2011). AR as an emerging form of experience and as an evolving subject, is defined by outlining three characteristics that should be present for true AR. Firstly, AR combines real-world elements and virtual information. Secondly, AR is interactive in real-time. Thirdly, AR is used and registered in a 3D environment (the display of virtual information is presented in its location and orientation in the real-world environment). These were first listed by Azuma (1997).

In addition, initial definitions of AR were restricted to specific devices, such as the head-mounted display. However, more updatedly AR is defined as a technology in which virtual computer-generated information is overlaid onto physical objects (Zhou et al., 2008). Rather than regarding it as a technology, Yuen et al., (2011) refer to AR as a range of technologies that generate information on users' perception. Furthermore, it is argued that AR should be viewed as a concept including aspects more than technology because this would be more productive for researchers and designers (Wu et al., 2013).

3.1.2. Taxonomy of augmented reality

As mentioned by Milgram et al. (1994), the emergence of the AR concept is an extension of virtual reality (VR) and considering these two concepts together is quite important because of their relation. Instead of considering the two concepts separately, Milgram and his colleagues (1994) defined them as opposite ends of a continuum, the Reality-Virtuality (RV) continuum, which is illustrated in Figure 3.1. In this continuum, four types of environments are defined. At the left end of the continuum is the real environment that completely consists of real objects. At the right end of the continuum is the virtual environment, in which all information is completely generated by computer and is perceived as unrelated to the real environment. Mixed reality (MR) is defined as the representation of real-world and virtual world objects/information together. While AR is presented closer to the real world that is enhanced with computer-generated information, augmented virtuality (AV) is closer to the virtual environment that has additional objects from the real world.

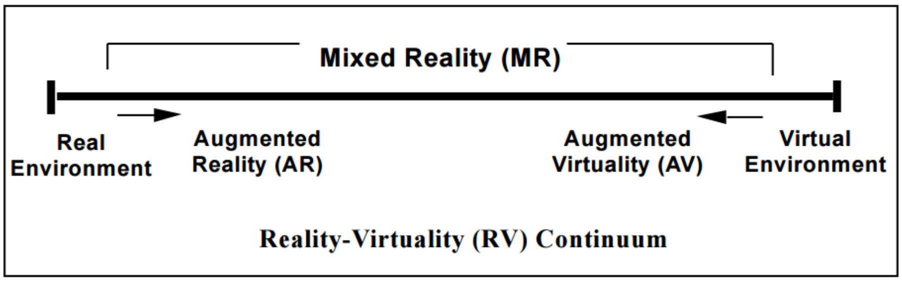

Figure 3.1. Simplified Presentation of RV Continuum (Milgram et al., 1994, p. 283)

The RV continuum proposed by Milgram et al. (1994) is a simplified taxonomy. Classifications of AR environments have been done in different concepts. An overview of these concepts in the literature is presented by Hugues et al. (2011). They propose a functional classification (Figure 3.2) in which AR environments are divided into two different groups, augmented perception of reality and artificial environment.

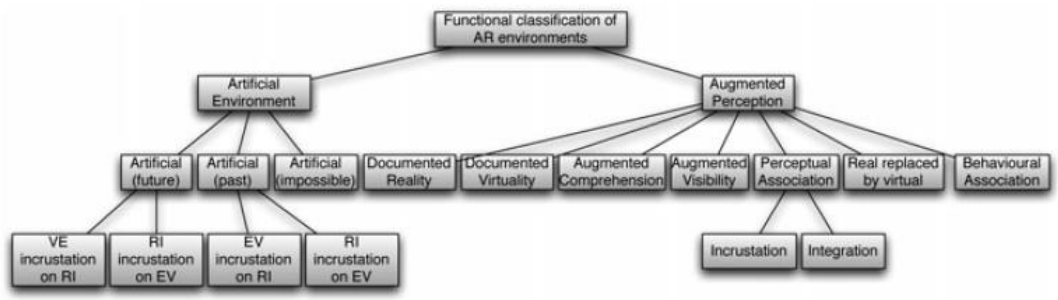

Figure 3.2. Functional classification of AR. (RI: image with "real" content, VE: virtual entity) (Hugues et al., 2011, p. 51)

Augmented perception is about different functionalities enabling a better understanding of the real-world environment, helping the optimization of one's actions. In some cases, AR produces environments that do not serve any practical requirements and functions. This concept is presented as the artificial environment.

3.1.3. Brief history of and developments in augmented reality

A brief timeline of AR history is presented in Figure 3.3, referring to different sources. A simulator called “Sensorama”, which is known as one of the earliest multisensory technologies consisting of visuals, sound, vibration and smell, was developed by Morton Heilig in 1962. In 1968, Ivan Sutherland developed the first AR system, “The Sword of Damocles”, using a head-mounted display, which is one of the earliest examples. Interaction with virtual objects emerged for the first time in 1975 with the creation of “Videoplace” by Myron Krueger. In 1989, the term “Virtual Reality” was introduced by Jaron Lanier.

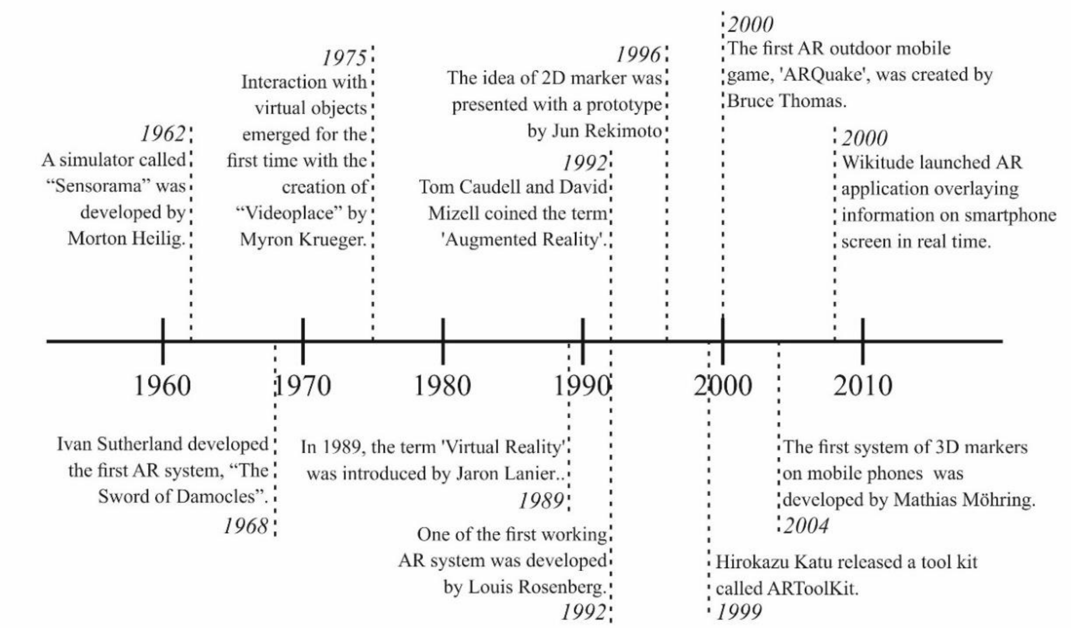

Figure 3.3. A brief timeline of AR History (composed from different sources; Hamilton, 2012; Kipper and Rampolla, 2013)

Shortly after, Boeing researchers Tom Caudell and David Mizell, coined the term “Augmented Reality” in 1992. One of the first working AR systems was developed by Louis Rosenberg in 1992. The idea of 2D marker, that is used to join real and virtual environments, was presented with a prototype by Jun Rekimoto in 1996. The three characteristics of AR mentioned in Section 3.1.1 were introduced by Ronald Azuma in 1997. In 1999, Hirokazu Katu released a tool kit called ARToolKit allowing the creation of AR systems. The first AR outdoor mobile game, "ARQuake", was created by Bruce Thomas in 2000. The first system of 3D markers on mobile phones allowing the detection of different markers was developed by Mathias Möhring in 2004. In 2008, Wikitude World Browser with AR overlaying generated information on smartphone screen in real time was launched. Although the development of AR technologies and how technology is used to enhance users' experience have been recorded for the past four decades (Billinghurst and Henrysson, 2009), the significant increase in research and development has started starting from 2000s (Yuen et al., 2011).

3.1.4. Tasks in augmented reality process

In AR systems, there are mainly four tasks in the process; *scene capture*, *scene identification*, *scene processing*, and *scene visualization* (Lopez et al, 2010) (Figure 3.4). Scene capture is the caption of the image from the real-world environment to augment virtual information over it in the next steps. The scene capture devices that are able to perceive reality can be divided into two types, namely, video-through devices such as smart phones with cameras and video cameras, and see-through devices such as head-mounted displays (Lopez et al, 2010).

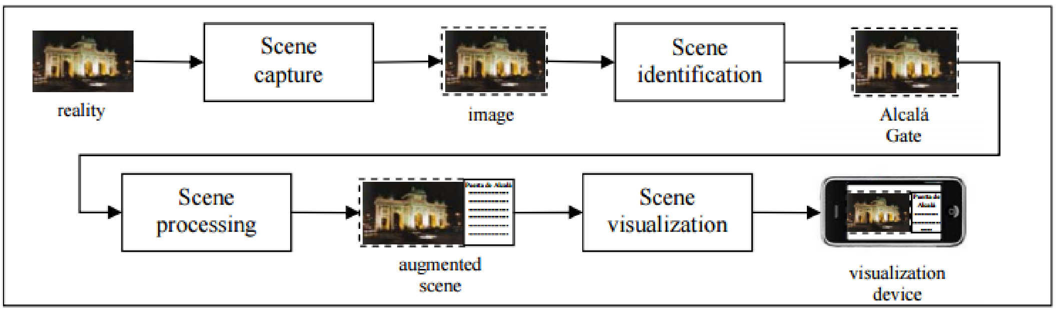

Figure 3.4. Four tasks in the AR process (Lopez, Navarro, and Relano, 2010, p. 245)

The second task is scene identification that needs to select the accurate information from reality to augment it by using marker-based or markerless-based identification techniques. After capturing and identifying the scene, scene processing occurs where augmenting any type of virtual content over real environment happens. Finally, the

AR system generates the final scene image, which is the integration of virtual information onto reality, for enhancing users' experience.

3.2. Augmented reality in education

Augmented reality (AR) provides new possibilities and opportunities for education. Educational applications have been developed and the studies were conducted to find out advantages, disadvantages and learning gains in order to support learning environments with AR technology. This section will present these topics to have a reflection for design education.

3.2.1. Augmented reality in education

Educational researchers have started to show interest in exploring new ways of both learning and teaching (Wu et al., 2013). AR has the ability to enable learners to explore different contents from different perspectives, and be useful for situations that cannot be experienced first-hand (Kerawalla et al., 2006). Situations that are hard to experience in reality or in other learning environments are provided by the integration of virtual objects with real environments to be experienced by users (Klopfer and Squire, 2008). The visualization of spatial relationships and the interactions of elements in a 3D space become possible to show in real environments seamlessly enhanced with virtual information (Kerawalla et al., 2006). These advantages of using AR in education give this technology an important role in education, as also shown by the analysis of Horizon reports conducted by Martin et al. (2011).

Although using AR in education has some challenges, such as integration with learning methods and general resistance to new technologies, AR has the potential to attract learners by allowing them to explore materials from different perspectives not being considered in real life (Lee, 2012). Lee (2012) also mentions that the approaches of using AR in education have wider user adoption than before with the developments in technology. By enhancing reality with virtual information, current efforts of using AR in education or learning are mostly employed in sciences as well as other fields, such as mechanics and medicine, in order to improve the complex understanding of learners.

3.2.2. Educational applications of augmented reality

According to Yuen et al. (2013), AR books are a major starting point in creating a connection between the real and digital worlds for educational applications. As an example given by Yuen (2010), a 3D AR geology textbook is developed by The Institute for the Promotion of Teaching Science and Technology in Thailand allowing students to explore the different layers of the earth, their discovery, their relationships, and functions in interactive ways, such as illustrations of 3D and demonstrations of information.

AR systems can enhance collaboration between the teacher and students. "Construct3D", a 3D geometric construction tool, is developed specifically for mathematics and geometry education in order to improve spatial abilities and maximize transfer of learning (Kaufmann, 2002). The application enables users to collaboratively create virtual geometric shapes with head-worn displays provided for them and share this real and virtual environment constructed by them (Figure 3.5a).

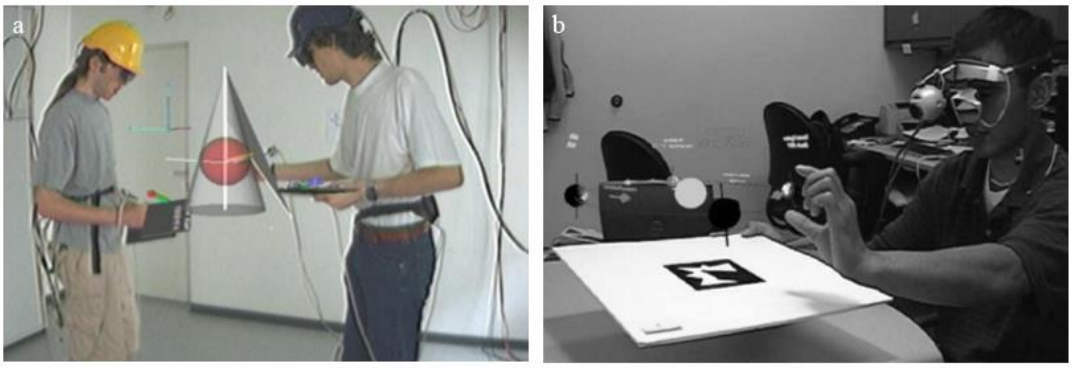

Figure 3.5. (a) "Construct3D", AR geometric construction tool (Kaufmann, 2002, p. 656) (b) A student interacting with real and artificial objects through AR (Shelton and Hedley, 2004, p. 324)

The studies conducted by Kaufmann and Schmalstieg (2003) show that the "Construct3D" tool encourages users to experience with geometric shapes and improves their spatial skills in addition to collaborative learning. The relationship between objects can be learned interactively by integrating virtual information on the real world in many fields, such as biology, chemistry, and astronomy. For instance, AR has the ability to help users learn the relationship between the planets and the sun by enabling them to see virtual data in their environment and by giving the control of the viewing angle to make invisible ones visible, as seen in Figure 3.5b (Shelton and Hedley, 2003). Shelton and Hedley (2003, p. 324) state that "the unique characteristics of 1st person manipulative AR appear to embody significant potential for the cognition of visualizations of spatial information". Allowing students to regenerate, rotate or manipulate virtual information provides them immediate feedback based on the changes by enabling users to experience how objects would look in different settings (Yuen et al., 2011).

Many AR educational applications have the ability to provide a live experience by using a discovery-driven learning approach, such as a visitor going to a historic site or a museum, being able to access AR applications that enhance real world with virtual information (maps, images, videos, or audio content) in real time (Hamilton, 2013). Campus tours developed by using AR technologies are now provided by universities and colleges. An iPhone application, "uTourX", supports tours of Harvard, MIT, Yale, and Stanford (osnapplicationsLLC, 2009). Students can discover information about buildings or areas on campus by pointing their iPhone (Figure 3.6a). Similarly, AR has the potential to allow users to discover how a historical location looked like in different time periods, such as the application "Archeoguide". Considering this example, AR applications could be helpful for students, especially those who are interested in archeology and history. To discover new locations in a city that a tourist visits, new ways to enhance experiences are developed by integrating virtual information on real environment, giving information or showing a video about a location in a city. "CultureClic" is an example of an AR application for smartphones, enabling visitors in France to discover museums, other touristic places and also information about cultural events, as seen in Figure 3.6b (CultureClic Augmented Culture, 2010).

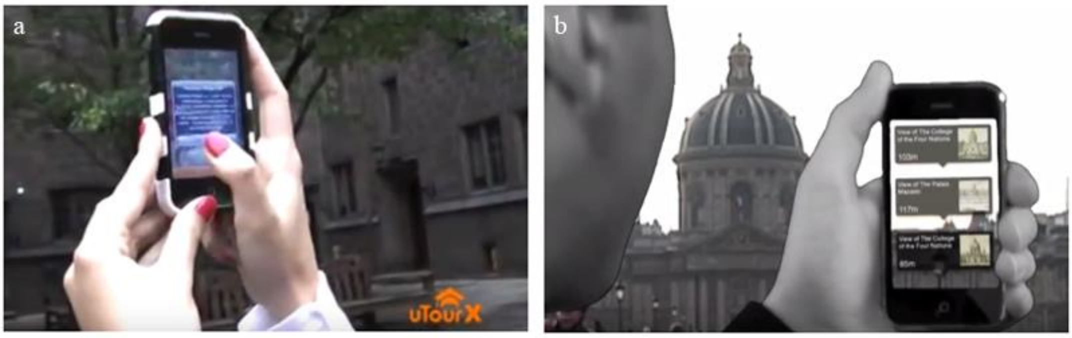

Figure 3.6. (a) “uTourX”, an iPhone application supporting tours of Harvard, MIT, Yale, and Stanford (osnapplicationsLLC, 2009) (b) “CultureClic” application allowing visitors in France to discover touristic places (CultureClic Augmented Culture, 2010)

Games based AR applications have the potential to engage students in learning. Yuen et al. (2013, p. 399) state that “through AR games, educators have the chance to let students experience a form of highly interactive, collaborative, problem-based learning that holds students’ attention while teaching a variety of highly transferable skills”. The potential of AR games as engaging environments for learning, and practicing necessary skills is evaluated by Schrier (2006) with a game called “Reliving the Revolution”. In this game, various roles of a battle are assigned to the game players and they are interacting with historic virtual characters and different evidences to explore the battle by using a hand-held device that utilizes location triggering events in order to reach their goals. The result of initial evaluation shows that when AR games are developed for pedagogical purposes properly, they can improve 21st century skills, such as interpretation, problem solving, multimodal thinking, teamwork, information management, flexibility, and the acceptance of diverse perspectives (Schrier, 2006). However, a game called “Alien Contact” also points out some disadvantages of AR games. The game is similarly developed (assigning roles, collecting evidence, and reaching answers) by Dunleavy et al. (2009) to teach math, language arts, and scientific literacy skills. The study shows that students are heavily engaged in hand-held display. Although it seems an advantage to get enough attention of students, they can ignore the real world around;

thus, losing track of actual surroundings, which poses a physical safety risk for students (Dunleavy et al., 2009). In spite of these disadvantages, AR games have the potential to create effective systems for increasing students' attention in addition to teaching different skills (Yuen et al., 2011).

3.2.3. Advantages and disadvantages of education with augmented reality

Many researchers have studied the advantages and disadvantages of AR technologies in terms of how to improve educational aspects. The studies also show that AR is a promising technology for improving learning performance and motivation based on virtual information. Bacca et al. (2014) conducted a review of using AR in education, analyzing 32 studies published in six indexed journals in the last decade; the review shows that AR applications support learning gains (43.7%), build motivation (31.2%), reinforce collaboration (18.75%), facilitate interaction (15.63%), increase experience (12.50%), provide just-in-time information (12.50%), and are low cost (12.50%). High level of motivation, students' satisfaction of materials used in AR learning environment, the possibility of different information formats, the feeling of being in control of the activities, and the personal preference to choose the topic and to revisit are the advantages explored in a study conducted by Di Serio et al. (2013) to improve the education of visual arts. They also report that students showed high levels of concentration during the tasks, managed to easily memorize the content, and spontaneously started discussion within groups to analyze the interesting materials found in the content after exploration. In addition, AR is found to have the potential to improve several aspects of education; students' engagement, learning motivation of students, better learning performance, and positive attitudes (Bacca et al., 2014).

On the other hand, maintaining stability of AR technologies becomes important. For instance, Dunleavy et al. (2009) report in their study that GPS or computer errors annoyed students. In addition to the hardware problem, software instability is also documented as a problematic issue. With the rapid development of the technologies, the stability problems could be eliminated (Wu et al., 2013; Dunleavy et al., 2009). Losing track of actual surroundings while engaged too much in the system could pose a physical safety risk (Dunleavy et al., 2009). Some researches show that students in an AR environment can become cognitively overloaded with the information provided by AR technologies, the technological devices they need to use, and the complex tasks they have to perform (Wu et al., 2013; Dunleavy et al., 2009). Another usability study conducted by Di Serio et al. (2013) indicates that students had no difficulty in using the AR system under study, and completed the tasks successfully in time. These contradicting findings are mainly about the technological defects and how the AR system is implemented into the learning environment. Therefore, the disadvantages could be easily eliminated in the near future with the rapid development of technologies related to AR and the proper implementation of AR systems in the learning environment. The usefulness and effectiveness of AR learning systems could be increased to improve education.

3.2.4. Learning gains supported by augmented reality

Several researches found out that AR experiences increase collaboration in different group settings. For instance, Freitas and Campos (2008) turned the classroom into an interactive learning environment with an AR experience to provide an enjoyable education setting. Sharing a display to experience AR technology improved participation and collaboration. The other results of this study indicated an enjoyable AR experience, leading to high motivation and positive effects in improving weak students' learning. Another research conducted by Morrison et al. (2009) investigated the collaborative use of an AR navigation map, with two groups, one given digital information displayed on a mobile screen over a paper map, and the other given a digital map displayed on a mobile screen. Team collaboration within the group using AR was found to be more effective than the group using the digital map. In addition, the AR group concentrated on AR experience, resulting in problem solving with interaction and negotiation when compared to individual use of AR. On the other hand, as mentioned in Section 3.2.3, usability problems might have had negative impact on effective collaboration.

Various researches indicate increased user motivation when engaged in an AR experience. A study conducted by Kaufmann and Dünser (2007) found higher user satisfaction in using AR when compared to the CAD version, even though the AR version was rated lower in terms of technical aspects. Although the participants of the study experienced problems related to technical issues, the AR version enabled higher user motivation supported with other advantages; namely, controllability, learnability and usefulness, which are also rated higher for the AR version. Similarly, another study carried out with children reported that they considered an AR game to be more fun than the real game and enjoyed playing the AR version more, even though playing the AR game was found more difficult than the real game (Juan et al., 2010). Surprisingly, although technical problems about the system might decrease user motivation, AR has the potential to provide higher user motivation and satisfaction.

Memory recall is another learning gain supported by AR experience. Several researches report memorizing a content with an AR experience as having a more positive effect on both immediate and long term memory. Vincenzi at al. (2003) conducted a study to find out the effectiveness of immediate and long term recall with AR versus different instructional mediums; video, interactive video and printed version. The results of this study indicated that learning instructions through AR experience had positive impact on immediate recall when compared to interactive video and printed version. In addition, learning instructions through AR experience was only rated higher than the video medium for long term recall. On the other hand, participants in AR group did not perform better than the print and interactive video groups for long term recall. However, as stated by Vincenzi et al. (2003), this difference between groups might be insignificant for long term recall because if the method of the study was more controlled in terms of learning variables and user variability, more significant results for AR experience would more likely emerge, resulting in more instructional advantage in favor of AR. Macchiarella et al. (2005)

found in their research that AR and interactive AR were more effective to retain information considering long term memory recall. Memory loss during a period of one week did not happen significantly and the difference between immediate and long term recall was not significant. On the other hand, printed and video versions of the research had significant differences between immediate and long term recall. In addition, although AR experience did not exemplify higher recall, information retained over time was more for AR. As also stated by Macchiarell et al. (2005) instructional modes of AR and interactive AR bring about improved ability for long term memory recall.

Multiple researches indicate that AR experiences increase effective learning and content understanding when compared to other mediums such as videos, printed versions or computer experiences. Hedley's (2003) research about learning geography showed that AR experience had positive impact on perception, performance and constructing cognitive representation of visualizations. Users in the AR group performed higher in spatial visualization tasks than users in the computer group, resulting in more detailed learning representations in AR experience. Sin and Zaman (2010) assessed a tangible AR tool, in which the AR application was supported with tangible user interface to provide easier interaction, versus a conventional way of learning with textbook to learn astronomy. This interactive learning experience with AR application helped the students learn better and increase their test performance by %46, whereas the students in the conventional group only increased their performance by %17. In addition, the students defined this interactive tangible AR application as easy to use and easy to learn astronomy. Easiness of using and learning might have positive effects on learning performance.

Considering industrial design education, these learning gains supported by AR, namely *effective collaboration, high user motivation and satisfaction, memory recall* and *better content understanding*, may have positive effects on design students' product development processes when the process is supported with AR technology. Integrating AR into the process may help the students increase collaboration during desk crits with studio tutors and further build their motivation to continue with the development process. During desk crit sessions, design students can explain their development process to the tutors with a better understood content so that they can get better feedback. This also leads to an increase in effective communication during desk crit sessions.

3.3. Augmented reality in industrial design

The role of 3D activities carried out in different stages of a design process is vital for the industrial designers to find better solutions. With the developments of AR technology, different AR applications were developed to support designers and studies were carried out to explore the benefits and drawbacks of AR technology for the product development process. This developing technology could provide potentials for design process with the advances and new studies.

3.3.1. Augmented reality in the product development process

AR technology can enhance the product development process by enabling industrial designers to interact with 3D virtual data that is integrated into a real environment. AR applications for different stages of the design process were developed to support the product development process, namely, *3D drawing and modelling, collaborative design, concept evaluation, mock-up for design evaluation, rapid prototyping (interactive or tangible), user interface,* and *user study*. Several researches that were conducted in the field of product development process is summarized in Table 3.1.

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Table 3.1. Overview of AR applications developed for different stages of the product development process

3D drawing and modelling		(Ng, Ong & Nee, 2010; Santos et. al., 2003)
Collaborative design		(Shen, Ong, & Nee, 2010; Gjøsæter, 2009; Ong & Shen, 2009)
Concept design		(Arbeláez-Estrada & Osorio-Gómez, 2017; Mair et al., 2014)
Evaluation (concept, physical ergonomics, etc.)		(Arbeláez-Estrada & Osorio-Gómez, 2018; Mair et al., 2014; Arbeláez-Estrada & Osorio-Gómez, 2013; Ng et al., 2011; Fründ et al., 2005)
Mock-up for design evaluation		(Park, 2008)
Rapid prototyping	**Interactive**	(Porter et al., 2010; Verlinden & Horváth, 2006)
	Tangible	(Park, Moon, & Lee, 2009; Sidharta, Oliver, & Sannier, 2006; Lee & Park, 2005)
User interface		(Escalada-Hernández et al., 2019)
User study		(Bonardi et. al, 2012; Carvalho et. al., 2011; Park, Moon, & Lee, 2009; Fründ et al., 2005, Lee & Park, 2005)

AR has provided several possibilities for the product development process by integrating virtual 3D data into the real environment. According to Cerovšek, Zupančič and Kilar (2010), in order to provide communication between several stakeholders, design processes need an externalization stage, in which digital models are deployed to realize the ideas from imagination to AR (Figure 3.7). Each externalization method has its strengths and weaknesses for different stages of the design process (Okeil, 2010). AR may help industrial design students to develop their skills with digital representation tools.

It is essential to increase engagement with the emerging technologies that can be used in design, so as to use the advantages they provide (Aldoy and Evans, 2011). Using technological representation tools can enhance the product development process in industrial design education. In addition, motivation can be positively affected with the use of AR technology when properly integrated into students' environment, leading to high levels of engagement (Serio et al., 2012). In addition, virtual prototyping enables students to save time when compared to traditional methods (Yan et al, 2006).

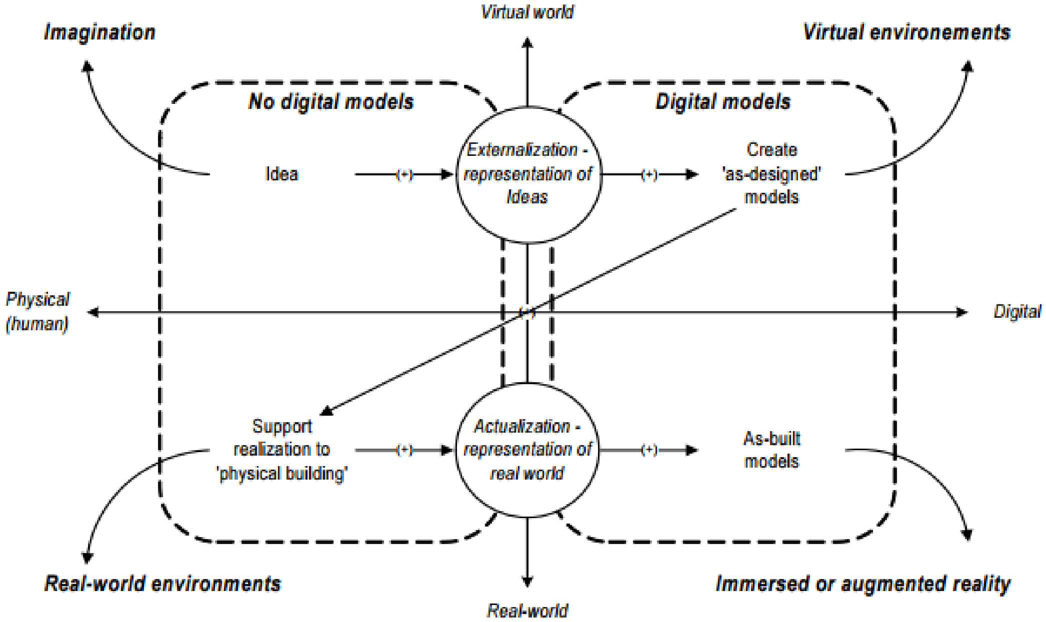


Figure 3.7. The realization of project ideas from human imagination to augmented reality (Cerovsek et al., 2010, p. 6)

The studies mentioned in Table 3.1 are mainly related to the professional field. There seems to be a lack of studies on the use of AR technologies in the field of industrial design education carried out with industrial design students.

3.3.2. Augmented reality applications in the product development process

Interest in the use of AR in the product development process is continuously increasing. Examples of applications developed for the use of AR in different stages of the product development process can be found (Table 3.1). Volkswagen provides an example that shows the projection of virtual data on physical objects with actual proportions and sizes to be assessed effectively by interior designers during the design development process (Figure 3.8) (Volkswagen, 2016). In addition to the assessment of designers, user evaluation analysis can also be conducted through the virtual data with the different design alternatives. The use of AR provides the opportunity to show, modify and assess different variants, starting from the beginning of the process; thus, this process could reduce required time and cost.

Figure 3.8. Use of spatial augmented reality
in the interior design process (Volkswagen, 2016)

The AR system developed by Santos et al. (2003) offers free-form sketching on a physical prototype leading to the flexibility of developing different design alternatives. The designer can create and manipulate the curves by using the physical prototype in the field of his view, which provides tangible feedback to create curves or surfaces more precisely (Figure 3.9). This study shows that virtual prototypes combined onto physical prototypes can provide highly 3D-interactive environments and therefore be beneficial to improve the design activities of this stage.

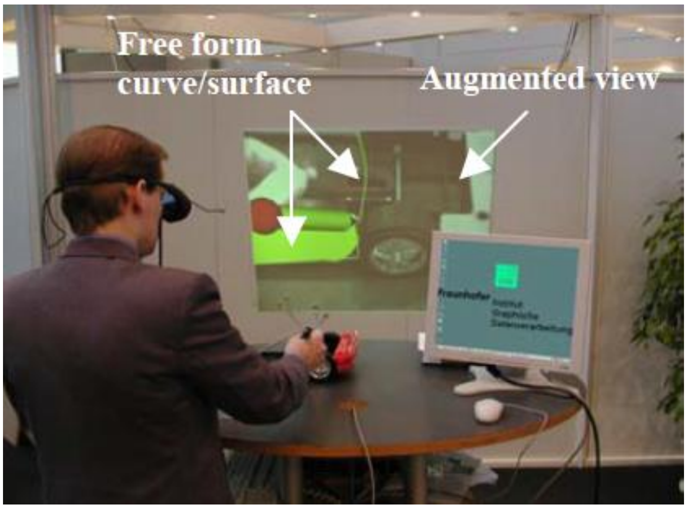


Figure 3.9. Sketching of free-form surface in augmented reality
(Santos et al., 2003, p. 1206)

Mair et al. (2014) focused on the use of AR in the conceptual stage of the product design process, with the belief that the use of AR may lead to an increase in creativity for the conceptual stage of the design process with proper interactions for the designer. An AR application was implemented into mobile devices allowing users to view different virtual models of the concepts on physical models by holding and touching them in order to make an evaluation (Figure 3.10). The results of the study showed that AR had potential to enable collaborative evaluation between the designer and the user for early evaluation of the concepts during the conceptual stage of the design process without any need to build prototypes.

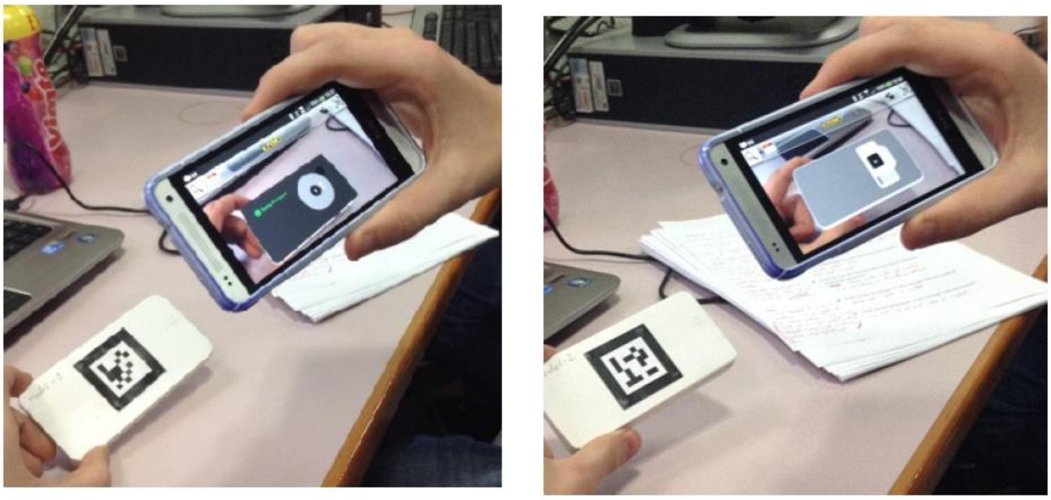


Figure 3.10. Use of augmented reality in the conceptual stage of product design (Mair et al., 2014)

An AR application for mobile devices is developed to make evaluations of concepts with potential users in terms of aesthetics, in order to get feedback or comments about the selected concept to make further improvements (Arbeláez-Estrada and Osorio-Gómez, 2013) (Figure 3.11). The interaction is in two different ways, designer and user interaction. The application allows the designer to load the 3D concepts orderly for displaying the evaluation rating of each concept and taking screenshots to compare the different concepts. The application offers users to take screenshots, give scores to the concepts, and send the completed evaluation after the rating is finished. In addition, this application is also suggested to be used for getting feedback from users about how the concept will look like in users' context. This can help designers gain insights about how the concepts are perceived.

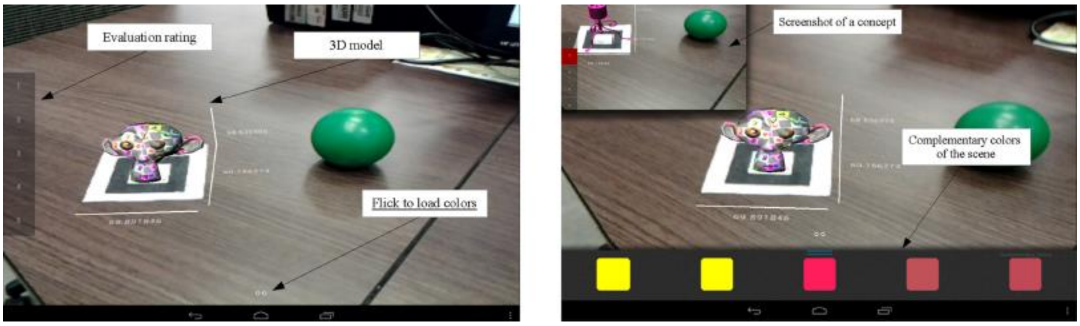


Figure 3.11. Screenshot of the start of the application (Arbeláez-Estrada and Osorio-Gómez, 2013, p.396)

The conceptual design needs to be operated to see how it will function, in order to evaluate the concepts with the end-users and get feedback from them. An example of an AR-based mock-up is presented by Park (2008) for design evaluation (Figure 3.12). Several buttons on the concept is activated with the position of the fingertip, using AR technology. The results of this study show that it is interesting to construct the mock-up and be able to use the concept as if a real product. Using this process for product design in the professional field allows flexible changes, also saving time.

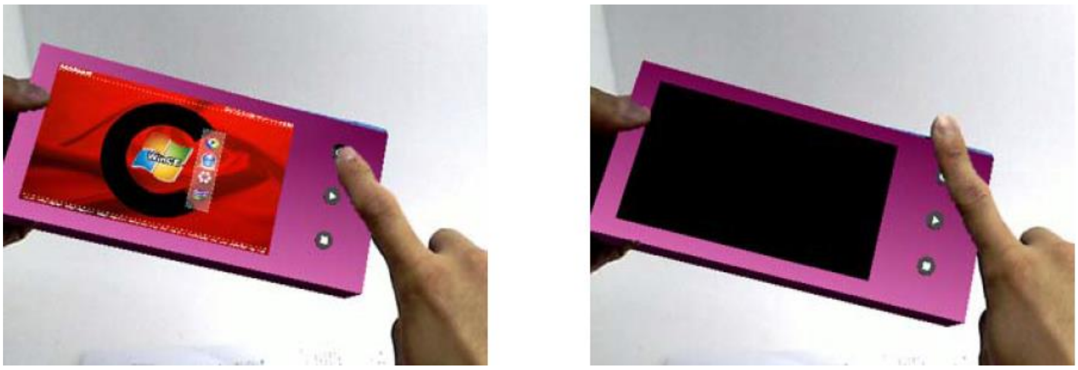


Figure 3.12. Mock-up manipulation (left, button pressed; right, button not pressed) (Park, 2008, p. 19)

3.3.3. Benefits of augmented reality for the product development process

As it can be seen from the examples of AR applications developed for the product development process, a virtual 3D model can be augmented on a real environment or on a physical mock-up. When augmented on a physical mock-up, there are several benefits of AR, as identified by Lee and Park (2005). Augmentation of virtual models on physical mock-ups allows the user to hold and touch the concepts and make efficient evaluations. If an AR application is provided with features of a real environment, such as reflectance and shadows, it gives the feeling of a natural visual presence of the concept. Moreover, AR applications allow the designer to make an exploration of the optimal attributes of design details on the concept, such as button size and position.

In addition, AR technology can enhance collaboration between designers and users, as mentioned in Mair et al.'s (2014) study. This is because sharing a display to experience AR application can improve the collaboration (Freitas and Campos, 2008). Similarly, communication between and interaction with partners, such as team members or tutors, can also be enhanced by AR technology with its potential to support better content understanding, resulting in better collaboration, communication and interaction during the product development process. This interactive learning environment supported with AR applications can also help design students to increase their performance with higher motivation (Juan et al., 2010; Kaufmann and Dünser, 2007).

Representation of the concepts, for which designers utilize different design tools such as sketching, visual mock-ups and 3D models, is an important part of the design process starting from earlier stages. These representation tools are mainly 2D representations on paper or screen disconnected from the real environment. AR has the potential to view 3D models as real, integrated into the real environment in the intended size. In addition, it allows the designer to interact with the model for a better understanding, by either moving around the model or controlling on AR technology. When compared to other forms of 3D representations, such as visual mock-ups, AR is less time consuming for designers to visualize with the details of the concept earlier in the process.

As mentioned in examples of AR applications for product development, AR has the potential of allowing designers to make user testing in early stages of design (Mair et al., 2014; Arbeláez-Estrada and Osorio-Gómez, 2013). Without the need of building prototypes that takes time, designers can easily make evaluations. Instead of viewing the concept on 2D screens, designers enable users to view the concept with AR, by giving the feeling of visual presence of the concept in real environment, resulting in better evaluations and insights. In brief, there are several benefits of AR technology in supporting design students during the product development process.

3.3.4. Drawbacks of augmented reality for the product development process

One of the most significant drawbacks of AR for the product development process is the difficulty of maintaining the stability of AR technology. Studies show that hardware problems, software instability and problems related to technology inside AR devices annoy the users, resulting in the decrease of their motivation (Dunleavy et al., 2009). For instance, Shen et al. (2010) developed and tested an AR application for supporting collaborative product design activities and reported that the participants' attention was distracted by the jittering of the virtual objects. Similarly, virtual image vibration in AR applications made it difficult to use for the participants (Escalada-Hernández et al., 2019). In addition, some usability problems related to AR were uncovered in a study that augmented the furniture design process to support prototyping and collaboration (Gjøsæter, 2009). However, usability problems are eliminated with the development of AR applications. Similarly, it was reported in Fründ et al.'s (2005) study that there was a demand for easy-to-use and user-friendly interfaces in the trial testing of the first AR prototype, which completed the automobile prototype with virtual objects to show variations allowing to review the design. However, usability and performance tests were conducted for AR applications to overcome these problems in the following versions. It was also reported in Fründ et al.'s (2005) study that 5 to 10 minutes were required for the participants to understand the function of the AR application. This is necessary to get used to every program or application. On the other hand, there were usability studies indicating no usability problems related to AR, such as Di Serio et al. (2013). The reasons behind this conflicting result of these studies might be technological flaws and differences in the implementation of AR into the learning environment. Stability problems can be eliminated with the development of the technologies (Wu et al., 2013).

The complex tasks could lead to cognitive overload, resulting in decreasing the students' performance. Although cognitive overload is not mentioned in AR researches related to product design, it was mentioned in the researches related to education as mentioned in Section 3.2.3. The students in the studies were seen to be confused with the complex tasks and overloaded with the information provided by AR technologies (Wu et al., 2013; Dunleavy et al., 2009). This might be an important factor that needs to be taken into consideration for the product design process.

3.4. Augmented reality tools to explore in industrial design education

There are a number of AR applications that have been used in the context of design, such as eDrawings, Arki, Wakingapp, Augment and Visidraft. Considering industrial design education, the most featured one is eDrawings, which can be integrated into desk crits in particular. Arki seems to be developed specifically for architecture content when looking at the project examples given in their website, whereas Visidraft seems to be more appropriate for interior design, allowing the architect, engineer or manager to visualize the project before construction to make necessary changes. The other applications, Wakingapp and Augment, seem to be showcases for marketing, allowing users or businesses to view the product before acquiring it.

The most prominent application is eDrawings, which is specifically developed for product design and aims at enabling communication and collaboration in an easy way in order to improve the design process. eDrawings has several features that support the industrial designers in interacting with their concept while using the application to explain their design considerations or developments (Figure 3.13). Once the user switches the AR mode, he/she can change the position of the concept with the rotate function, or simply move the screen around the QR code, or change the view by touching the screen. In addition, the scale of the concept and the view with or without isocurves on the 3D-model can easily be adjusted. While interacting with the eDrawings application, the user can also lock the viewport at a single view to discuss a particular issue. Moreover, the user can hide/show, or change the transparency of the parts of the concept, or isolate them in order to change the visibility of the parts. The user can also select a part to highlight and point directly to it. One of the most important features of the eDrawings application is to enable the designer to adjust different configurations beforehand in order to show them while communicating with others. The eDrawings application cooperates with the Solidworks software, in preparing a concept for use. This might be a limitation for designers because each designer has skills for different digital modelling software. Although each software has the export option that can be imported into Solidworks to prepare for the eDrawings application, eDrawings should be able to support different digital modelling software in order to provide flexibility.

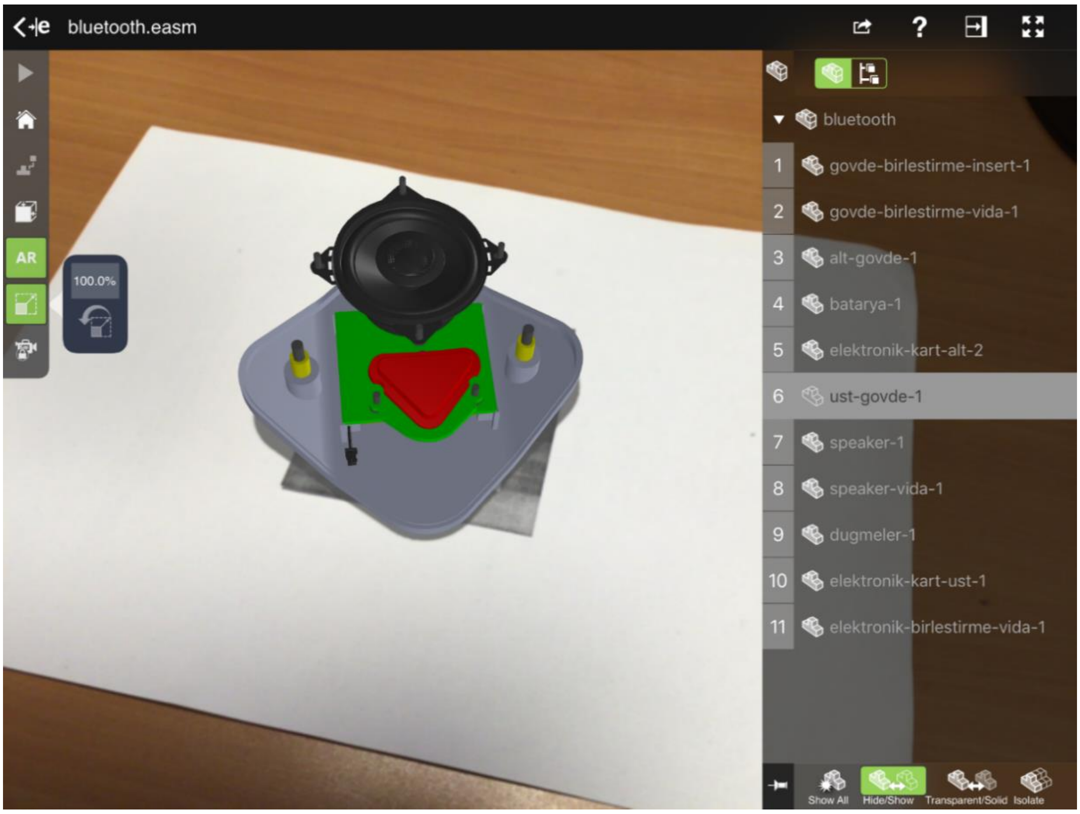


Figure 3.13. eDrawings application with different features

ARki is an AR application for mainly visualizing architectural models into the real environment architecture through several features of interactivity for presentation, such as see-through 3D model in real-time, showing different alternatives, and adjusting lighting and shadows, which are more suitable for architectural models (Figure 3.14) (Darf Design, 2019). Designers need to import the 3D models into the ARki software in the supported format, which they export from the modelling software they have used. Similarly, VisiDraft augments 3D models into a real environment interactively by using a mobile technology, either a mobile phone or a tablet (Figure 3.15) (Honesty, 2015). The application allows users to place and arrange virtual 3D models into the real environment to see and make changes simply by walking around with their devices.

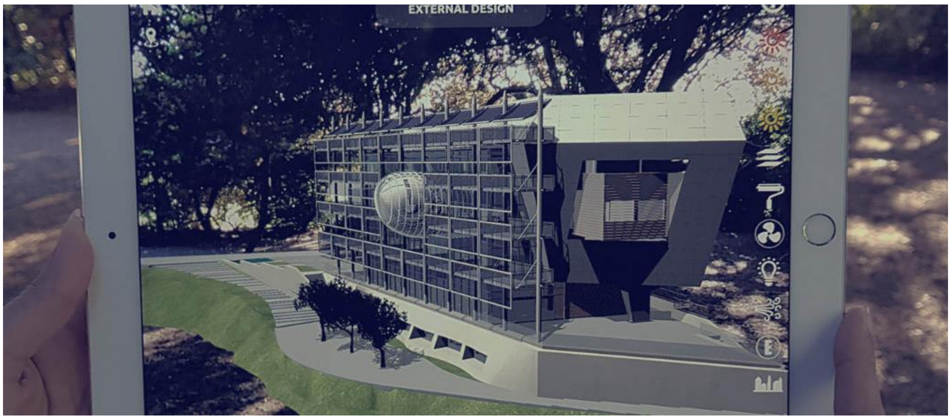


Figure 3.14. ARki, AR application developed mainly
for visualizing architectural models (Darf Design, 2019)

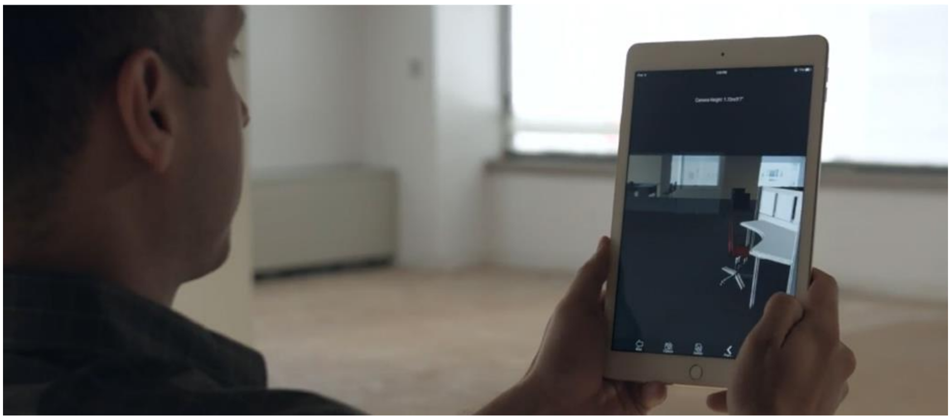


Figure 3.15. VisiDraft, AR application that augments 3D models
into a real environment interactively (Honesty, 2015)

Augment is a platform that offers mobile AR solutions for marketing and field sales. This application allows users to view the product in real environment and enables designers to turn 3D models into AR through mobile technology (Figure 3.16) with add-ons to the digital modelling software, such as Sketchup, Revit, 3DS Max, and Fusion 360, which the architects and designers use. However, the application is more focused on electronic commerce and field sales. WakingApp is a more professional AR platform that allows developers and designers to produce AR content with visual scripts with limited coding knowledge (Wakingapp, 2019) (Figure 3.17). This platform can recognize the image from a real environment to augment virtual data, thus having no dependency on QR code or printed visual when compared to other AR applications. New features can be integrated into the existing application.

However, this platform offers these services with a monthly fee, which might be not feasible.

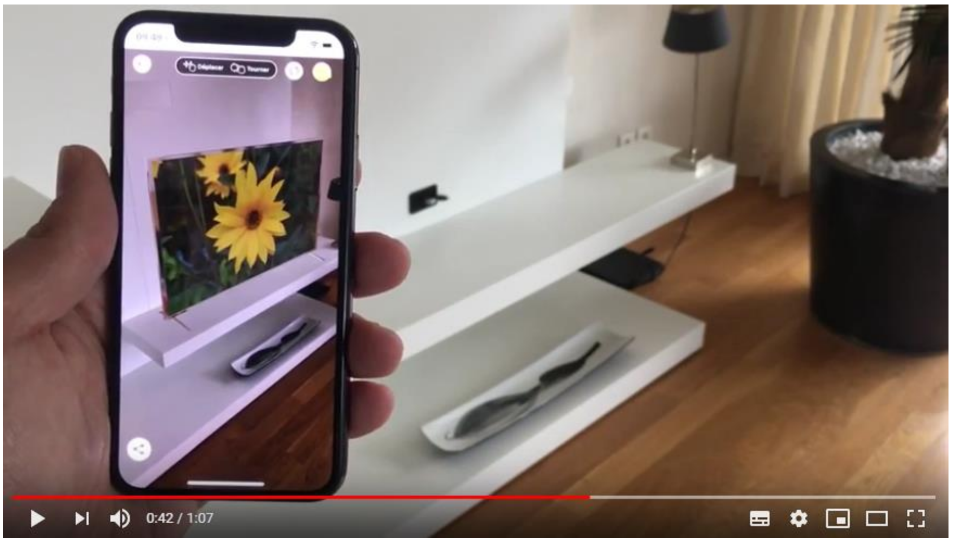


Figure 3.16. Augment, a platform that offers mobile AR solutions (Augment, 2019)

Figure 3.17. WakingApp, professional AR platform that allows developers and designers to produce AR content (Wakingapp, 2019)

3.5. Summary and discussion

Augmented reality is a developing technology that has started to be used in education. Since the publications of the Horizon 2010 and 2011 reports, it has been predicted that AR technology is likely to have growing impact on teaching and learning (Johnson et al., 2010; Johnson et al., 2011). It has also been reported in the latest Horizon report published in 2019 that the integration of AR is likely to have growing demand in the development and implementation of digital learning environments (Alexander et al., 2019). The demand for this integration, with its potential in transferring content into education (Becker et al., 2017) and constructing a wider understanding (Johnson et al., 2016) will continue to rise in order to enrich digital learning environments. There are several researches that show the advantages of AR in education. AR can support learning gains, motivation and collaboration, as well as facilitate interaction and increase the experience. In addition, it can support students' engagement, performance, concentration, retention of the content, better content understanding, and discussion within groups.

These advantages of AR can have positive effects on students' product development processes when supported with AR technology, such as increased communication and interaction between students and tutors, increased motivation and performance of the students during the product development process and increased content understanding resulting in better feedback from the tutors. In addition, AR has the potential to give the feeling of natural visual presence of the concept by viewing a 3D model in the environment. This also allows the user to control a 3D model interactively with 3D virtual presence. Although there may be some weaknesses of AR, such as stability and usability problems that could be eliminated with the development of the technologies, AR technology has many potentials to support design stages and activities. In addition, it is also important to validate the benefits of AR for product development process, which is presented in Section 3.3.3. This is because some of the benefits mentioned in this section, such as increasing performance and motivation (Juan et al., 2010), was deduced from the studies conducted in different educational contexts. Thus, these benefits need to be validated for product development process in industrial design education.

AR applications have been developed for different design stages and activities to enhance the design process by enabling industrial designers to interact with 3D virtual models integrated into real environments, such as 3D modelling, concept evaluation, mock-up for design evaluation, and rapid prototyping. The development of AR technologies and applications can also enhance the product development processes of industrial design students in a supportive way. The adaptation and integration of developing technologies into design process might influence the use of other design representation tools. Therefore, this integration of the current and developing technologies should be directed with guidance to enhance the product development process of design students and effective learning environments, such as desk crits in studio environments. Its integration into industrial design education is still in early stages and requires more research to create interactive and effective learning environments with AR technology.

CHAPTER 4

EXPLORING THE PRODUCT DEVELOPMENT PROCESS OF INDUSTRIAL DESIGN STUDENTS

This chapter mainly describes the study carried out to explore the product development process of industrial design students during the conduct of their studio projects and to explore how AR technology can be integrated into the product development process. How this study was conducted and the insights and findings of the study are presented.

4.1. Proposed methodology to explore the product development process

The first phase of this study is to explore the product development process of industrial design students in a graduation project course, aiming to have a well-grounded understanding of their process. The study was conducted with fourth year undergraduate level industrial design students in the Department of Industrial Design at the Faculty of Architecture at Middle East Technical University (METU) in Ankara, Turkey. To conduct this study, the researcher obtained permission from the chairperson of the department, who is also part of the team responsible for the graduation project course. The study was conducted in the Spring semester of 2016-2017.

The methodology of the study is briefly summarized in Figure 4.1. The data collection stages comprised of observation sessions supported with surveys of evaluation and focus group sessions right after the students finished their product development process. The observations were comprised of desk crits, juries and final screenings, which are ideal to learn extensively about the product development process of design students from different aspects. The surveys were conducted two fold, carried out both with students and tutors to evaluate the sessions that the researcher observed, which is also vital to support the analysis of the data collected during observation. After the students finalized the product development process, focus group sessions were conducted to ask them to evaluate their product development process from different aspects, evaluate the desk crits and obtain their insights about AR technology. The focus group study was carried out with the observed students to support the data taken from observation sessions.

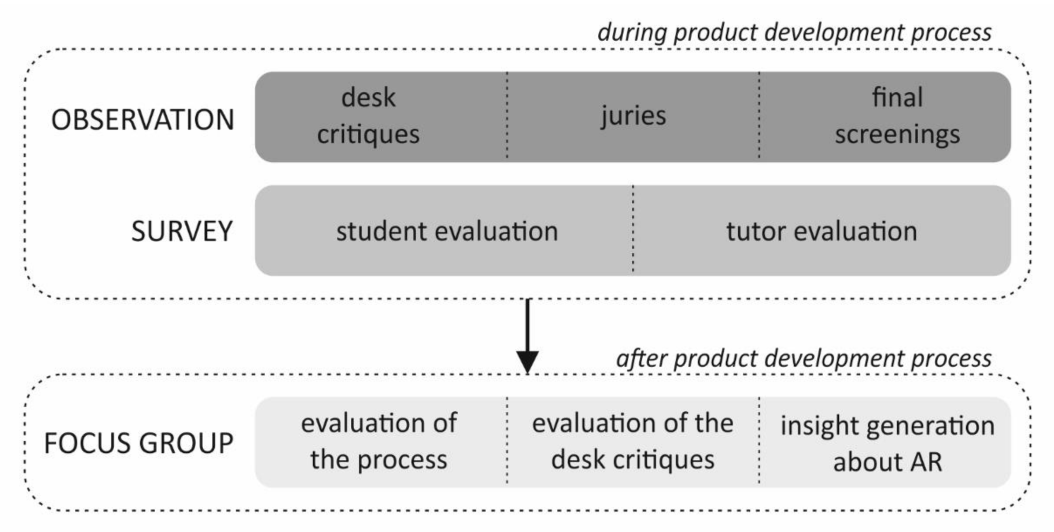


Figure 4.1. The summary of proposed methodology to explore the product development process

During the graduation project course, the industrial design students were expected to follow through their product development process as defined in the project brief and timetable distributed in the beginning of the semester, and the researcher did not demand any other extra activities. It was important to explore;

- design activities carried out by students during the product development process,
- design representation tools used to interact with tutors during studio sessions,
- product aspects developed during the course and their relation with the tools used by the students, and
- feedback from industrial design tutors during studio sessions.

These explorations provided insights about the relations between different design representation tools based on product aspects. These insights provided information to guide about how AR as a design representation tool can be used and can also enhance the product aspects during the product development process and to explore for which design stages AR provides potential. Moreover, it was essential to explore the thoughts or evaluations of industrial design students for AR technology.

Internal validity and reliability are important factors to establish the trustworthiness of a research (Guba, 1981). In order to increase the trustworthiness of this research, several strategies were employed by the researcher based on Shenton's (2004) suggestions.

1. *Triangulation* was used by involving different methods, observation and focus groups as data collection strategies. Using different methods exploits their benefits (Shenton, 2004). Information that can be verified from two sources should be accepted (Guba, 1981). As suggested by Guba (1981), the different methods should be used to cross-check insights. Division of the research team is also suggested but this is not possible for this study.
2. *Member check* was used for visual data but not for dialogues of the students and the tutors during desk crit sessions. This method is mainly used to cross-check the words for their intention. However, it requires at least a tape recorder. Recording the sessions was not used to avoid making the students feel uncomfortable during desk crit sessions. In addition, it was not possible to record all the sessions and to transcribe them right after the sessions in order to cross-check with the students and the tutors, as they forgot the session and due to time limitation. However, this strategy was used to cross-check visual data observed during desk crit sessions with digital data supported by the students while preparing the data as mentioned in Section 4.5.
3. *Background, qualifications and experience of the investigator* is an important factor for data collection and analysis (Patton, 2002). The researcher has the same background with the students and similar experiences about the product

development process in industrial design. In addition, he is an instructor in the same department, where the study was conducted, and has known the students starting from their first year. He has also taken part in various researches. As suggested by Shenton (2004), personal information relevant to the study is given in the related sections. The background, qualifications and experience of the researcher can somehow compensate for the member checking of the dialogues during desk crit sessions.

4. *Tactics to help ensure honesty in informants* was used by giving the opportunity to participate voluntarily in the study and to refuse participation. In addition, it was clearly stated in the consent form that the study is voluntary for the participants and they have the freedom to withdraw at any stage of the study. Moreover, it was indicated that the research did not involve any risks for them and they would not be evaluated as "right" or "wrong" about their own work in this study.
5. *Thick description of the phenomenon under scrutiny* was used by giving detailed explanations with illustrations using examples from the analysis of the data to convey the actual situations investigated during the study.
6. *Purposive selection* was also used as a strategy in order to harmonize the sampling. Although, random sampling is suggested by Shenton (2004) to ensure representative sample of the wider group. The disadvantage of random sampling is no control over the participants, resulting in uncooperative and quiet individuals. The number of the selected students in this study was almost half of the student population in the course, since the total number of the students was a small group. Purposive selection of the students was an ideal strategy to harmonize the sampling according to their levels, which are defined according to their cumulative and project grades, their project sectors and communication skills, which is explained in detail in Section 4.1.2.

External validity and objectivity are also important factors to establish the trustworthiness of a research (Guba, 1981). Conveying sufficient information about the research is vital to allow the readers to understand properly whether the findings of the research may be transferred to their contexts by comparing their situations with those stated in the research according to the level of similarity between these contexts (Guba, 1981; Shenton, 2004). This information includes the context of the study, the number of participants, the methods employed for data collection, the length and number of the sessions for data collection, time period in which data was collected and any restrictions during the study. In addition, a clear description of the methodology and its implementation, and the details of data gathering should be provided to establish the trustworthiness. To do so, sufficient information about the studies will be provided in related sections.

4.1.1. Schedule of the Graduation Project course

The timetable of the Graduation Project course is given in Table 4.1. The first two weeks of the course were allocated for the preparation of the Graduation Projects Exhibition poster. After that, the course took 13 weeks to finish the product development process. The course load per week during studio class is twelve hours, four hours on the 1st studio day of the week and eight hours on the 2nd studio day of the week. The conduct of the course mainly included studio activities, workshops, desk crits, evaluation juries and final screenings. The course was instructed by one professor, one assistant professor, three part-time instructors and four research assistants, all referred to as tutors.

On the first day of the course, the researcher informed the students about the study and the selection process of the students based on different criteria as it would be impossible to observe all the students. Observing the students started from the first desk crit that was on March 10th and continued until the final jury that was held between 5-7 June 2017. The pilot study was conducted in the first desk crit to try out and improve the observation process. The data for analysis was included starting from the initial ideas jury (20th and 23rd March) since the progress of the students before this jury showed individual differences. The initial ideas jury provided them to attain a similar milestone in their product development process. The industrial design students were observed one by one during ten different sessions in total throughout the course.

Table 4.1. Schedule of the Graduation Project course

Month	SW	OS	1st studio day of the week	2nd studio day of the week
February	SW1		Graduation exhibition poster	Graduation exhibition poster
	SW2		Graduation exhibition poster	Poster Jury
March	SW3		Workshop	Desk crits (Pilot study)
	SW4		Workshop	Desk crits
	SW5	OS1	Initial Ideas Jury (20-23 March)	
	SW6	OS2	Workshop	Desk crits
April	SW7	OS3	Workshop	Desk crits
	SW8	OS4-5	Desk crits	Desk crits
	SW9	OS6	Preliminary Jury (17-20 April)	
	SW10	OS7	Workshop	Desk crits
May	SW11	OS8	Holiday	Desk crits
	SW12	OS9	Final screening (design/model)	
	SW13	OS10	Final screening (board)	
	SW14		Preparation for final	
June	SW15		Preparation for final (focus group sessions)	
	SW16		Final Jury	
SW: Studio weeks, OS: Observation sessions				

The tutors of the course were divided into four groups during desk crit sessions and each of the students was matched with different tutor groups for each session; so that each student could get critiques from all tutor groups in different desk crit sessions. At the same time, four students could get feedback from four different tutor groups. The first studio day of the week, which was four hours, allowed each student to get feedback from one tutor group, whereas the second studio day, which was eight hours (with morning and afternoon sessions), allowed each student to get feedback from two tutor groups. Considering the desk crit schedule of the course, the researcher was able to follow twenty students in eight-hour studio session.

Department of Industrial Design has been established in 1979, has become the first member of International Council of Societies of Industrial Design (ICSID) from

Turkey (Korkut, 2012). The establishment of industrial design department was provided with preliminary studies conducted between 1969-1972 by Prof. Dr. David K. Munro, and a report about industrial design prepared by Mehmet Asatekin and Güner Mutaf by visiting design schools in Europe (Asatekin, 2006). In addition, it adapted and updated its program according to the Bologna criteria at the beginning of 2010s (Irkdaş-Doğu et al., 2015). Starting from its establishment, the Department of Industrial Design at METU follows and applies an international approach as also discussed in Section 2.1. The department at METU applies a model in which, graduation project course is carried out in cooperation with industrial organizations and it has been regularly exhibited since 2002 (Korkut, 2012). The different universities in Turkey follow METU Department of Industrial Design's approach and the conduct of their graduation project course is similar to the one at METU.

4.1.2. Selection of industrial design students

Fifty students *(41 female and 9 male)*, took the Graduation Project course (ID402) in the 2016-2017 academic year. It was not possible to observe all students because of the scheduling of the desk crits. In order to select the students to observe, they were categorized in four different levels according to their cumulative grade point average (CGPA) and the average of their industrial design project courses' grades. There were 14 students *(8 female and 6 male)* in the first level, 14 students *(14 female)* in the second level, 15 students *(13 female and 2 male)* in the third level and 7 students *(6 female and 1 male)* in the fourth and lowest level (Figure 4.2). The students in the lowest level were excluded because of the fact that it could be hard to follow their process during the studio (see Section 4.2.2). An important criterion to decide on the number of the students for observation was the time schedule of arranging individual desk crits, which were approximately 15 minutes and allowed the observation of 20 students one by one during the Graduation Project course. Another criterion was to follow the process of the projects carried out in collaboration with a diverse range of business sectors. Therefore, the homogeneity of these sectors that the students conducted their project with was also considered for the selection process. In addition, communication skills of the students were vital to ask them to provide information to the researcher. The students were asked to send the photos of the design representation tools or materials used during desk crit sessions, such as photos of their sketchbook parts, mock-ups, 3D-models in digital format and similar. Therefore, their willingness to participate in the study was vital for them to regularly send the necessary documents. Considering these criteria, the students were selected from the first three levels; 9 students *(6 female and 3 male)* from the first level, 6 students *(6 female)* from the second level and 5 students *(3 female and 2 male)* from the third level.

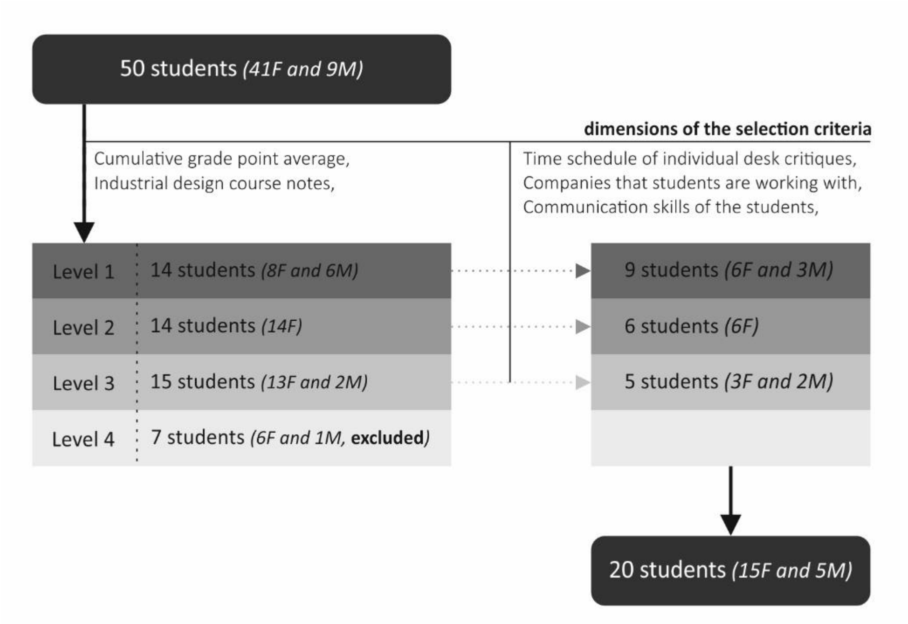


Figure 4.2. Selection of the industrial design students to participate in the study

Figure 4.2 briefly illustrates the selection process of the students for observation. To sum up the selection criteria, the students were selected considering the following;

- Cumulative grade point average (CGPA),
- Industrial design course grades,
- Time schedule of individual desk crits,
- Sectors of the companies that students worked with for their graduation project, and

- Communication skills of the students.

The participants taking part in the study are here on referred to as the students.

4.2. Observation during the graduation project course

As mentioned earlier, the students were informed on the study procedure and the expectations on the first day of the course. The selected students were given a consent form with brief information on the study (Appendix A). The observation technique used for the study was overt/disclosed participant observation, where the researcher joins as a member of the group in the environment and therefore, the students knew that the researcher would be collecting data about their product development processes. The researcher believes that the students did not change their process and behavior while they were being observed because they knew the researcher, who is one of the coordinators of the summer practice conducted at the end of the first year. This made them comfortable about the study, which was vital in order not to affect their product development process.

The main reason why participant observation was used for the study was not to ask the students do activities related to the study, which might take unnecessary time for them while continuing with their product development process. The other methods that could be used for this study are diary studies or cultural probes supported with focus groups to follow students' product development process. However, these studies require time for the students to fill in documents given to them and this should be done regularly to document the process properly. These documents are not compulsory for their project and this can be considered by the students as unnecessary during their project development process. It was considered as risky to ask the students to fill in documents that require time. In this study, the students were only asked to fill in the survey after each desk crit session, which took only around 5 minutes, and to send the design representation tools digitally to the researcher regularly by taking photos of these tools, such as sketches and mock-ups, or sending the digital versions, such as 3D-models and renderings. However, although this requires less time for the students, it was hard to digitally collect these tools from the students without reminding them multiple times. Collecting these tools from the students took a while. It can be said that asking the students to fill in the documents provided with diary studies or cultural probes takes time for them. They might not be volunteering for the study or might withdraw at any stage of the study, for which the freedom to withdraw was given to them as stated in the consent form. Considering these difficulties related to the other methods, participant observation was selected to follow the students' product development processes without asking them to do things that required much time.

4.2.1. Role of the researcher

The researcher's role in the course is peripheral membership (according to Adler and Adler's membership roles, 1987) or moderate participation (according to Spradley's continuum of participation, 1980) (Table 4.2), defined as where the researcher is present at the scene, is visible to students and interacts with them occasionally instead of actively participating (DeWalt and DeWalt, 2011). The researcher was present during all sessions of the course; studio activities, workshops, desk crits, juries and final screening, and interacted with both the selected students and the other students when requested to consult.

Table 4.2. Correspondence of Spradley's Continuum of Participation
with Adler and Adler's Membership Roles (DeWalt and DeWalt, 2011, p.21)

Continuum of Participation	***Membership Roles***
Nonparticipation	No membership role
Passive participation	No membership role
Moderate participation	Peripheral membership
Active participation	Active membership
Complete participation	Full membership

4.2.2. Tracking of the students during the course

The students were observed during ten different sessions in total, orderly, *one idea jury, four desk crits, one preliminary jury, two desk crits* and *two final screenings* (Figure 4.3). All students were observed during juries and final screenings, whereas there were missing observation sessions during desk crits because of the absence of the students or overlapping desk crits of two students at the same time. Therefore, the data of four students, which were not observed for more than three desk crits, were excluded for the data analysis. All of the removed students were in the third level, which may suggest that their relatively lower performance in design studio courses may be related to their tendency towards absence in studio.

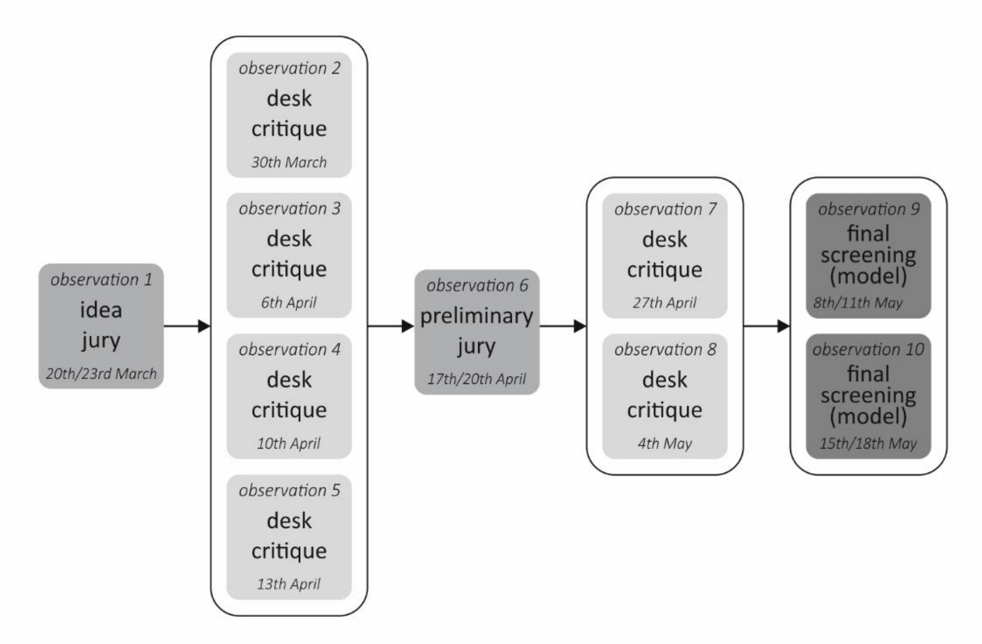


Figure 4.3. Tracking of selected students during the course

4.2.3. Materials used for data collection

The materials used for data collection during the sessions are mainly observation sheets and evaluation surveys, which are explained in Section 4.3. The observation sheet is prepared with considerations given to the different types of the data to be collected. After the pilot study, the observation sheet (Figure 4.4, Appendix B.1) was revised in order to collect data more efficiently. The observation sheet is an A4 size paper including different sections for note taking during sessions. The points to be noted during observation were;

- The different tools used by the student,
- The product aspects developed by the student,
- The explanations about the product aspects made by the student,
- The critique/feedback of tutors given in relation to the student's explanation,
- General or unspecific explanations about the design made by the student,
- General or unspecific critique/feedback given by the tutors, and
- Additional notes related to the observation session.

Considering the data types to be noted, the sheet consisted of eleven sections (Figure 4.5, Appendix B.2);

1. Titles to track the observation notes (student number, design critique number, tutors and date),
2. Titles of the observation notes (product aspects, reminder, notes, student explanation, tutor critique/feedback),
3. Reminders for note taking (products aspects, critique/feedback type),
4. Notes on product aspects,
5. Drawings of materials/tools used by students during the session,
6. Notes about materials/tools,
7. Notes on the student explanations about product development process,
8. Notes on the tutors' critique/feedback in relation to the student's explanation,
9. Additional notes,
10. Notes on the students' general explanation, not specific to concept/product, and
11. Notes on the tutors' critique/feedback in relation to the student's general explanation.

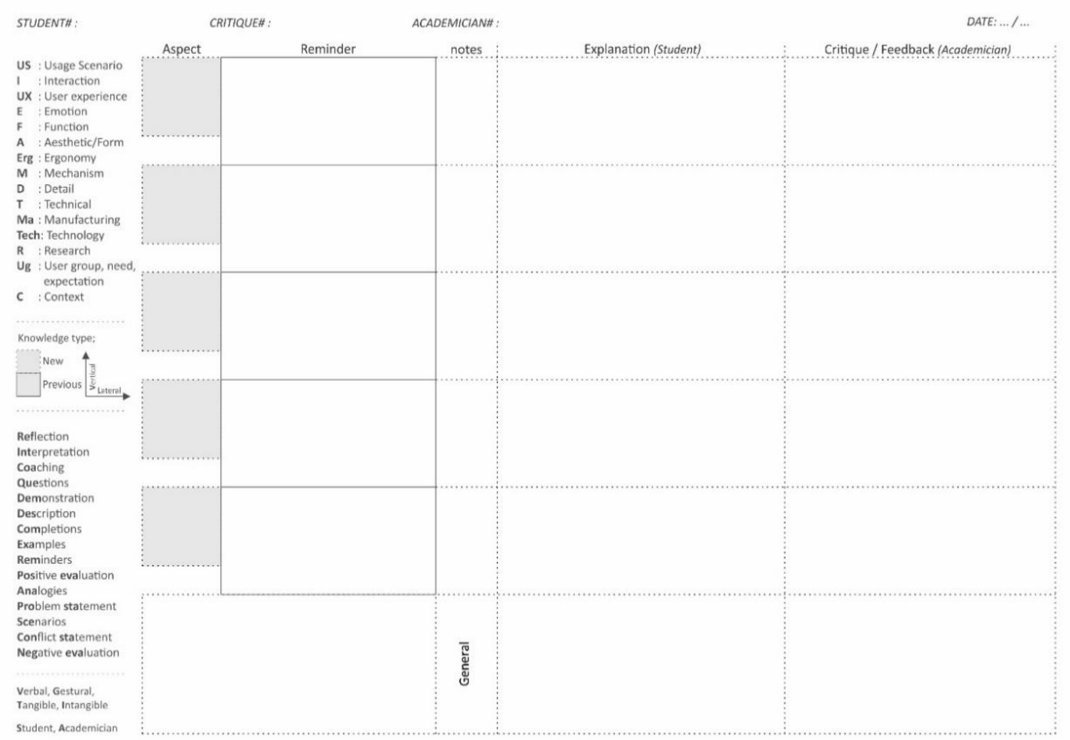


Figure 4.4. Observation sheet used in the sessions

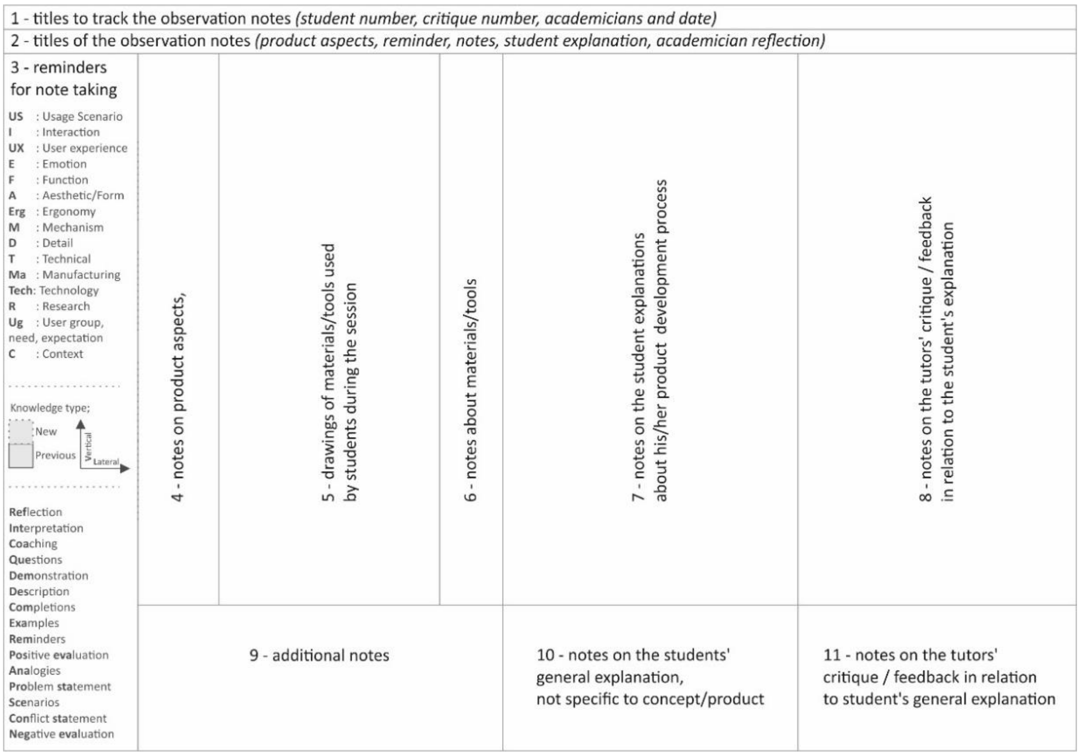


Figure 4.5. Explanation of observation sheet used in the sessions

4.3. Survey: Evaluation of each observation session

A follow-up survey was conducted immediately after each observation session with one of the tutors of the desk crit group and with the student, in order to support the data collected in the observation sessions. The data collected with the survey was to reveal descriptive statistics data about evaluation to find out the considerable differences between student evaluation and tutor evaluation in order to review deeply these observation sessions. The reason for finding out the considerable differences is to understand in which ways the data of these sessions can be included in the analysis or instead to exclude the data from the analysis if the session does not have the potential to provide insights.

4.3.1. Data collected with the survey

Evaluation was mainly based on the tools used by the students during the observation sessions to interact with the tutors in order to get critique/feedback about their product development process. An evaluation survey was given to both the student and one of the tutors of the desk crit session in order to make evaluations about the tools. By considering the tools used during the observation sessions, the students were asked to evaluate their preparation, explanation during desk crit session and tutors' comprehension, whereas the tutors were asked to evaluate the explanation of the student and their own comprehension. During the course, the survey was revised and extended with different evaluation criteria for different observation sessions. For the first five observation sessions, sketches, extra information, mock-ups and other options were included in the survey. Render evaluation was added to the survey starting from the preliminary jury (observation 6). For the next two desk crits, which were observations 7 and 8, 3D-model evaluation was included. The survey was revised according to the preparation of the students for the final screenings by excluding sketches and extra information. Mock-up evaluation was also excluded for the second final screening session conducted to review the final boards of the students. The revision of the tools evaluated in the survey is concisely given in Table

4.3. In addition, there was the option of “other”, which was mostly filled in by the researcher, according to the design representation tools used by the students in desk crit sessions before giving the survey to the students or the tutors. If photos, videos or graphic tools were used by the students, the researcher would add these tools in the “other” category.

Table 4.3. Revision of the tools evaluated in the survey

Tools	**Observation sessions**									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
sketching	■	■	■	■	■		■	■		
writing	■	■	■	■	■	■	■	■		
mock-up	■	■	■	■	■	■	■	■	■	
render						■	■	■	■	■
3D-model							■	■	■	■
other, *e.g. video*	■	■	■	■	■	■	■	■	■	■
observation 1- initial ideas jury, observation 2,3,4,5- desk crits, observation 6- preliminary jury, observation 7,8- desk crits, observation 9,10- final screenings										

4.3.2. Format of the survey

Each survey given to the students and the tutors was an A4 size sheet consisting of three questions for student evaluation (Appendix C) and two questions for tutor evaluation (Appendix D). The students were asked to evaluate;

- How well they prepared their concept/product with the tools used during the session,
- How well they explained their concept/product with the tools used during the session,
- How well the tutors understood their concept/product with the tools used during the session.

The tutors were asked to evaluate;

- How well the student explained their concept/product with the tools used during the session,

- How well they understood the student’s concept/product with the tools used during the session.

For each question given in the survey, the students and the tutors were required to evaluate the tools (Table 4.4) that were revised according to the observation sessions, which can be seen in Table 4.3.

Table 4.4. Complete list of the evaluation in the survey

	Not applicable		**Not very good**						**Very good**
sketching	NA		1	2	3	4	5	6	7
writing	NA		1	2	3	4	5	6	7
mock-up	NA		1	2	3	4	5	6	7
render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
other, *e.g. video*	NA		1	2	3	4	5	6	7

Using different Likert scales has been discussed in the literature in terms of response rate, response quality, reliability, comprehensibility and simplicity, showing that different scales are used for different purposes. This evaluation of the students and the tutors was important to find out the considerable differences between these evaluations in order to decide selecting observation sessions for the analysis of the observation data. A 7-point Likert scale could clearly highlight these differences; thus, this scale for evaluation in the survey was preferred instead of 5-point Likert scale.

4.4. Focus group sessions: Evaluation of the product development process

Three focus group sessions were conducted to ask the students to evaluate their product development process, to evaluate the desk crits, and to generate insights about Augmented Reality (AR) technology at METU in 2017. The researcher was present at each session and moderated all three sessions. Before arranging the focus group sessions, the researcher informed the students and asked about their availability for these sessions in order to form homogeneous groups from different levels.

4.4.1. Participants of the focus group sessions

Eighteen students, out of 20 selected students, participated in the focus group meetings that were conducted in three sessions. The researcher provided a timetable, which included seven days of the last preparation week, for the students to select their available time. While arranging each session according to students' availability, the students from different levels were selected to create homogeneity in each group. Five students *(2 students from first level, 2 students from second level* and *1 student from third level)* participated in the first session, seven students *(4 students from first level, 1 students from second level* and *2 student from third level)* participated in the second session, and six students *(3 students from first level* and *3 students from second level)* participated in the third session (Figure 4.6).

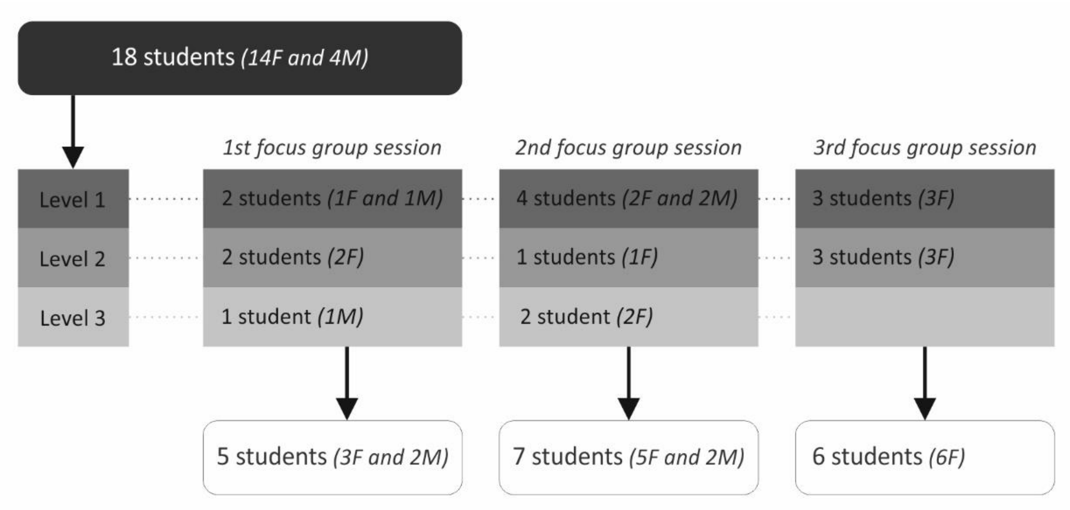


Figure 4.6. Selection of the students for the group sessions

4.4.2. Focus group setting

The focus group sessions were conducted in a lab environment at METU Department of Industrial Design, and recorded with two dome cameras and one voice recorder to review the sessions (Figure 4.7). Before starting each session, the researcher set the environment with focus group materials and pencils, pens, markers, and post-it notes to fill these materials. The students randomly sat around the table.

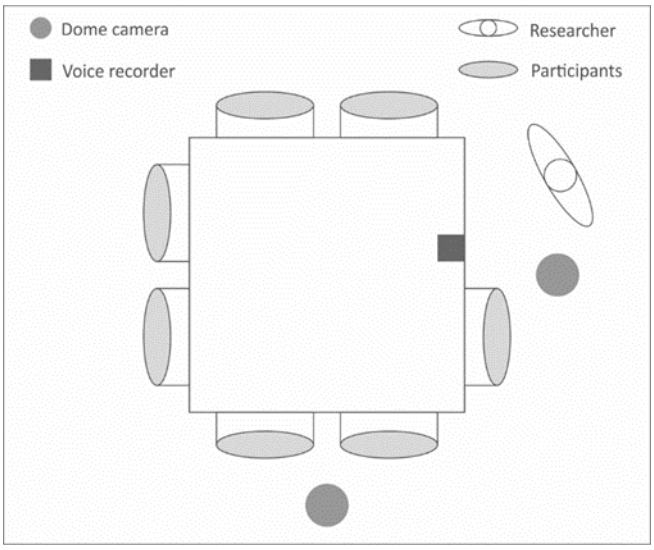


Figure 4.7. Focus group setting in the lab environment

4.4.3. Focus group procedure

Before starting the focus group sessions, the students were given a consent form with brief information on the study. They were provided with instructions for each step of the session while giving the related sheets, which will be explained in details in Section 4.4.4. Focus group sessions consisted of three main parts; 1) self-evaluation of the product development process, 2) evaluation of the desk crits and 3D modelling process as a group discussion, and 3) individual insight generation on AR. Each focus group session took approximately two hours.

Part 1. Self-Evaluation

In the first part of the focus group session, the product development process was individually evaluated by the students. This self-evaluation included four different evaluation sheets to be filled in by the students for;

1A – The evaluation of the tools used during the product development process (15 minutes),

1B – The evaluation of the product aspects developed during the product development process (15 minutes),

1C – The evaluation of the product aspects with the tools used during product development process (15 minutes),

1D – The evaluation of the product aspects of the final product (5 minutes).

Part 2. Group Discussion

The second part was to evaluate the desk crits, both in terms of the positive and negative effects on the product development process, and the 3D-modelling process in the form of group discussions, based on the questions provided to the focus group participants. This part consisted of three evaluation sheets to be filled in by the researcher while the students were making evaluations or discussing;

2A – The negative effects of the desk crits on the product development process (15 minutes),

2B – The positive effects of the desk crits on the product development process (15 minutes),

2C – The evaluation of 3D modelling during the product development process (15 minutes).

Part 3. Insight generation on AR

Third part of the focus group session included 2 activities;

3A – Four AR examples developed for the industrial design context were shown to the students at first to give them an idea about AR technology (10 minutes).

3B – Students were then asked to evaluate the importance of product aspects for the development of AR technology in industrial design education (15 minutes).

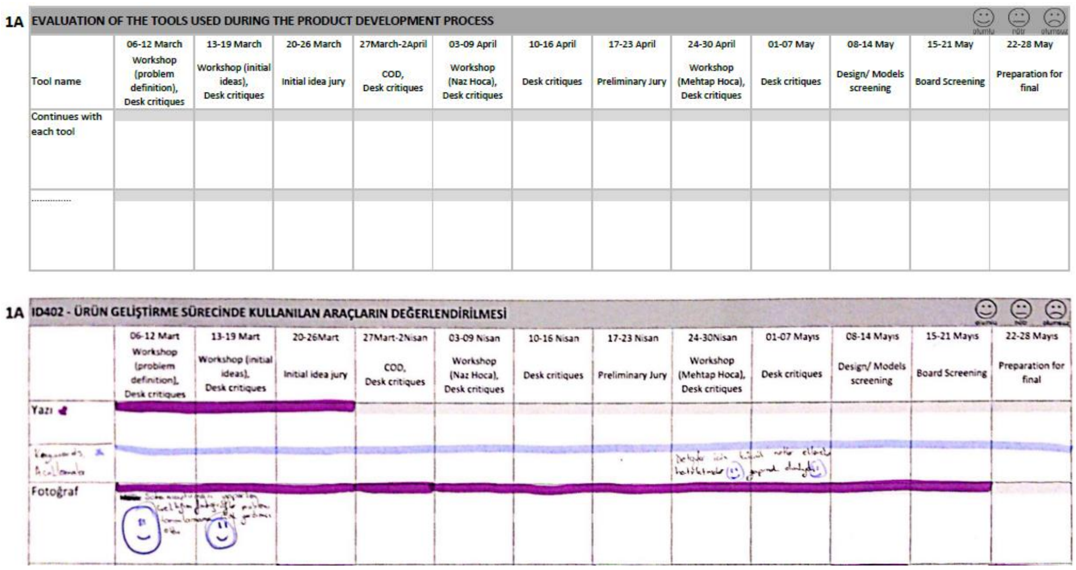
4.4.4. Focus group materials

The first part of the focus group session included four evaluation sheets (three A3 sheets and one A4 sheet) to be filled in by the students. The second part consisted of three A2 sheets to be filled in by the researcher. The materials in the third part were four videos and one A3 sheet. All sheets to be filled in were prepared in Turkish, which is the native language of the students.

4.4.4.1. Part One: Self-evaluation of the product development process

The first task given to the students was the evaluation of the tools used during the product development process. For this, an A3 size sheet (1A) was given, providing a timeline showing the explanations of each week to remind each stage of the product development process in the course and a list of the tools used by the students for them to fill this timeline with the tools placed at the stages they were used in (a section of the sheet in Figure 4.8, full sheet in Appendix E.1). In addition, the students were expected to note down the moments that they considered to be important by adding an icon representing these moments as positive, negative or neutral.

The second task required the students to make an evaluation of the different product aspects that they developed during the product development process. Similar to the tool evaluation sheet, a two-sided A3 size sheet was given (1B), also providing a timeline for the course and including the product aspects developed by the students, for them to fill in the stages in which they developed these (a section of the sheet in Figure 4.9, full sheet in Appendix E.2). The students also noted down the important moments with an icon representing positive, negative and neutral moments as they did in the tool evaluation sheet.



1A EVALUATION OF THE TOOLS USED DURING THE PRODUCT DEVELOPMENT PROCESS

Tool name	06-12 March Workshop (problem definition), Desk critiques	13-19 March Workshop (initial ideas), Desk critiques	20-26 March Initial idea jury	27March-2April COD, Desk critiques	03-09 April Workshop (Naz Hoca), Desk critiques	10-16 April Desk critiques	17-23 April Preliminary Jury	24-30 April Workshop (Mehtap Hoca), Desk critiques	01-07 May Desk critiques	08-14 May Design/ Models screening	15-21 May Board Screening	22-28 May Preparation for final
Continues with each tool												
....												

1A ID402 - ÜRÜN GELİŞTİRME SÜRECİNDE KULLANILAN ARAÇLARIN DEĞERLENDİRİLMESİ

	06-12 Mart Workshop (problem definition), Desk critiques	13-19 Mart Workshop (initial ideas), Desk critiques	20-26Mart Initial idea jury	27Mart-2Nisan COD, Desk critiques	03-09 Nisan Workshop (Naz Hoca), Desk critiques	10-16 Nisan Desk critiques	17-23 Nisan Preliminary Jury	24-30Nisan Workshop (Mehtap Hoca), Desk critiques	01-07 Mayıs Desk critiques	08-14 Mayıs Design/ Models screening	15-21 Mayıs Board Screening	22-28 Mayıs Preparation for final
Yazı												
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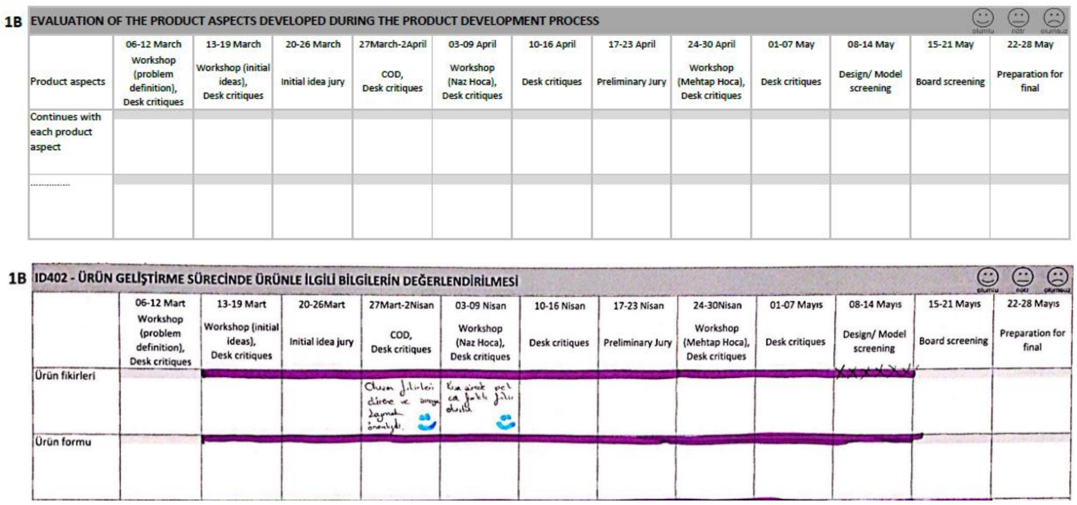
Figure 4.8. The section of the sheet used for the evaluation of tools.
Top: Empty sheet; Bottom: Sheet filled in by one of the students



1B EVALUATION OF THE PRODUCT ASPECTS DEVELOPED DURING THE PRODUCT DEVELOPMENT PROCESS

Product aspects	06-12 March Workshop (problem definition), Desk critiques	13-19 March Workshop (initial ideas), Desk critiques	20-26 March Initial idea jury	27March-2April COD, Desk critiques	03-09 April Workshop (Naz Hoca), Desk critiques	10-16 April Desk critiques	17-23 April Preliminary Jury	24-30 April Workshop (Mehtap Hoca), Desk critiques	01-07 May Desk critiques	08-14 May Design/ Model screening	15-21 May Board screening	22-28 May Preparation for final
Continues with each product aspect												
....												

1B ID402 - ÜRÜN GELİŞTİRME SÜRECİNDE ÜRÜNLE İLGİLİ BİLGİLERİN DEĞERLENDİRİLMESİ

	06-12 Mart Workshop (problem definition), Desk critiques	13-19 Mart Workshop (initial ideas), Desk critiques	20-26Mart Initial idea jury	27Mart-2Nisan COD, Desk critiques	03-09 Nisan Workshop (Naz Hoca), Desk critiques	10-16 Nisan Desk critiques	17-23 Nisan Preliminary Jury	24-30Nisan Workshop (Mehtap Hoca), Desk critiques	01-07 Mayıs Desk critiques	08-14 Mayıs Design/ Model screening	15-21 Mayıs Board screening	22-28 Mayıs Preparation for final
Ürün fikirleri												
Ürün formu												

Figure 4.9. The section of the sheet used for the evaluation of product aspects.
Top: Empty sheet; Bottom: Sheet filled in by one of the students

The third task given to the students was the evaluation of how well they explained their product aspects with the tools they used during the product development process. A two-sided A3 size sheet (1C) including a survey with 7-point Likert scale was used for this evaluation to ensure consistency with the survey used for evaluating each observation session (a section of the sheet in Figure 4.10, full sheet in Appendix E.3).

1C EVALUATION OF THE PRODUCT ASPECTS RELATED TO THE TOOLS DURING THE PRODUCT DEVELOPMENT PROCESS

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?

Product aspects	TOOL NAME								TOOL NAME								TOOL NAME								TOOL NAME							
		Not very well						Very well		Not very well						Very well		Not very well						Very well		Not very well						Very well
	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7
Continue with product aspects	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o

Figure 4.10. The section of the survey used for the evaluation of the product aspects with the tools used during product development process

The fourth task given to the students was the evaluation of the product aspects of the final product considering the final points they reached. For this, an A4 size sheet (1D) was given to the students including a survey with 7-point Likert scale (a section of the sheet in Figure 4.11, full sheet in Appendix E.4).

1D EVALUATION OF THE PRODUCT ASPECTS OF THE FINAL PRODUCT

Could you evaluate the product aspects of the final product of the product development process?
It is expected to evaluate each aspect related to your product.

Product aspects	Not applicable	Not very good					Very good
	NA	1	2	3	4	5	6	7
Continue with product aspects	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o

Figure 4.11. The section of the survey used for the evaluation of the product aspects of the final product

4.4.4.2. Part Two: Evaluation of the desk crits and 3D modelling process

Three A2 size sheets were used to be filled in by the researcher for the evaluation of the desk crits and 3D modelling process carried out as group discussion. The first one was for the evaluation of the desk crits considering their negative effects on the product development process. A one-sided A2 size sheet (2A) included a timeline for each week to remind the stages of the product development process in the course, and it was used to fill in the stages in which the students faced a challenge affecting their process negatively (a section of the sheet in Figure 4.12, full sheet in Appendix E.5). The questions that were asked to the students in order to make them think and start discussions were:

- In which stages of the product development process did you encounter challenging moments during the desk crits? Could you tell us briefly?
- How could you have made the challenging moments easier?
- Do you think there were differences between your explanation of the concept/product and the tutors' comprehension during the desk crits? If so, what were the factors affecting this difference? Could you tell us briefly?

2A EVALUATION OF THE DESK CRITIQUES DURING THE PRODUCT DEVELOPMENT PROCESS (NEGATIVE EFFECTS)

- o At which stages of the product development process did you encounter challenging moments during the desk critiques? Could you tell us briefly?
- o How could you make the challenging moments easier?
- o Do you think whether there is a difference between your explanation of the concept/product and tutors' comprehension during the desk critique? If so, what were the factors affecting this difference? Could you tell us briefly?

	06-12 March	13-19 March	20-26 March	27March-2April	03-09 April	10-16 April	17-23 April	24-30 April	01-07 May	08-14 May	15-21 May	22-28 May
	Workshop (problem definition), Desk critiques	Workshop (initial ideas), Desk critiques	Initial idea jury	COD, Desk critiques	Workshop (Naz Hoca), Desk critiques	Desk critiques	Preliminary Jury	Workshop (Mehtap Hoca), Desk critiques	Desk critiques	Design/ Models screening	Board Screening	Preparation for final
The number of the participant												
....												

Figure 4.12. The section of the sheet for the evaluation of desk crits (negative effects)

The second sheet was also filled in by the researcher and was used to ask the students to make an evaluation of the desk crits considering their positive effects on the product development process. Similar to the first sheet, a one-sided A2 size sheet (2B) included a timeline of the course and was used to note down the stages and moments influencing the desk crits in a positive way (a section of the sheet in Figure 4.13, full sheet in Appendix E.6). In this sheet, the questions asked for evaluation were:

- What were the positive moments that influenced the explanation of your idea/concept/product during the desk crits? Could you tell us briefly?
- What were the tools that affected the desk crits positively (*writing, pictures, videos, graphics, sketches, technical drawings, renders, 3D-models, mock-*

ups); in which stages and in which ways did these tools provide positive effects?

- What other kinds of contribution can be provided in order to increase the comprehension of your idea/concept/product during the desk crits?

2B EVALUATION OF THE DESK CRITIQUES DURING THE PRODUCT DEVELOPMENT PROCESS (POSITIVE EFFECTS)

- What were the positive moments that influence the explanation of your idea/concept/product during the desk critiques? Could you tell us briefly?
- What were the tools that affect the desk critiques positively (writing, picture, video, graphic, sketches, detail drawings, technical drawings, render, 3d-model, mock-up) and at which stages and in which ways did these tools provide positive effects?
- What kind of contributions can be provided in order to increase the comprehension of your idea/concept/product during the desk critiques?

	06-12 March	13-19 March	20-26 March	27March-2April	03-09 April	10-16 April	17-23 April	24-30 April	01-07 May	08-14 May	15-21 May	22-28 May
	Workshop (problem definition), Desk critiques	Workshop (initial ideas), Desk critiques	Initial idea jury	COD, Desk critiques	Workshop (Naz Hoca), Desk critiques	Desk critiques	Preliminary Jury	Workshop (Mehtap Hoca), Desk critiques	Desk critiques	Design/ Models screening	Board Screening	Preparation for final
The number of the participant												
....												

Figure 4.13. The section of the sheet for the evaluation of desk crits (positive effects)

After the evaluation of the desk crits, the students were expected to evaluate the 3D modelling process during the product development process through discussions. The researcher used a one-sided A2 size sheet (2C) that included the questions to be noted while the students were evaluating and discussing (a section of the sheet in Figure 4.14, full sheet in Appendix E.7). The questions in the evaluation of 3D modelling process were;

- In which stage of product development process should 3D modelling start?
- Are there any restrictions in using 3D modelling?
- Which of the product aspects (such as form, details and mechanism) do you explain more easily by using 3D-models?
- When considered among other tools, what are the effective points of using 3D-models in explaining the concept/product?
- What are the advantages and disadvantages of using 3D-models during desk crit sessions?
- Considering the product development process, in which stages should 3D-models be used during the desk crits to explain the concept/product?

2C	EVALUATION OF 3D MODELLING DURING THE PRODUCT DEVELOPMENT PROCESS		
	In which stage of product development process should 3D modelling start?	Are there any restrictions in using 3D modelling?	Which of the product aspects (such as form, details, mechanism, etc.) do you explain more easily by using 3D models?
	When considered with the other tools, what are the effective points of using 3D models in explaining the concept/product?	What are the advantages and disadvantages of using 3D models during desk critique sessions?	Considering the product development process, in which stages should 3D models be used during the desk critiques to explain the concept/product?

Figure 4.14. The evaluation sheet of 3D modelling

4.4.4.3. Part Three: Evaluation of the product aspects for AR

In the third part of the focus group session, four videos of AR examples used in the industrial design context were shown to the students in order to give an idea about AR technology and the use of this technology in industrial design (3A, Figure 4.15). These videos were selected to show different use alternatives during the product development process. The first video showed the use of AR technology during a boat design process, to see the product visually (Octosense, 2017). The second AR example was eDrawings that allows the user to view the concept/product and control with different functions (Solidworks, 2017). eDrawings was selected to show real-time interaction by adjusting the product on AR application. The third example was the use of AR technology for product design, which was tested through a helmet design (Arcanetech, 2017). This example was selected to show both user-product interaction and testing possibility. The fourth video was about using AR technology to visualize the interactions of physical objects, a real-time interactive user interface on a mock-up (Heun et al., 2013; ACM, 2017). Showing different possibilities used in the product development process was to give an idea about AR technology.

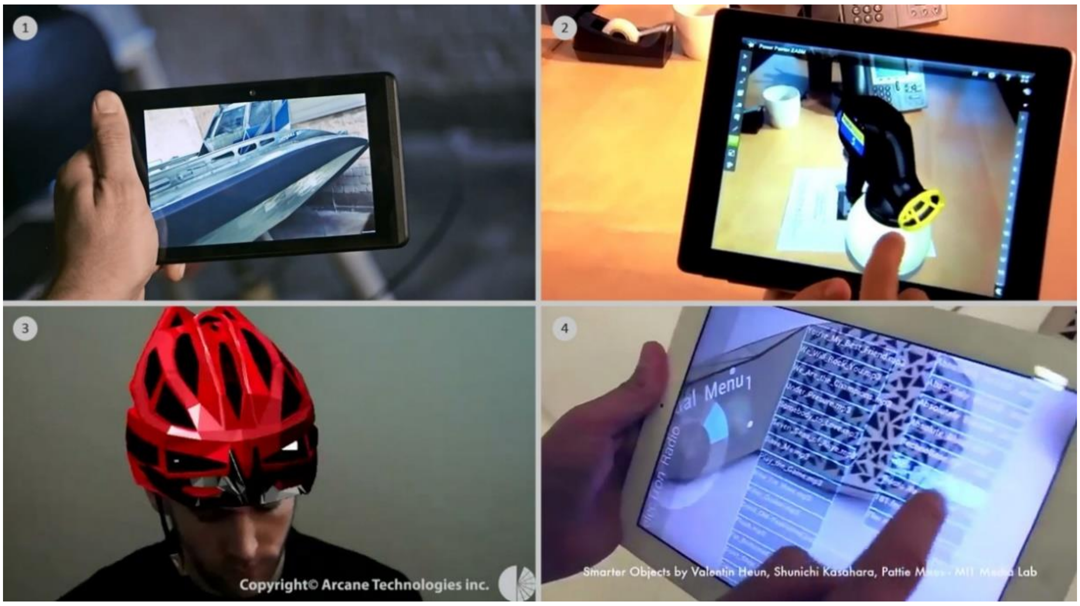


Figure 4.15. The AR examples shown to the students in focus groups sessions
(1, Octosense, 2017; 2, Solidworks, 2017; 3, Arcanetech, 2017; 4, ACM, 2017)

After watching the videos of AR examples developed for product design, the students were next expected to evaluate how important each of the product aspects was for the development of AR technology considering the product development process. The necessity of each product aspect in developing AR application was also evaluated in order to find out the hierarchy of these product aspects. In addition to the product aspects, the students were asked to evaluate other important information that they might have used during desk crits, such as project keywords, similar products, user needs and so on. For this evaluation, a one-sided A3 size sheet (3B) including a 7-point Likert scale survey for the importance of the product aspects was used (a section of the sheet in Figure 4.16, full sheet in Appendix E.8).

3B	EVALUATION OF THE IMPORTANCE OF THE PRODUCT ASPECTS IN DEVELOPING AR TECHNOLOGY							
	Could you evaluate the importance of each product aspect given below in developing an augmented reality application for the product development process? Please evaluate the each product aspect.							

Product aspects	NA	Not very important 1	2	3	4	5	6	Very important 7
....	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o
....	o	o	o	o	o	o	o	o

Figure 4.16. A section of the evaluation sheet for rating the importance and necessity of the product aspects in developing AR technology for the product development process

4.5. Preparation of the data for analysis

The collected data was processed to prepare it for analysis in order to reach findings. This process mainly includes three steps, *data documentation, data transfer on board* and *data transfer to excel sheets*. Figure 4.17 briefly illustrates the data preparation and analysis process. This section describes the data preparation process.

4.5.1. Data documentation

The data related to the documentation of the students' design processes included all design representation tools, sketches, photos, videos, graphics, jury boards, mock-ups, 3D-models and renders. The first step is data documentation, in which missing data was collected and a complete data board was prepared in order to gather all documents together. The missing data that the researcher completed was the design representation tools used by the students during studio sessions.

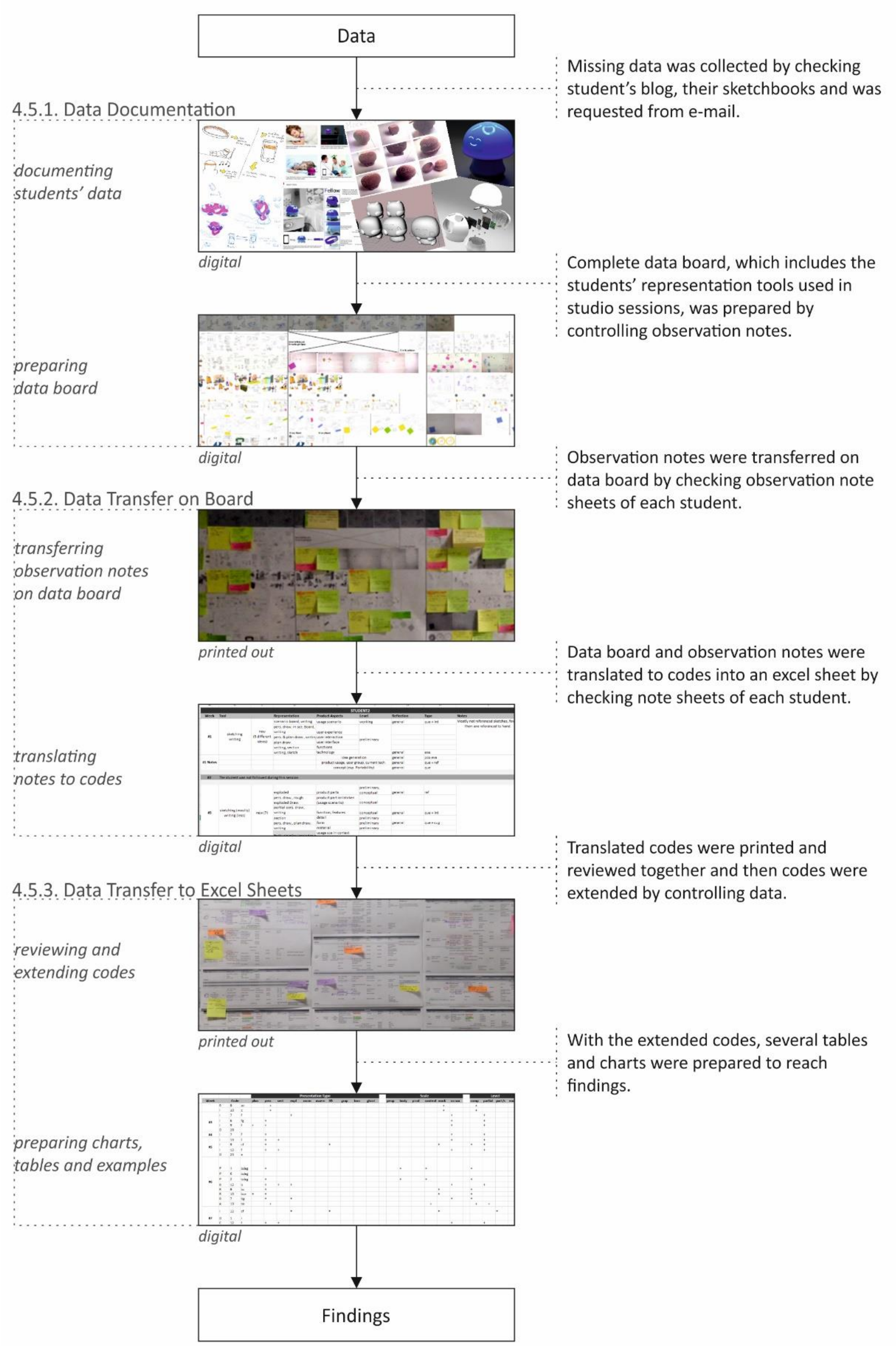


Figure 4.17. The data preparation and analysis process from data to findings

4.5.1.1. Documenting the students' data

The researcher firstly collected the students' sketchbooks and digital version of their course blogs from the website to check and complete the missing data after completing the study. However, there were still missing data; therefore, the students were then asked through e-mail to send the missing data in a digital format that could not be found in their sketchbooks and blogs, such as 3D-models and photos of mock-ups. Collecting the missing data from the students took almost four months by sending reminder e-mails, from July 2017 till October 2017.

4.5.1.2. Preparing the data board

A data board including students' representation tools used in studio sessions during the product development process was prepared in a digital format by controlling observation notes. This board was a 90X350cm chart that separates each observation session on columns and each student on rows, filled with images and photos of students' representation tools (Figure 4.17). While filling this chart, each observation session note was reviewed to find related representation tools. After completing the data board, it was printed out to be used in the next step.

4.5.2. Data transfer on board

The second step was the data transfer on printed data board filled with students' representation tools used in studio sessions in order to review and unitize all data together; representation tools with observation notes. The researcher then translated these notes to codes in a separate excel sheet for each student in order to code and categorize all data.

4.5.2.1. Transferring observation notes on data board

Transferred observation notes were mainly the product aspects developed during the product development process, explanations of these aspects and the feedback given by the tutors during studio sessions. In addition to these, general explanations and feedbacks were transferred on the printed data board. These notes were transferred by writing on different colored post-its on related observation sessions and representation tools.

4.5.2.2. Translating notes to codes in excel sheets

Observation notes were translated to codes in an excel sheet for each student by cross checking them. This excel sheet includes session number, tools used during this session, product aspects that the student explained, representation tools used to explain these aspects, level of these product aspects, reflection level and type given by the tutors, and notes of the researcher for this session if there is any. An example of first coding showing the 9th observation session of a student can be seen in Table 4.5.

Table 4.5. An example of first coding of observation notes into excel sheet (9th observation session of a student)

<table>
<tr><th></th><th colspan="2">Representation Tools</th><th colspan="2">Product Aspects and Level</th><th colspan="2">Reflection Type and Level</th><th>Notes</th></tr>
<tr><td rowspan="9">**#9**</td><td rowspan="9">render
mock-ups
exploded render
3D-model</td><td>3D-model</td><td>*usage scenario*</td><td>finished</td><td></td><td></td><td rowspan="9">Mostly 3D-model and render is used to explain. 3D-model is more interactive.</td></tr>
<tr><td>3D-model (move)</td><td>*product parts*</td><td>finished</td><td>question
reflection
suggestion</td><td>specific</td></tr>
<tr><td>3D-model</td><td>*product buttons, functions*</td><td>detailed</td><td>reflection
suggestion</td><td>specific</td></tr>
<tr><td>3D-model (hide, unhide)</td><td>*mechanism*</td><td>almost finished</td><td></td><td></td></tr>
<tr><td>3D-model (zoom)</td><td>*details*</td><td>detailed</td><td>question
interpretation
suggestion</td><td>specific</td></tr>
<tr><td>3D-model (hide, unhide)</td><td>*maintenance*</td><td>detailed</td><td></td><td></td></tr>
<tr><td>mock-up</td><td>*size*</td><td>finished</td><td></td><td></td></tr>
<tr><td>perspective render</td><td>material, color</td><td>detailed</td><td>question
reflection
suggestion</td><td>specific</td></tr>
<tr><td>perspective render, mock-up</td><td>product form</td><td>detailed</td><td>reflection
interpretation
suggestion</td><td>specific</td></tr>
</table>

4.5.3. Data transfer to excel sheets

The third step was to review the printed excel sheets in order to select the sessions of each student to include in the analysis and eliminate the irrelevant ones, according to the survey results and observation notes. Then the coding list of excel sheets was extended in order to reach inferences. The researcher then prepared tables and charts by using extended excel sheets.

4.5.3.1. Reviewing and extending codes

While reviewing printed excel sheets together, the sessions of each student were selected according to the survey findings, interactivity of the session, use of multiple tools and knowledge representation with 3D-model and render tools, which might have direct inferences for AR technology. How the survey findings were used for selection will be explained in Section 4.6.2. The tenth session was the final board screening, in which printed boards were critiqued; therefore, this session was excluded. In addition, the first session was initial ideas jury and the students were exploring conceptual ideas at this stage. Similarly, the students had not given any direction to their ideas yet in the second sessions. Moreover, after preparing tables and charts for each observation session, the fourth session results showed that there was limited information when compared to other sessions. The fourth session was a half-day studio session and less than half of the students were followed during this session, therefore, this session was also excluded. As a result, these sessions were excluded and the data from the third and fifth to the ninth sessions were selected based on these considerations (*selected sessions can be seen in Table 4.6*).

On the other hand, the first, second, fourth and tenth sessions were included in the analysis to have insight about the students' product development process, such as the use of design representation tools and the ratio of product aspects mentioned in each session.

Table 4.6. Selected observation sessions based on criteria

Students	Observation sessions									
	#1	***#2***	***#3***	***#4***	***#5***	***#6***	***#7***	***#8***	***#9***	***#10***
#1										
#2										
#3										
#4										
#5										
#6										
#7										
#8										
#9										
#10										
#11										
#12										
#13										
#14										
#15										
#16										

These selected sessions were extended by controlling the data. While extending the coding, the data were coded and clustered under five main themes, *categorization of the findings*, *representation tools used by students during observation sessions*, *design considerations including product aspects and research related information that the students paid attention during studio sessions*, *reflection /feedback/critique given by tutors of the desk crit/evaluation sessions and its level*, and *presentation of the product in terms of type, level and scale*. The complete list of these themes can be seen in Table 4.7.

Table 4.7. Complete coding list

Categorization	Representation	Design Considerations		Reflection	Presentation	
Findings	**Tool**	**Product Aspects**	**Information**	**Type**	**Type**	**Scale**
Direct Inference	3d-model	usage scenario*	project statement**	Reflection	plan	people
Indirect Inference	render	user experience*	problems**	Interpretation	perspective	part of the body
Challenges	mock-up	user interaction*	research**	Coaching	section	other product
Documentation	graphic	emotion*	user group**	Questions	exploded	context
Preparation	photo	user interface	product example**	Demonstration	zoom	no scale
	sketching	features/function	moodboard**	Description	assembly	
	writing	part/parts	keywords**	Completions	2D	
	orthographic	ergonomy	critiques**	Examples	iconic	
	jury boards	aesthetic/form	evaluation**	Reminders	ghosted	
	older versions	size		Pos. evaluation		
	video	material/color		Neg. evaluation	**Level**	
		mechanism		Analogies	complete	
		detail		Problem statement	partial	
		technical		Scenarios	part/parts	
		product conf.		Conflict statement	multiple	
		assembly/set-up				
		inner parts		**Level**		
		technology		general		
		context/env.		detailed		
		maintenance		specific		
		Level				
		preliminary				
		conceptual				
		working				
		detailed				
		finished				

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included in product aspects.*

*** These considerations are research related information that gives direction to the product development process.*

The findings were divided into five categories; *direct inference, indirect inference, challenge, documentation,* and *preparation* (Table 4.7). The *direct inference* category is directly related to the use of 3D-models and renders, this is mainly because preparing a 3D-model is essential to transfer this model into AR application. On the other hand, the *indirect inference* category is related to the other design representation tools that might have potential insights for AR. Findings included in the *challenges* category are those that might have potential for AR but might be difficult to develop when compared to others, such as interactive user interface on a product. Findings related to the *preparation* category can be considered as using AR to prepare design representations outside studio sessions in order to use these representations during the studio sessions. For instance, taking screenshots of the product in context or making evaluation with users can be given example for preparation. Findings that take place in the *documentation* category are those research related information, such as showing research or product examples, or using older versions or jury boards during studio sessions.

Design representation tools and design considerations were also extended while reviewing the data. Design representation tools are 3D-model, render, mock-up, graphic, photo, sketching, writing, orthographic, jury boards, older versions of tools and video. 3D-model refers to the use of computer screen to show the product in modelling software whereas render refers realistic visual views of the design concept/product which was shown from computer screen or printouts. Mock-up refers to either visual mock-up to present the key characteristics of the product or working mock-up to make an exploration about design concept in order to continue development process. Graphic mainly refers to the illustration of human and body parts, which was used to support explaining product aspects. In addition, graphic directly refers to the illustration of user interface. Photo refers to photos taken by the students or found on the internet in order to support explaining product aspects, such as context and material. Sketching refers to hand drawings of the students whereas writing refers to keywords or explanations written on presentations to support design considerations. Orthographic refers to the presentation of the product from three different views. However, this representation was only used in preliminary and final juries; therefore, orthographic was excluded. Similarly, using jury boards after jury sessions and older versions of the tools was excluded to avoid duplication of data.

Design considerations includes product aspects and research related information that the students paid attention to during product development process, especially observation sessions. Although usage scenario, user experience, user interaction and emotion are not considered as product aspects, they give direction to the development of product aspects; thus, they are included in product aspects. Similarly, research related information, such as user group and product example, gives direction to the product development process. While reflection given by tutors were extended, presentation of the design concept in terms of type, level and scale of the product were added to understand how the product aspects were represented.

4.5.3.2. Preparing tables, charts and examples

To reach findings, the selected sessions of each student in excel sheets were extended according to the list given in Table 4.7. After finalizing the coding of the data, the following steps were taken to prepare tables, charts and examples that give insights into the study.

- All final coded data were gathered together under the categorization made for the findings, namely, *direct inference, indirect inference, challenges, documentation* and *preparation*. Under each categorization, the findings were grouped according to *product aspects* and *students*.
- An excel sheet showing observation session-based findings according to this categorization and the product aspects was prepared. This excel sheet showed the density of findings for each aspect in each observation session.
- Student and session-based excel sheets were prepared in order to make a filtered version of the excel sheet.

- Finally, the filtered excel sheet was prepared according to observation sessions, categorization of findings, design considerations including product aspects and research related information, and design representation tools.
- Tables and charts were prepared by using this filtered version of excel sheet and according to these findings, examples were prepared by selecting the students' data related to the findings, which will be used to illustrate the findings.

4.6. Analysis of the data

4.6.1. Observation sessions

The data collected during the observation sessions was analyzed with a procedure defined by Stringer (2014) as reviewing and unitizing the data (Section 4.5.1), categorizing and coding (Sections 4.5.2 and 4.5.3), identifying themes and organizing a category system (Section 4.5.3). The data about representation tools collected from students were gathered together in a board by unitizing the data according to the observation sessions and the students. In addition, the observation notes were transferred on this board. Then this board, together with the observation notes, were reviewed to familiarize with the content and to identify the relevant information for exploration. The data was coded into related groups in two different steps by controlling the raw data. After the first coding process, the data was selected and extended. The coding processes were conducted based on both open and axial coding (Corbin and Strauss, 1990). The purpose of open coding is to gain new insights with assessment and analysis of the data by breaking down according to dimensions, comparing the similarities and differences with labels to group them into categories and subcategories. This process helps the coding and categorization of the data. Once it is defined, the researcher looks into the data to define similar instances. In axial coding, the relationship between categories and subcategories is explored while categorization process of the data develops with new indications, which the researcher looks into. These processes were carried out by the researcher during data preparation and analysis process by controlling the data several times as mentioned in Section 4.5.

Observation sessions were mainly analyzed with an internal comparison by looking at the data in two different ways (Table 4.8). One is internal comparison by looking at the same observation session of each student based on the same product aspect. For instance, three students used different design representation tools to explain mechanism on the same observation session, eighth observation session. One student used visual mock-up supported with sketching, other student used visual mock-up supported with video showing how mechanism works. Another student used working mock-up supported with 3D-model to explain mechanism. Effectiveness of these tools used by the students during desk crit sessions was determined by looking at the data in terms of student's explanation and communication between the student and the tutors (Table 4.9). This was also controlled through observation notes (Figure 4.18).

Table 4.8. Analysis of observation sessions

Students	Observation sessions included in analysis					
	#3	*#5*	*#6*	*#7*	*#8*	*#9*
#1						
#2						
#3						
#4						
#5						
#6						
#7						
#8						
#9						
#10						
#11						
#12						
#13						
#14						
#15						
#16						

Table 4.9. Internal comparison example of the students that explained mechanism at the same observation session

Student	Representation	Product Aspect	Reflection Type	Notes
#2	mock-up	mechanism (detailed)	suggestion question + interpretation + reflection	
#12	mock-up demonstration	mechanism (detailed)	Reflection + suggestion	Trying to find solutions by using working mock-up (interactively). Tutor tried mock-up and other tutor took video to show to the student.
	mock-up demonstration	mechanism (detailed)	interpretation + reflection	
	mock-up + 3D-model	mechanism problem	reflection + suggestion	
#15	mock-up + video	mechanism and detail	reflection reflection + suggestion + example	

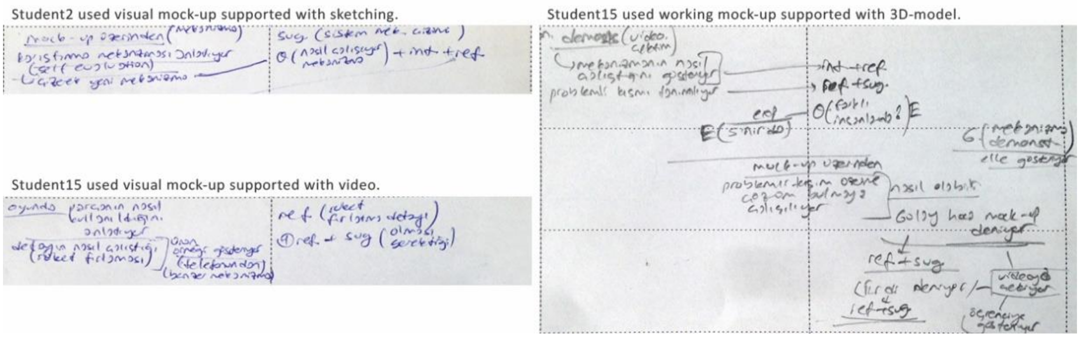


Figure 4.18. Observation notes of the students that explained mechanism at the same observation session

Second way to analyze the observation sessions was to look at the data three observation sessions in a row of the same student. To give an example, one student explained aesthetics/ form in sixth observation session with visual mock-up supported with render. In the previous session, he explained form mock-up supported with sketching. In the following session (seventh observation session), he explained form 3D-model supported with mock-up. By looking at the data and observation sessions based on the product aspects and design representation tools used during desk crit sessions, the effectiveness of these tools were determined. In addition, if an effective use of design representation tools appeared only once, this use of design representation tools was not included in the insight. For instance, detail of the product was explained with mock-up supported with video by one student in only one session. Therefore, this effective use to explain was excluded.

In addition to internal comparison of the data to determine the effective use of design representation tools based on the product aspects, charts were prepared. These charts show how the students presented the product aspects with the tools used during desk crit sessions. The charts include three parts; type such as presenting with perspective or section, level such as presenting the design concept completely or partially, and scale such as referring to human or body part. These charts were prepared for each product aspect but there was limited information for some of them, such as assembly/set-up and technical standards.

4.6.2. Surveys used in observation sessions

As mentioned earlier, the data collected with the survey was to reveal descriptive statistics about evaluation to find out the considerable differences between student and tutor evaluation in order to look deep into these observation sessions and to decide on whether to include this studio session in the analysis or not. For each student, a survey evaluation results table, an example of which seen in Table 4.10, was prepared to find out the considerable differences. A session was included if it had the potential to give insight; otherwise, it was not included in the analysis.

By using these tables prepared for each student, comparative tables and charts were prepared. To give an example about how the results of the survey was analyzed, the evaluation of sketches until the seventh session and 3D-models in the eighth and ninth sessions used by Student 8 as the tools during studio sessions is given as an example in Table 4.11 and the graphical representation of this data can be seen in Figure 4.19.

The considerable differences to look deep into were observed especially in the third and seventh sessions. Therefore, it was necessary to decide on whether to include this data in the analysis or not by looking at the tools used by the student, interactivity of the session, and whether the design representation tools were used to support one another. If the session had potential to give insight, it was included but otherwise it was not included in the analysis. By using these tables and charts, the sessions that had considerable differences were reviewed, and the sessions to include in the analysis were selected, as mentioned in Section 4.5.3.

Table 4.10. An example survey evaluation results table showing differences in the evaluation of the student and the tutor

Evaluation		**Tools**	**Observation Sessions**									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
student evaluation	preparation (S1)	sketching	4	4	3		2		1	4		
		writing	5	4	3		2	3		6		
		mock-up						7				
		render						7			4	4
		3D-model								6	4	
	explanation (S2)	sketching	5	3	5		4		1	4		
		writing	4	3	5		4	4		6		
		mock-up						4				
		render						4			4	4
		3D-model								6	4	
	tutors' comprehension (S3)	sketching	4	5	1		4		6	4		
		writing	3	5	1		4	1		4		
		mock-up						4				
		render						4			4	4
		3D-model								4	4	
tutor evaluation	student explanation (T1)	sketching	3	3	5		4		5	5		
		writing	5	2	4		5	6				
		mock-up						7				
		render						7	3		6	4
		3D-model								5	7	5
	tutors' comprehension (T2)	sketching	4	3	6		3		6	5		
		writing	5	2	5		5	5				
		mock-up						7				
		render						7	4		7	4
		3D-model								5	6	5

Table 4.11. Evaluation data of the sketch and 3D-model tools used by Student 8

Evaluation		**Observation sessions**								
		sketch							*3D-model*	
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
student evaluation	preparation (S1)	4	4	3	0	2	0	1	6	4
	explanation (S2)	5	3	5	0	4	0	1	6	4
	tutors' comprehension (S3)	4	5	1	0	4	0	6	4	4
tutor evaluation	student explanation (T1)	3	3	5	0	4	0	5	5	7
	own comprehension (T2)	4	3	6	0	3	0	6	5	6

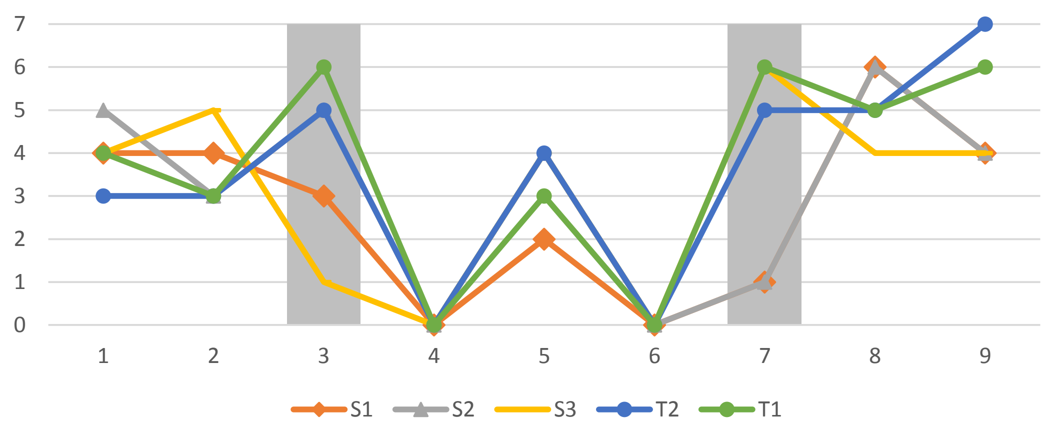


Figure 4.19. Graphical representation of the data of the sketch and 3D-model tools used by Student 8

4.6.3. *Focus group sessions*

The data collected during the focus group sessions included quantitative and qualitative data. The results of the focus group sessions are mainly used to verify and support the data collected from observation sessions. The statistical data of focus groups sessions was to reveal descriptive statistics about evaluation to support the findings of the observation study. While the self-evaluation of the students about the design representation tools they used during their product development process was analyzed to verify the findings about the use of design representation tools during studio sessions, self-evaluation about the product aspects developed during the product development process was used to verify the findings about the product aspects mentioned during studio sessions. In addition, the self-evaluation of the product aspects with the tools and self-evaluation of the product aspects of the final product were analyzed in order to support the relation between design representation tools. Data gathered from group discussions was used to provide additional exploration about desk crits carried out, and 3D-modelling used, during the students' product development processes. In addition, the evaluation about the importance of the product aspects for the development of AR technology was analyzed to verify and support for which product aspects AR has potential. All the data from focus group sessions was transferred to excel files. The graphics and charts were prepared to represent descriptive statistics. For qualitative data, the data were transcribed by listening to the recordings of the sessions. The unrelated data was excluded from analysis and the related data was coded based on both open and axial coding (Corbin and Strauss, 1990) under different categories, namely, *desk crits*, *design representation tools*, *product development process*, and *3D-modelling*.

4.7. Findings of the study

The number of the findings based on the categorization of *direct inference, indirect inference, challenge*, *documentation* and *preparation*, can be seen in Figure 4.20 to give an idea about the density of these findings, which will be explained in detail in the following sections. The direct inferences, which are related to 3D-models and renders, start from the fourth session and continue until the ninth session, and have higher number of findings in the sixth and ninth sessions because these sessions are preliminary screening and 3D-model screening. The students needed to make more preparations for these studio sessions when compared to others. In addition, the use of 3D-models increased starting from the preliminary jury. The indirect inferences related to other representation tools can be seen in all observation sessions and have the highest value in fifth session, just before the preliminary jury. The reason might be that the students improved their progress to prepare for the preliminary jury.

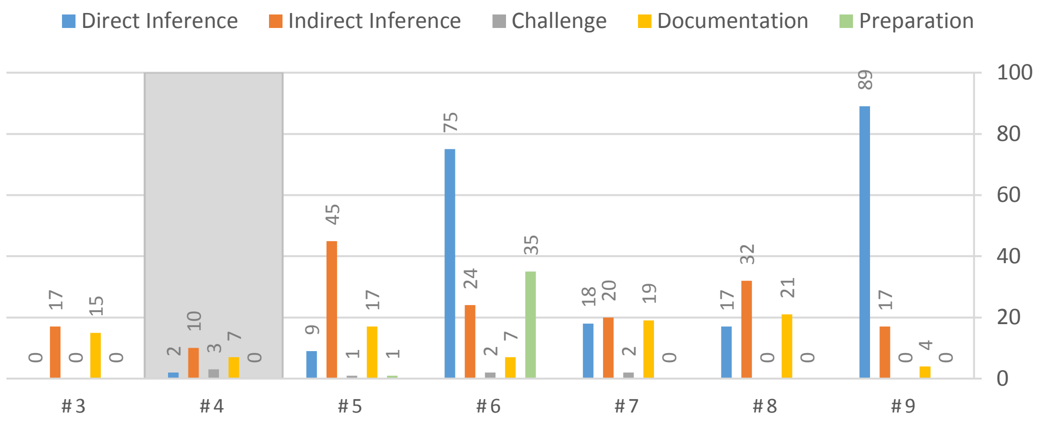


Figure 4.20. Findings based on the categorization

Moreover, findings for challenges are rarely seen between the fourth and seventh sessions. Findings for preparation are mainly seen in the sixth session, which is the preliminary jury, for which the students prepared different design representations as they were presenting their concepts to all tutors of the studio, different from desk crits. The findings for documentation can be seen in all observation sessions because the students needed to re-mention an information related to their concept/product or re-use older design representations during their product development process.

4.7.1. Use of design representation tools

The use frequency of the design representation tools used by the students in the product development process are shown in Figure 4.21. While the writing and sketching tools were used more frequently until the preliminary jury week, which was between the third and sixth sessions, the use of mock-ups, 3D-models and renders as tools became more frequent until the jury board preparation stage, between the sixth and ninth sessions.

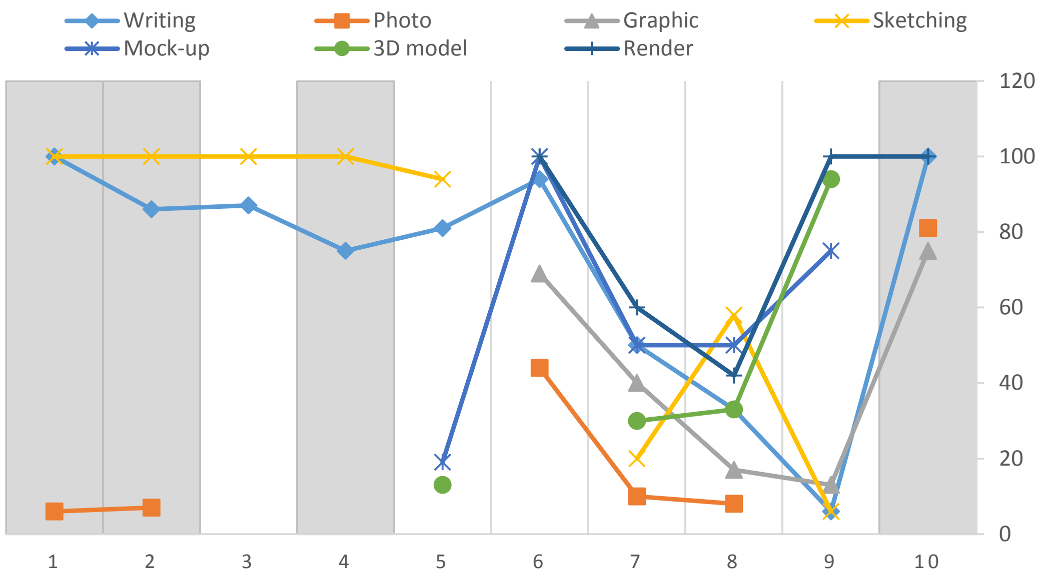


Figure 4.21. Representation tools used in the product development process

Although *sketching* was not used as often as after the preliminary jury, it was used as support for other tools. *Mock-ups* were frequently used during the preliminary jury (sixth session) and until the final board screening session (tenth session). *3D-models* were used between the preliminary jury and the final board screening sessions. *Renders*, which started to be used in the pre-jury, continued to be used frequently until the final board screening session. The use of *graphics* and *photographs* was seen more frequently for preparations for the juries, which were the sixth and tenth sessions. However, graphics, which are rarely used between the preliminary jury and the final screening, were more frequently used in the product development processes (between sixth and tenth sessions) for some projects in which the user interface came into prominence. It was observed that there were no notable differences between the students' ability to use different tools in the product development process.

Based on Owen and Horváth's (2002) classification and reflection of Chandrasegaran et al.'s (2013) experience listing different forms of knowledge representations used in different stages, knowledge representations used in the product development process are pictorial, linguistic, physical and virtual (Figure 4.22). While pictorial and linguistic representations were predominantly used in the early stages of the product design process, after the preliminary jury, 6th session, knowledge representation was predominantly physical and virtual. It can be seen that there is a transition between different tools just before the preliminary jury.

In addition, there are some differences between the design representation tools used during studio sessions (data from observation) and tools used during the product development process (data from the students' evaluation obtained in the focus group sessions) (Figure 4.23). The negative values illustrate that although the students used these tools to develop their concept/product, they did not use these tools during studio sessions. For instance, the main differences are about using 3D-models in the sixth session (preliminary jury) and tenth session (final presentation board critique). This is because 3D-modelling is used as a preparation tool for these sessions.

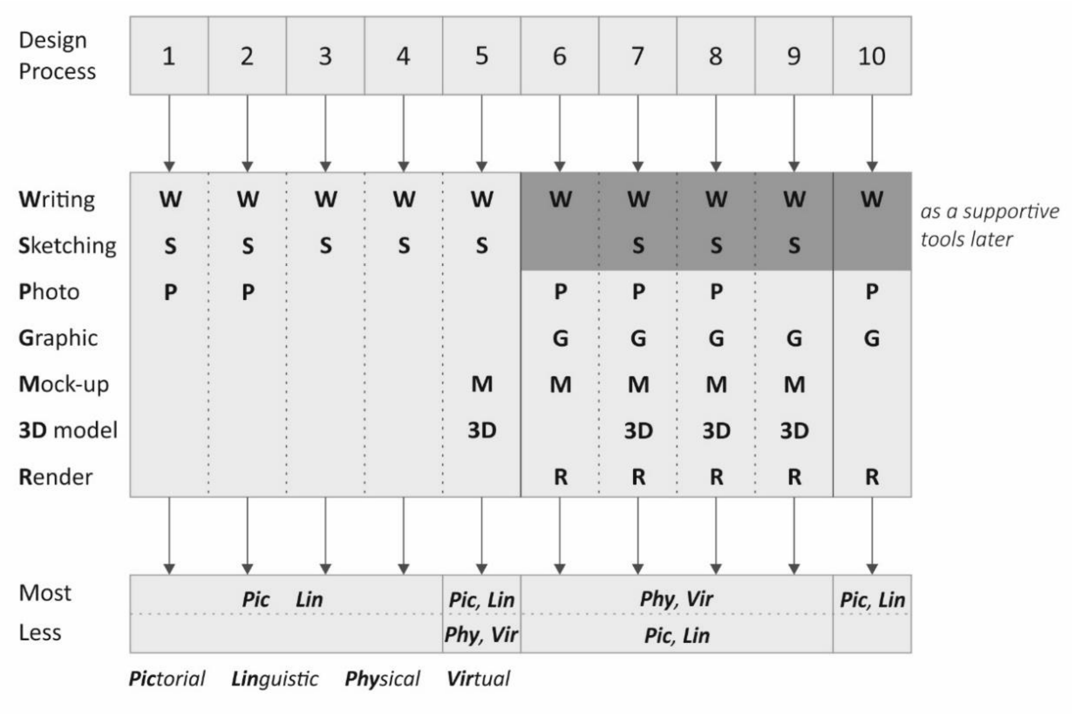


Figure 4.22. Knowledge representation in the product development process

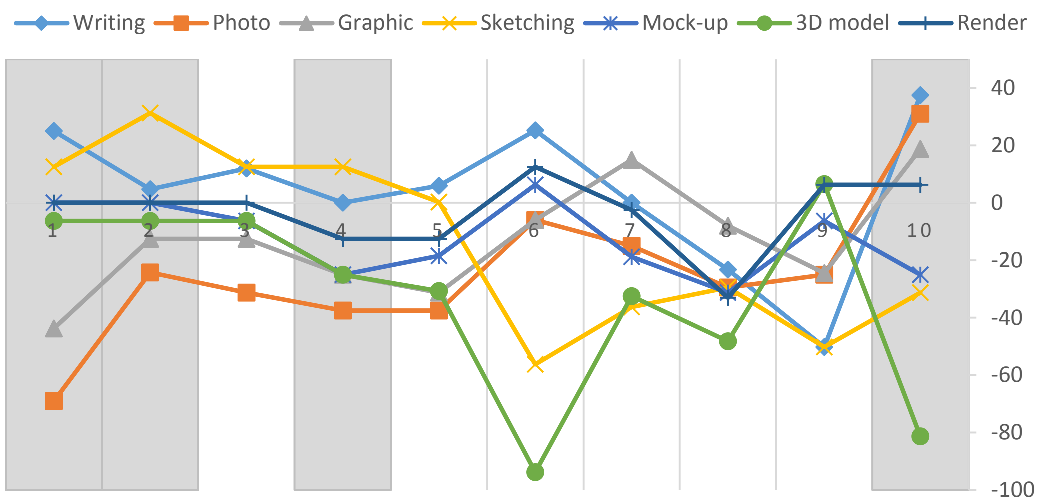


Figure 4.23. Difference between design representation tools used during product development process and studio sessions

The students use these design representation tools while developing their concept/product or preparing design representations for studio sessions. It can be seen that from time to time, students did not prefer using the tools that they used outside the studio sessions. The reasons might be using these tools as preparation tools and therefore having no need to use them during studio session, using them as development tools, the inadequate quality of which presented during studio session, or insufficient documentation of the design representation tools.

4.7.2. Product aspects developed during the product development process

This section presents information about product aspects in terms of the ratio of each product aspect, differences between the product aspects explained during the studio sessions and developed during the product development process, and design representation tools used to the explain product aspects. Without excluding any data to reach findings, the ratio of each product aspect mentioned in each session was calculated to have an insight about 1) which product aspects were considered more, 2) when the students started to think about these product aspects, and 3) which product aspects were never considered. The values were calculated according to the followed students in each observation session and which student mentioned these product aspects during the studio sessions. For instance, all students mentioned usage scenario at least once during their product development process; so that, usage scenario ratio of each session included all the students in the calculation. To give another example, while calculating user interface ratio, the students that mentioned user interaction at least once during their product development process were considered by looking at each session. Therefore, each session had a different calculation rate for each product aspect.

Table 4.12 shows the ratio of product aspects for each session. According to the changes in the ratios of product aspects, there are mainly five groups; *stable, increasing, decreasing, fluctuating* and *spot*. The stable group of product aspects includes usage scenario, feature/function, and physical ergonomics; though usage scenario and feature/function have higher values than physical ergonomics. The group of increasing product aspects includes product part(s), mechanism, detail, and inner parts.

In addition to these product aspects, aesthetics/form has both increasing and fluctuating values. Other product aspects that have fluctuating values are user interaction, user interface, assembly/set-up, technology, and context/environment (which has also a spot ratio during the product development process). The other product aspects in the spot group are size, material/color, technical standards and maintenance. Product aspects in the decreasing ratio group are emotion and user experience, which has also spot values.

Table 4.12. The ratio of product aspects developed by the followed students

Product Aspects	Observation Sessions #1	#2	#3	#4	#5	#6	#7	#8	#9	Change in ratio
usage scenario*	100	100	93	86	73	100	89	91	80	stable
feature/function	67	69	71	86	67	93	78	55	47	stable
physical ergonomics	25	25	33	33	25	25	33	0	50	stable
parts	47	15	29	43	40	80	44	55	87	increasing
mechanism	0	20	20	25	50	33	50	50	83	increasing
details	0	0	11	40	40	20	67	57	60	increasing
inner parts	0	0	0	0	20	40	50	0	60	increasing
aesthetics/form	13	0	43	86	47	100	56	64	100	increasing, fluctuating
user interaction*	90	75	50	0	50	90	50	63	50	fluctuating
user interface	38	17	13	0	13	88	80	40	13	fluctuating
assembly/set-up	0	50	0	0	50	50	100	0	50	fluctuating
technology	55	33	36	0	27	64	43	22	45	fluctuating
context/environment	22	43	11	0	0	78	14	25	11	fluctuating, spot
size	0	0	10	0	18	73	0	29	36	spot
material/color	0	0	25	0	11	0	20	50	100	spot
technical standards	0	0	0	0	0	100	0	0	0	spot
maintenance	0	0	0	0	0	67	0	0	33	spot
user experience*	67	40	27	0	8	33	0	0	0	decreasing, spot
emotion*	100	0	33	0	0	0	0	0	0	decreasing
	The ratios are given in %100 percentage.									

Legend: *stable* · *increasing* · *decreasing* · *fluctuating* · *spot*

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*

Moreover, there are some differences between the product aspects explained during the studio sessions (data from observation) and the product aspect developed during the product development process (data from the students' evaluation in focus group sessions) (Table 4.13). The negative values show that although the students developed these product aspects during their product development process, they did not explain these product aspects during studio sessions. The fourth session does not show realistic values because this session (half-day desk crit session) allowed the researcher to follow less than half of the students. When looking at the other sessions' values, the students considered and developed the product aspects but they did not explain these during studio sessions. This self-evaluation was done right after finishing their product development process but they may not have been able to remember their process properly. On the other hand, the reasons might be that their design process may not have developed as expected, so that, they did not explain during the studio sessions or they did not use a proper design representation tool to explain during studio sessions.

Table 4.13. Difference between product aspects explained during studio sessions and developed during product development process

Product Aspects	Observation Sessions								
	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
usage scenario*	27	20	6	**-14**	**-14**	0	16	18	27
feature/function	13	7	25	9	**-10**	8	24	1	**-15**
physical ergonomics	17	17	8	**-17**	**-25**	**-33**	**-17**	**-100**	**-33**
parts	30	**-10**	-13	**-7**	**-18**	**-12**	**-14**	**-12**	20
mechanism	**-10**	0	0	**-25**	**-10**	**-17**	**-20**	**-20**	3
details	**-14**	**-14**	-10	11	11	**-37**	10	**-36**	**-40**
inner parts	**-8**	0	0	**-25**	**-5**	7	8	**-75**	**-40**
aesthetics/form	**-40**	**-33**	10	13	**-26**	20	**-11**	**-23**	27
user interaction*	26	32	7	**-71**	**-7**	19	7	13	0
user interface	29	**-1**	-5	**-55**	13	24	35	**-42**	**-51**
assembly/set-up	**-50**	50	0	**-50**	0	0	50	**-100**	50
technology	**-35**	**-7**	16	**-50**	**-23**	14	**-7**	**-38**	5
context/environment	**-45**	**-24**	**-36**	**-47**	**-47**	25	**-19**	**-2**	**-9**
size	**-33**	**-40**	**-10**	**-53**	**-42**	6	**-67**	**-64**	**-64**
material/color	**-7**	**-14**	18	**-14**	**-3**	**-50**	**-37**	**-7**	29
technical standards	**-14**	**-14**	**-29**	**-43**	**-29**	36	**-64**	**-79**	**-86**
maintenance	**-9**	**-27**	0	**-9**	-9	58	-9	**-27**	**-22**
user experience*	47	20	7	**-70**	**-52**	**-47**	**-60**	**-70**	**-50**
emotion*	NA								

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*

The product aspects developed during the product development process by the students were explained with different design representation tools, either single use of them or multiple use of these tools. Table 4.14 shows the use of these tools to present and explain each product aspect during design studio sessions of the students.

For instance, aesthetic/form was presented and explained during studio sessions with 3D-model, 3D-model with render or mock-up or sketching, render, render with mock-up or sketching, mock-up and mock-up with sketching.

Table 4.14. Design representation tools used to present and explain product aspects

Product aspects	**Design representation tools used to explain product aspects**
usage scenario*	mock-up, mock-up + render + graphic/photo, mock-up + 3D-model/render, mock-up + sketching + writing, mock-up + sketching/graphic, 3D-model, 3D-model + sketching, render, render + graphic/writing, render + graphic + writing, render + photo + sketching, sketching, sketching + writing, photo, video
user experience*	*limited information to conclude*
user interaction*	*limited information to conclude*
emotion*	*limited information to conclude*
user interface	graphic, graphic + mock-up/sketching, mock-up, render + graphic, sketching, sketching + writing
features/function	3D-model, 3D-model + render, render, render + mock-up + graphic/sketching, render + graphic + photo/sketching, render + writing, mock-up, mock-up + graphic, graphic + graphic + writing, sketching, sketching + writing
part/parts	3D-model, 3D-model + render/mock-up, 3D-model + sketching +writing render, render + writing/mock-up, render + mock-up + writing sketching, sketching + writing
physical ergonomics	mock-up, mock-up + 3D-model/sketching, sketching, render, sketching + writing, render + graphic + mock-up
aesthetic/form	3D-model, 3D-model + render/mock-up/sketching render, render + mock-up/sketching, mock-up, mock-up + sketching
size	mock-up, mock-up + 3D-model/render/sketching, mock-up + render + photo, render + graphic
material/color	render, render + mock-up/sketching, render + photo, sketching, sketching + writing
product configuration	render, 3D-model + render + mock-up
context/environment	render + photo, render + graphic + photo, photo, writing
mechanism	3D-model, 3D-model + mock-up/sketching, mock-up, mock-up + sketching/video, sketching, sketching + writing
detail	3D-model, 3D-model + render/mock-up, render, render + mock-up, mock-up, mock-up + sketching/video, sketching, sketching + writing
technical standards	*limited information to conclude*
assembly/set-up	*limited information to conclude*
inner parts	3D-model, 3D-model + render/writing, render, render + writing
technology	3D-model, 3D-model + render/writing, 3D-model + render + writing, render, render + writing, sketching + writing
maintenance	*limited information to conclude*
** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*	

To give another example, inner parts were presented and explained with 3D-model, 3D-model with render or writing, render, render with writing. This data was analyzed with an internal comparison as mentioned in Section 4.6.1. Internal comparison of the design representation tools that were used by the students during studio sessions for each aspect was done by looking at these different uses of these tools. The comparative expressions stated in Section 4.7.3 were based on this internal comparison of the data.

4.7.3. Insights from the direct and indirect inferences

To remind what direct and indirect inferences refer to, *direct inferences* are directly related to the use of 3D-models and renders, this is mainly because preparing a 3D-model is essential to transfer this model into AR application. On the other hand, the *indirect inferences* are related to the other design representation tools that might have potential insights for AR. In this section, the insights of the direct and indirect inferences for each product aspect will be explained by giving representation examples of the students. As mentioned in Section 4.6.1, the comparative expressions that will be stated under this section were based on this internal comparison of the data.

4.7.3.1. Usage scenario, user experience and emotion

While explaining the usage scenario, perspective views were predominantly used and supported with plan views (Figure 4.24). Mock-ups were mostly used to explain the usage process by showing the mock-up on human body step by step in order to give an idea about the relation between the user and the product. Similarly, presenting the usage scenario by giving reference to either human graphics or human sketches helped the student explain the relation between the user and the product.

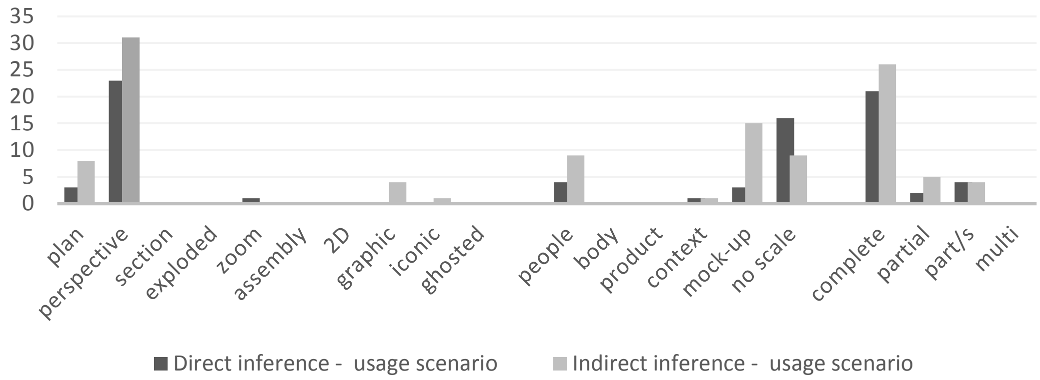


Figure 4.24. Direct inferences and indirect inferences about the usage scenario

On the other hand, there were also studio sessions in which the students explained the usage scenario without giving any scale for the product. While explaining the usage scenario, the complete concept/product was mainly shown and partial views of a complete product or just part/s of the product were shown when necessary, to support explanations. For the usage scenario, the results show that the relation between the user and the product are important for explaining step by step.

As mentioned, while explaining the usage scenario using mock-ups, even a simple rough mock-up, or giving reference to human graphics helped the student show step by step how the product is used and the relation between the user and product. These representations also enhanced the interaction during studio sessions and helped students receive better feedback from tutors. Figure 4.25 shows an example of usage scenario representation with mock-ups supported with sketches for a game project for children. Preparing even a simple mock-up together with sketches helped the student explain the game scenario easily and this mock-up enabled game playing during the studio session in order to understand the concept in a better way, leading to a more interactive session. Similarly, students used mock-ups on their body to show the relation between the user and product. The advantage of a mock-up was to enable the students to explain step by step interactively.

Figure 4.25. Usage scenario representation with mock-ups supported with sketches (Student 3)

In addition, students also preferred renders with or without human graphics to show the usage scenario (Figure 4.26). This type of presentation appeared mostly in evaluation juries and less in desk crits. One reason for this might be the time needed to prepare this type of a presentation and this is why it may have been less preferred in desk crits. This will be further explained in Section 4.7.5 Insights of Preparation. The effective way in explaining the usage scenario was to use different representation tools together in supporting one another.

Figure 4.26. Usage scenario representation examples with renders and human graphics (Left: Student 4 and Right: Student 9)

The students did not prepare any specific representations during the product development process for user experience and emotion. These product aspects were covered while the students explained the usage scenario; thus it can be said that user experience and emotion are mainly related to how the usage scenario is presented. There was no special representation needed by the students during the process. If the usage scenario is well presented with the design representation tools, user experience and emotion are also well explained through the use of the same representation.

4.7.3.2. User interaction

User interaction can be considered as a product aspect that is related to the other product aspects, mainly usage scenario and user interface. As it can be seen in Figure 4.27, the presentation types used for user interaction during the product development process are mainly perspective view, graphics, plan views and iconic representation. To explain user interaction, body part and mock-up was mainly used and human graphics/sketches are less preferred. Complete or partial representations of the product were mostly used in order to support explaining user interaction. If the user interaction is related to usage scenario, perspective views together with human graphics or mock-ups comes into prominence, helping the students show how the user interacts with the product. On the other hand, if the user interaction is related to user interface, the graphics are more important by showing either on plan or perspective views or on mock-ups. The effective representation for user interaction related to user interface is to see graphics on a real size mock-up in order to have better interactive studio sessions. This will be explained in Section 4.7.3.3 User interface. To represent user interaction in a better way, the students need to present the product aspect related to user interaction in a better way. Figure 4.28 shows examples of students' user interaction representations related to usage scenario or user interface.

Figure 4.27. Direct inferences and indirect inferences about user interaction

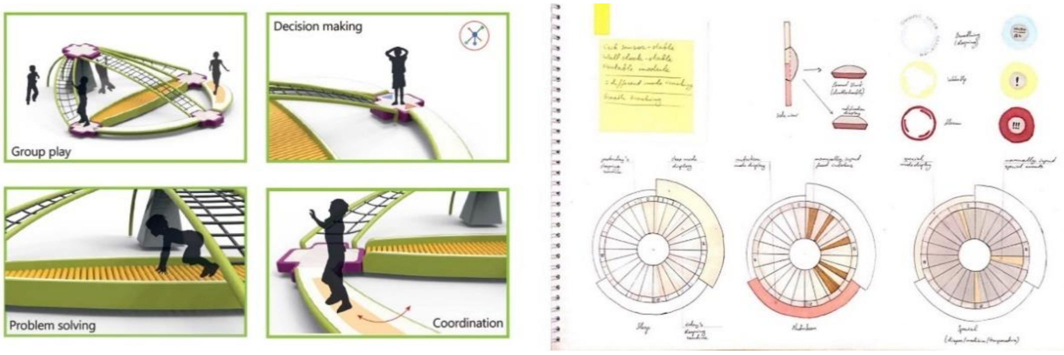


Figure 4.28. User interaction representation examples together with other aspects.
Left: Usage scenario (Student 14) and Right: User interface (Student 7)

4.7.3.3. User interface

When the students explained user interaction, a better way to represent this aspect was to use graphics with either perspective or plan views by using mock-ups or showing on product renders (Figure 4.29). This representation, showing graphics on mock-ups or product, increases interaction with the tutors in studio sessions as well as the critiques and feedbacks when compared to presentation of user interface without giving scale. Furthermore, representing user interface by using mock-ups and graphic representation helps the students explain the interaction between the user and the interface of the product. Whether the product is represented as complete or partial, showing user interface in real size is vital for both development of user interface and effective studio sessions.

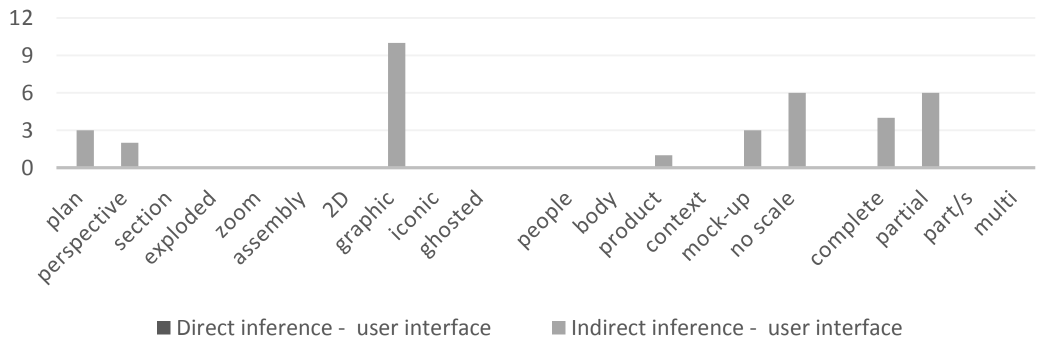


Figure 4.29. Direct inferences and indirect inferences about user interface

To give an example, Figure 4.30 shows the user interface representations of two students used in the seventh observation session. While one of the students used mock-ups and graphic drawings in real size, the other student mainly used computer graphics without giving an idea about scale even though a hand icon was used but not showing the real scale. The one with real size increased the interactivity of the studio session and helped the student get better feedback about user interface. On the other hand, computer graphics helped the student show how user interface is used step by step.

Figure 4.30. User interface representation examples. Left: Mock-up and graphic drawings in real size (Student 7) and Right: Computer graphics without giving real size (Student 8)

4.7.3.4. Feature/function

Product feature/function was represented in different ways. During studio sessions, perspective views were predominantly used and plan views, zoom views and graphics were also used to explain feature/function without giving the real size and by showing the product completely or partially (Figure 4.31).

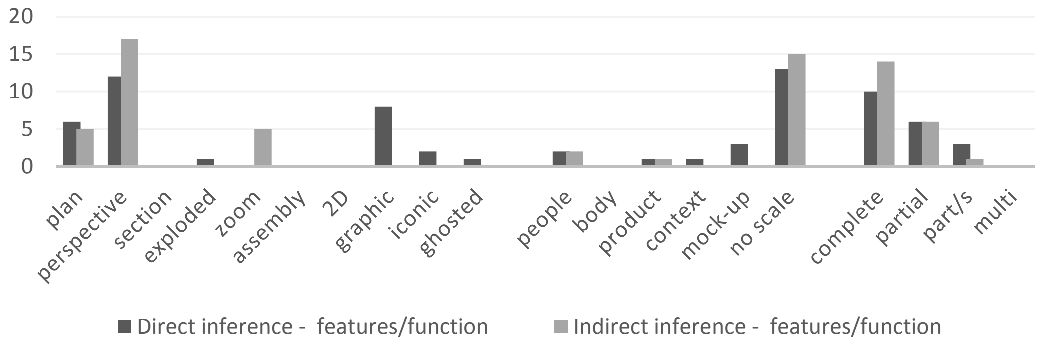


Figure 4.31. Direct inferences and indirect inferences about feature/function

Different representations of this aspect stem from the need of the students for their project. This is mainly because feature/function could be related to either mechanism, user interface, product parts or any other related product aspect. Therefore, this product aspect is mainly represented with other related aspects by showing additional representations for feature/function if necessary. In other words, the representation of feature/function was integrated into the representation of other product aspects. Figure 4.32 exemplifies feature/function representation of a student in the following observation sessions. Feature/function representation was firstly integrated into product parts and mechanism representation and user interface was also added in the following session.

Figure 4.32. Feature/function representation example together with other related aspects (Student 2)

4.7.3.5. Parts

During the product development process, 3D-models and renders were main design representation tools used in explaining product parts as can be seen in Figure 4.33.

The figure illustrates that the direct inferences are numerically more than the indirect inferences, which are related to other design representation tools. While explaining parts, perspective and plan views by exploding or zooming were used, showing the product completely or partially or just the relevant part without illustrating the real size (Figure 4.33). The important thing in representing parts for the students was to point out the related part that the student explained.

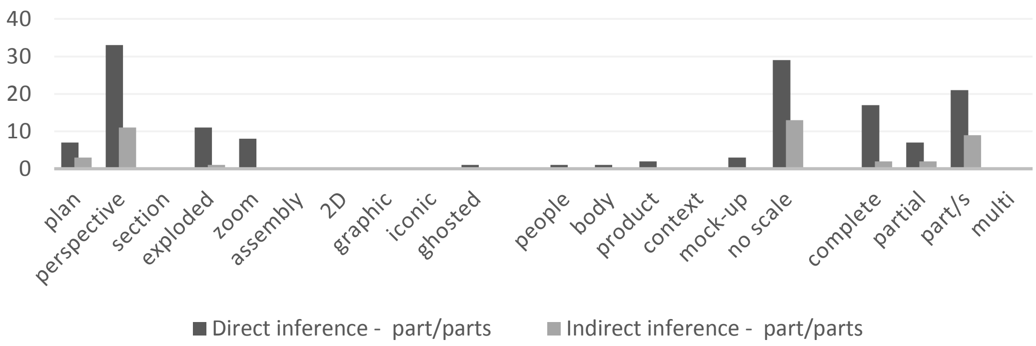


Figure 4.33. Direct inferences and indirect inferences about parts

Figure 4.34 shows two different representations of product parts, 3D-model representation of a student before the preliminary jury and render representation of another student in the final screening. While 3D-models enable the student to show product parts interactively, by zooming or hiding/unhiding parts, render representation does not enable interactivity like 3D-models.

Figure 4.34. Parts representation examples. Left: 3D-model (Student 9) and Right: Render (Student 10)

4.7.3.6. Physical ergonomics

Physical ergonomics is one of the most important product aspects that the students need to show in representing the relation between the user and product. When looking at Figure 4.35, it can be easily seen that physical ergonomics was presented with mock-ups or human graphics to show this relation by illustrating perspective, plan or section views completely or partially. Mock-ups need to be in real size in order to show this relation and to explain the physical ergonomics aspect.

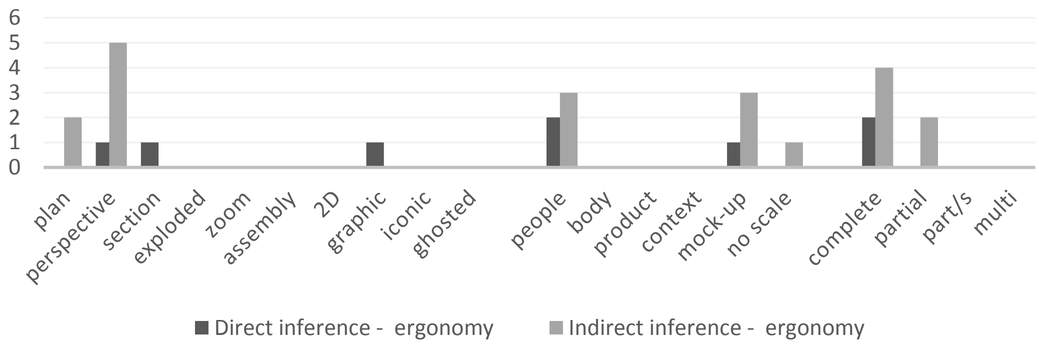


Figure 4.35. Direct inferences and indirect inferences about ergonomics

To give an example, Figure 4.36 illustrates physical ergonomics representation of two students in the preliminary jury and after the jury, whereas another student explained this product aspect by holding parts and showing a mock-up on his body in an interactive way. The student preferred section renders and human graphics for showing different steps of the product. The student that used mock-up also explained physical ergonomics with mock-ups in the preliminary jury. It was difficult for the student who used renders and human graphics to make real size mock-ups; therefore, he used these design representation tools. The effective representation to explain physical ergonomics is to use mock-ups in real size, resulting in better interactive studio sessions.

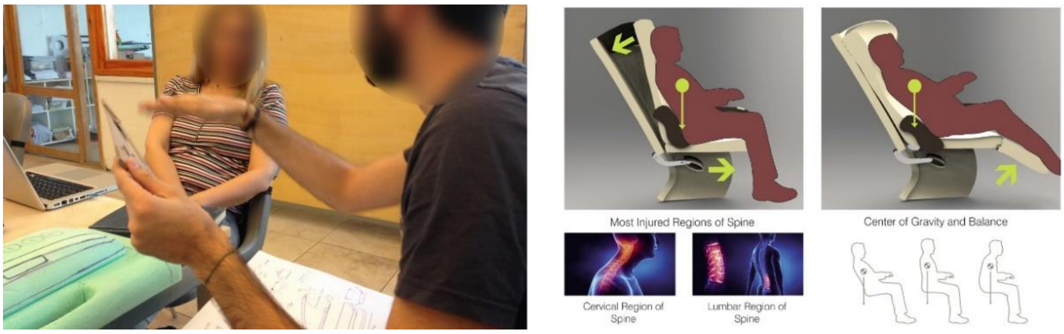


Figure 4.36. Physical ergonomics representation examples. Left: Mock-up supported with sketches (Student 1) and Right: Section renders and human graphics (Student 16)

4.7.3.7. Aesthetics/Form

As it can be seen in Figure 4.37, perspective views were mainly used and supported with plan views to explain aesthetics/form without giving real size or by using mock-ups. During the studio sessions, the product was mostly presented completely and also in a multiple way, in other words showing different versions at the same time or separately (Figure 4.37). Human graphics, body parts, other products or context were also utilized while showing aesthetics/form of the product, even though they were less used. During the product development process, 3D-models and renders with or without using mock-ups were the main design representation tools used in explaining aesthetics/form in addition to mock-ups supported with sketches. Figure 4.38 shows examples of aesthetics/form representations with different tools supporting each other. 3D-model or render tools supported with mock-ups were utilized to show the aesthetics/form of the product. In both cases, the 3D-model or render was more detailed than the mock-up. In addition, while 3D-models enhance the interactivity by enabling students to change the view, zoom in, or show different versions together or separately, renders do not provide these possibilities. Showing different versions of aesthetics of the product together or separately is necessary for the students during the product development process. Using different tools, *3D-models or renders supported with mock-ups or sketches,* altogether supporting each other is an effective way for representing aesthetics/form, leading to more interactive studio sessions.

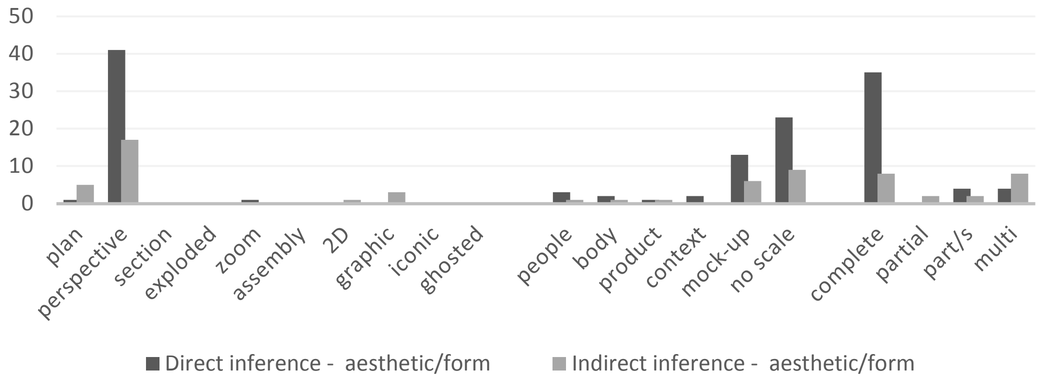


Figure 4.37. Direct inferences and indirect inferences about aesthetics/form

Figure 4.38. Aesthetics/form representation examples; Left: 3D-model and mock-up (Student 5) and Right: Render and mock-up (Student 6)

4.7.3.8. *Size*

When explaining the size of the concept/product, a better way to represent this aspect was to use mock-ups or to show the concept/product in reference to the human body, body part, or other related products or context (Figure 4.39). This product aspect was represented with perspective and plan views. Representing size by using mock-ups increases interaction with the tutors in studio sessions as well as the critiques and feedbacks. Moreover, representing size by giving reference to the human body, body part, other products or context helps the students explain this product aspect better. Although size was explained by showing the concept/product partially, complete product representation in real size is essential for both the development of size and effective studio sessions.

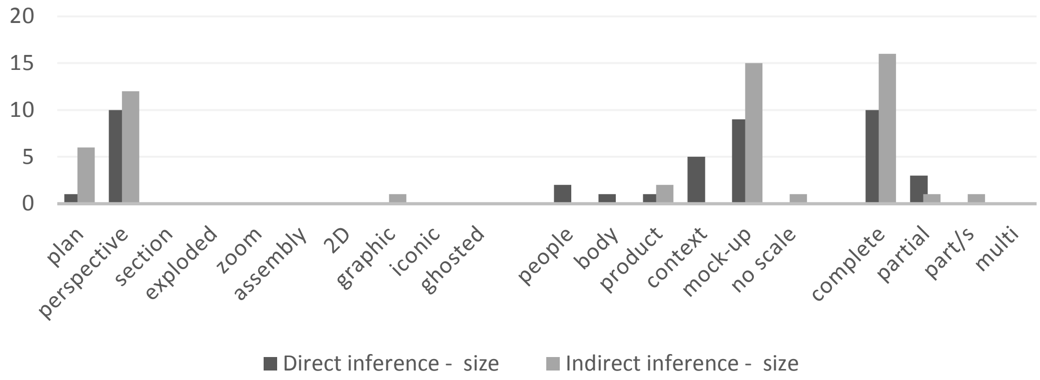


Figure 4.39. Direct inferences and indirect inferences about size

To give an example, Figure 4.40 illustrates size representation of a student used in the fifth observation session and size representation of another student used in ninth observation session. Mock-ups in real size and sketching was used just before the preliminary jury to represent size by one of the students. The other example given in Figure 4.40 shows mock-up representation supported by a 3D-model to explain size. When looking at the use frequency of the mock-up tool, it increased after the preliminary jury, like the use of 3D-models (Figure 4.21). It can be said that using 3D-models could help students prepare mock-ups; thus, the increase in using mock-ups after the preliminary jury might be related to the use of 3D-models. Another factor might be that the students had started to give direction to their concept/product so that the use of mock-ups in studio sessions increased. Real size mock-up is an effective representation tool for the projects for which real size mock-ups can be done. Though, preparing real size mock-ups is not feasible for every project. In that case, giving references by using human graphics/body parts/other product/context on renders or 3D-models or sketches has more potential for those projects for which real size mock-ups cannot be done.

Figure 4.40. Size representation examples: Left: Mock-up and sketches (Student 5) and Right: Mock-up and 3D-model (Student 2)

4.7.3.9. Material/color

The students predominantly used perspective views to explain material/color without giving any scale during studio sessions (Figure 4.41). They mostly presented complete concepts/products and less presented as parts or multiple representations. Figure 4.41 shows that the direct inferences are more than indirect inferences, resulting in that 3D-models and renders were the main design representation tools used in explaining material/color during studio sessions. Although students started to visualize material/color starting from the preliminary jury, they explained this product aspect mostly in the last two observation sessions.

Figure 4.41. Direct inferences and indirect inferences about material/color

Figure 4.42 shows two different material/color representations of two students used in the ninth observation session. While one of the students presented this product aspect with different alternatives, another student presented with one alternative.

Showing the product with different alternatives is an essential representation for students who suggest different material/color options for their projects.

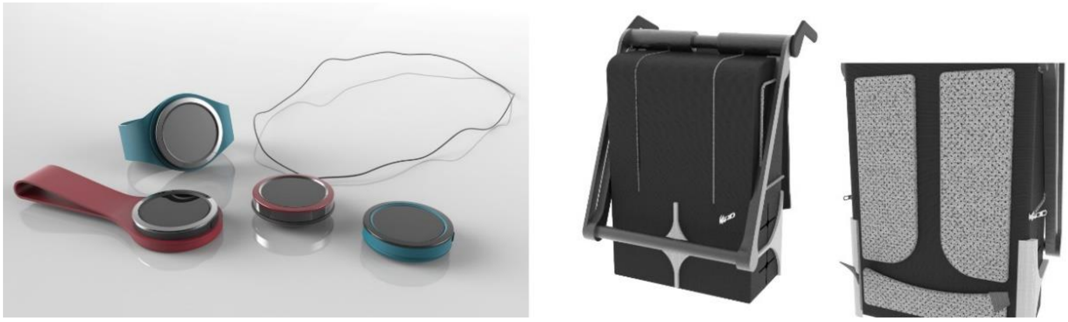


Figure 4.42. Material/color representation examples: Left: Render (Student 8) and Right: Render (Student 12)

4.7.3.10. Product configuration

Product configuration is one of the rarely seen product aspects during the studio sessions. This product aspect was developed by two of the students and explained during two different sessions, the sixth (preliminary jury) and ninth sessions. This is why Figure 4.43 illustrates little information about product configuration. As it can be seen in the figure, perspective and zoom view, were used to explain this product aspect mostly without giving the real size or any reference to user. In addition, the product was represented completely or partially or with multiple products at the same time (Figure 4.43).

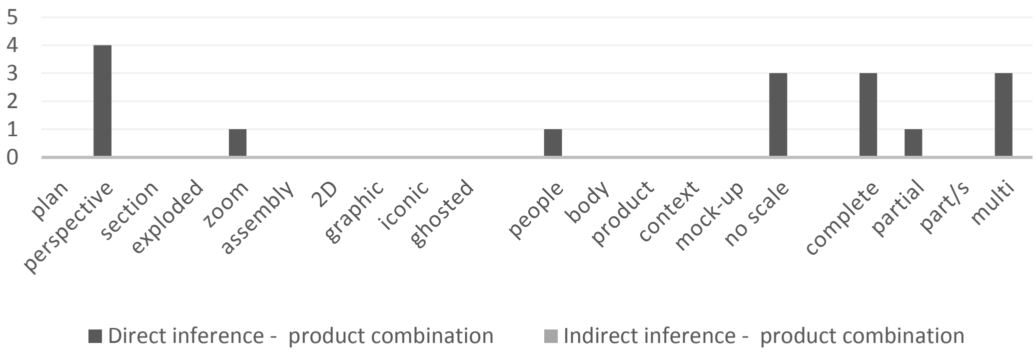


Figure 4.43. Direct inferences and indirect inferences about product configuration

To give an example, Figure 4.44 shows product configuration representations of two students used in the ninth observation session. While one of the students used a 3D-model supported with mock-ups in real size, the other student only used renders because of the size of the project, which made it difficult to make mock-ups in real size (Figure 4.44). Mock-ups helped the student show different product configurations interactively, leading to an increase in the interactivity of the studio session. In addition, mock-ups were more beneficial for the student because her project had a variety of product configurations when compared to the other student. On the other hand, renders were quite enough for the student to explain product configuration because her project had limited configurations.

Figure 4.44. Product configuration representation examples. Left: 3D-model supported with mock-ups (Student 3), Right: Render (Student 10)

4.7.3.11. Context/environment

During the product development process, context/environment as a product aspect was represented with perspective views in contextual environment by giving reference to context or user or other products (Figure 4.45). In addition, the product was represented either completely or partially while explaining the context/environment. After the preliminary jury, renders in context were the main design representation tool to explain the context/environment. Figure 4.45 illustrates that the findings are the direct inferences and there are no indirect inferences. Figure 4.46 shows two different representations of context/environment in the preliminary jury by using the render tool with context photo. While a student represented this product aspect by integrating into usage scenario process, the other student represented context/environment separately. For the project which context was integrated into usage scenario, showing how the product is used in context/environment was more essential instead of representing context separately. On the other hand, showing a product might be a need for the students to give an idea on how the product will look in its context/environment.

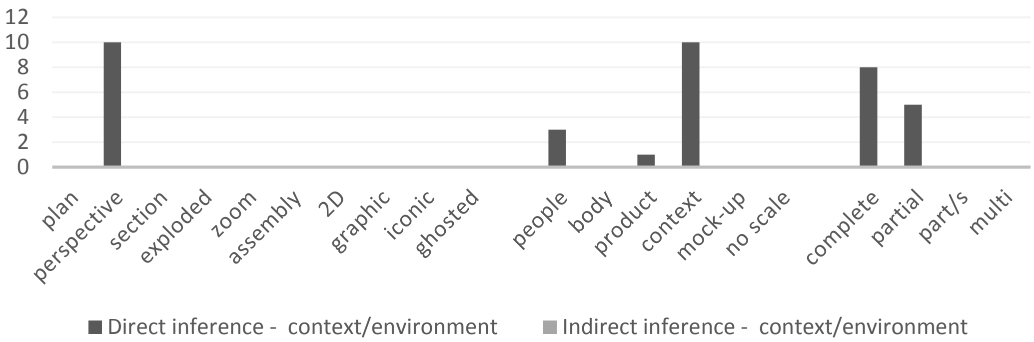


Figure 4.45. Direct inferences and indirect inferences about context/environment

Figure 4.46. Context/environment representation examples. Left: Context representation in usage scenario with renders (Student 11) and Right: Render in context (Student 14)

4.7.3.12. Mechanism

Mechanism is a product aspect that might be related to the other product aspects, such as usage scenario and feature/function. This product feature was represented in different ways. During studio sessions, perspective and exploded views were predominantly used and plan, section and zoom views were also used to explain mechanism in addition to 2D and ghosted views (Figure 4.47). In addition, it was represented in real size with mock-ups or without giving any idea about size by showing the product completely, partially or the product parts separately (Figure 4.47). It can be said that the students need different representations depending on their projects. Mechanism might be directly related to how the product is used or how the product functions.

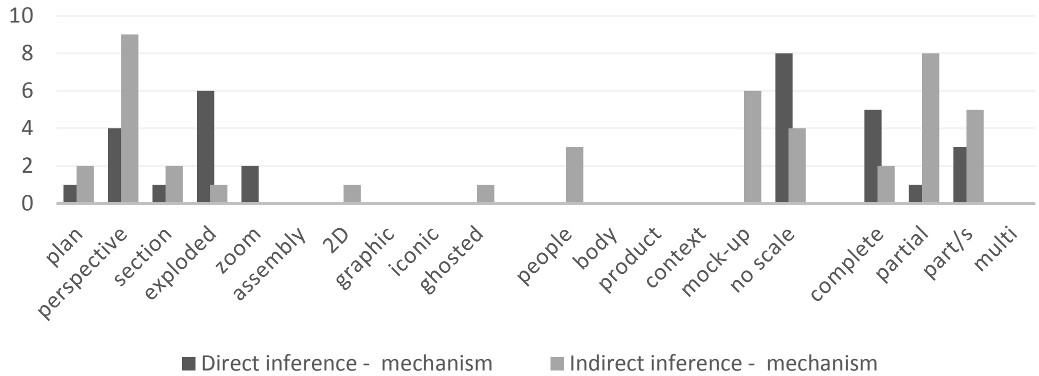


Figure 4.47. Direct inferences and indirect inferences about mechanism

In the case of a project in which the mechanism was related to how the product is used, real-size working mock-up helped the student show how the mechanism works step by step (Figure 4.48). In addition to this, the tutors used this working mock-up during the studio session, resulting in an increase in the interactivity of the session and better feedback about the project. Moreover, this mock-up helped the student develop the mechanism in a better way.

Figure 4.48. Mechanism representation example, demonstration with working mock-up (Student 12)

Similarly, another student used a video demonstration in a studio session, that she prepared by using the mechanism mock-up that she had built for her project (Figure 4.49). In this example, the demonstration enabled the student to show that the mechanism would work as intended. Although video demonstration example is not as interactive as the working mock-up used in the studio session, it helped the student explain the mechanism effectively and to receive better feedback from tutors. Demonstrating mechanism is an effective representation in explaining this product aspect, especially by using mock-ups in real size, resulting in interactive studio sessions.

Figure 4.49. Mechanism representation example, video demonstration used in the studio session, prepared with the mock-up (Student 15)

On the other hand, if the mechanism is related to how the product functions, exploded views with 3D-models or renders or sketches become more important for showing related parts of the product. Figure 4.50 shows an example of a student's mechanism representations used in the eighth and ninth sessions. While the student represented mechanism with sketches supported with explanations, she used 3D-model and render tools to explain mechanism in the ninth session. Using the 3D-model together helped the student show the mechanism interactively, by zooming into the related parts or hiding/unhiding the other parts to focus on related parts, and the 3D-model was supported with render representations. Representing mechanism interactively with a 3D-model helped the student explain effectively, resulting in a more interactive studio session.

Figure 4.50. Mechanism representation example, sketch used in the eighth session, render and 3D-model used in the ninth session (Student 2)

4.7.3.13. Details

As it can be seen in Figure 4.51, perspective views and zoom views were mainly used and supported with plan views, section views and exploded views to explain details without giving the real size or by using mock-ups. During the studio sessions, the product was mostly presented partially and the parts related to the detail of the product were presented (Figure 4.51). Giving reference to other products and showing the product completely or in multiple ways were also used while explaining details but they were less used when compared to other representations. Figure 4.51 shows that the direct inferences are more than indirect inferences, resulting in that 3D-model and render tools were more used in explaining details than the other tools during studio sessions.

It can be said that 3D-models help the students show the detail interactively by enabling them to change the view, zoom in or show the related parts, whereas renders do not provide these possibilities. However, renders supported with mock-ups help the student explain the detail of the product in a better way, and they thus enhance the interactivity of the studio session. Figure 4.52 shows examples of detail representations with 3D-model and render supported with mock-up. Using only renders to represent a detail is not as interactive as using renders supported with mock-ups. Mock-ups that show how the detail works are helpful for the students to explain this aspect and receive feedback from the tutors during the studio session. Similarly, 3D-models are effective in representing details, leading to more interactive studio sessions.

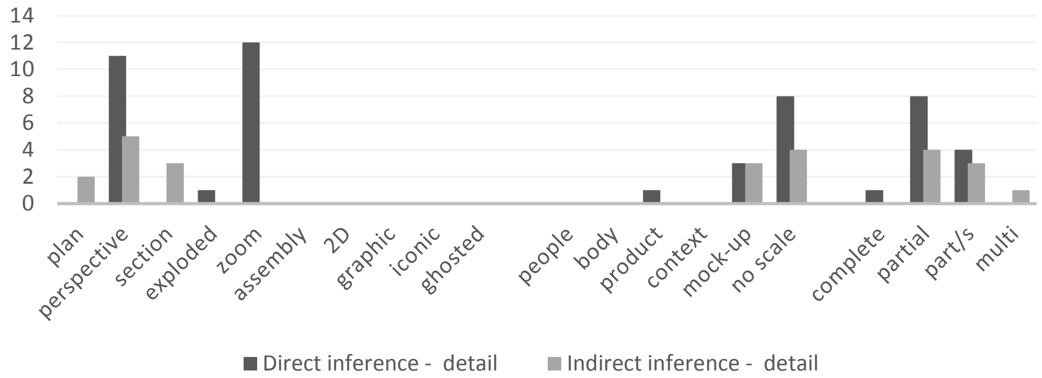


Figure 4.51. Direct inferences and indirect inferences about detail

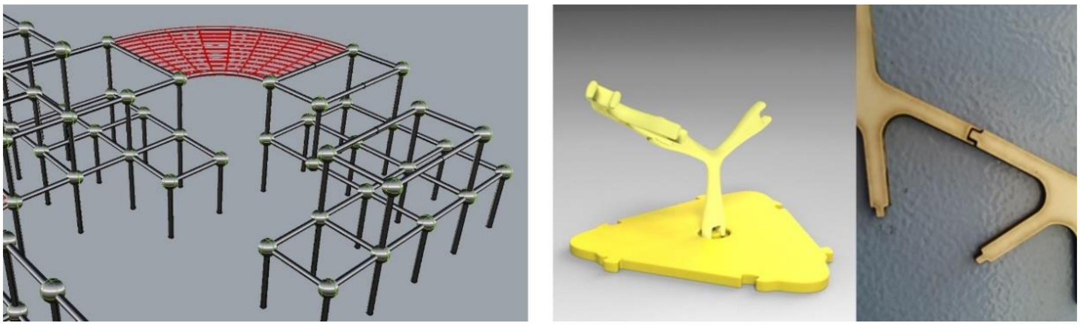


Figure 4.52. Detail representation examples. Left: Detail representation with 3D-model (Student 14) and Right: Render supported with mock-ups (Student 3)

4.7.3.14. Technical standards

Technical standards about the product is one of the rarely seen product aspects during the studio sessions. This product aspect was considered only by one of the students and explained during the sixth (preliminary jury) session. This is why Figure 4.53 illustrates little information about technical standards. As it can be seen in the figure, section views and exploded views were used to explain technical standards by giving reference to other products by showing the product completely.

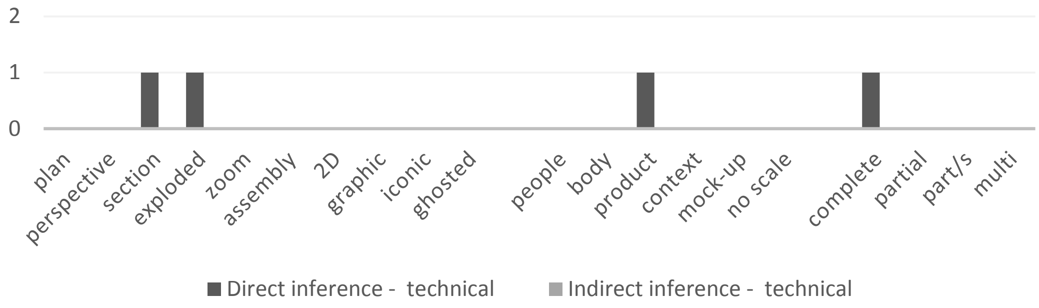


Figure 4.53. Direct inferences and indirect inferences about technical standards

Figure 4.54 shows technical representation used in the sixth (preliminary jury) session. The student represented technical standards of the product with exploded renders and section drawings. There is no other representation used for technical aspects during the product development process. Therefore, it is not possible to develop deep insights on the interactivity of the sessions related to the design representation tools.

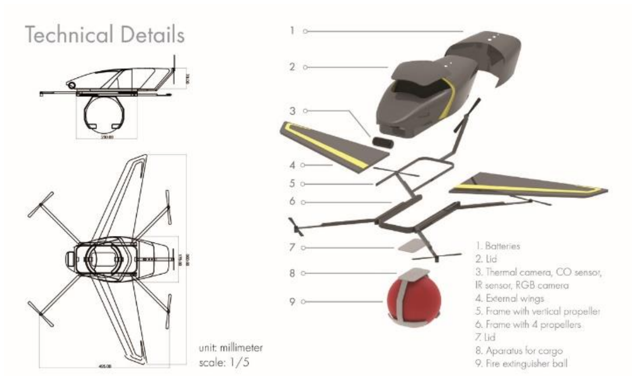


Figure 4.54. Technical representation example, section drawing and exploded render (Student 6)

4.7.3.15. Assembly/set-up

Assembly/set-up is another product aspect that is rarely seen during the studio sessions. This product aspect was developed only by one of the students and explained in different studio sessions. Thus, Figure 4.55 shows limited information about assembly/set-up. Plan view, perspective view and zoom view were used to explain this product aspect without giving any idea about size or with mock-ups by showing the product completely or partially or only the part/s related to assembly (Figure 4.55).

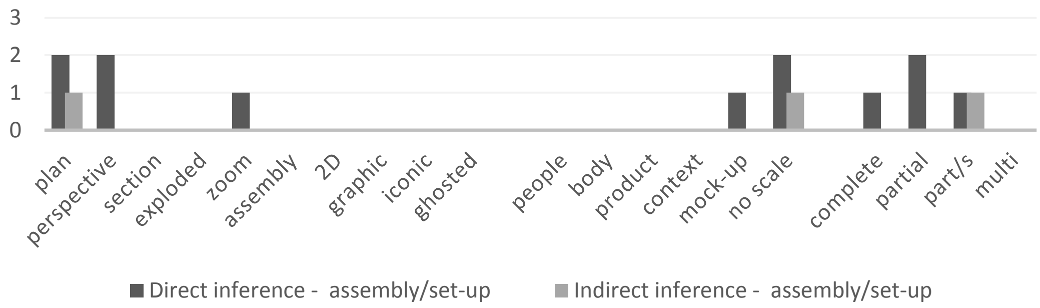


Figure 4.55. Direct inferences and indirect inferences about assembly

Figure 4.56 shows assembly/set-up representations used in the seventh and ninth sessions. While the student used render, mock-up and sketch tools that supported each other to explain assembly/set-up in the seventh session, she used only render representation in ninth session. Like technical standards, it is not possible to draw insights about interactivity of the sessions related to the design representation tools because of limited information on assembly/set-up.

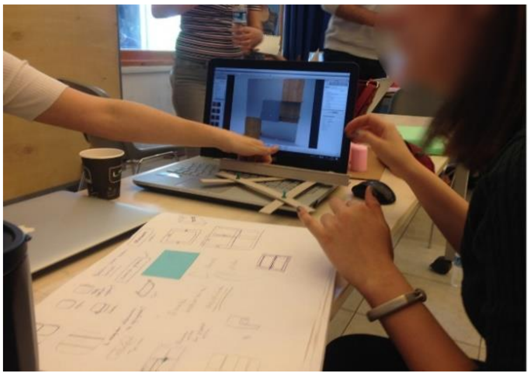


Figure 4.56. Assembly representation examples. Left: Assembly representation with render, mock-up and sketch, and Right: Assembly representation with render (Student 10)

4.7.3.16. Inner parts

Inner parts were mostly represented with perspective views and exploded views without giving any reference during the product development process (Figure 4.57).

In addition, the product was represented either completely or by showing the parts while explaining inner parts. Zoom views and ghosted views were also used to explain the inner parts of the product, although they were used much less. Figure 4.57 shows that the findings are the direct inferences and there are no indirect inferences. 3D-models and renders were the main design representation tools used in explaining the inner parts and these tools were used during and after the preliminary jury.

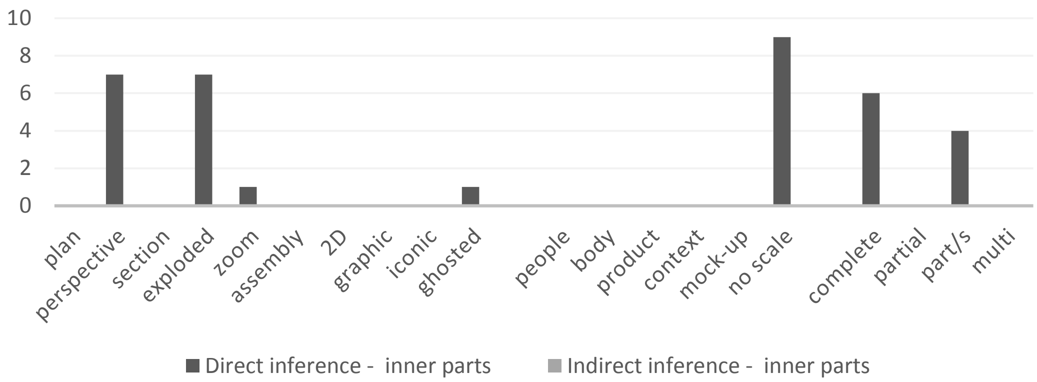


Figure 4.57. Direct inferences and indirect inferences about inner parts

Figure 4.58 shows two inner parts representation examples in the ninth session. While a student represented inner parts with a 3D-model and renders together supporting each other, another student represented inner parts with renders. 3D-models enable the student to show inner parts interactively, by highlighting, zooming in or hiding unrelated parts to focus on the parts that the student highlights, whereas using only render representation does not provide these possibilities that a 3D-model offers. Using 3D-models together with renders increased the interactivity of the studio session. For projects that consist of many inner parts, using these tools together becomes more important to explain this product aspect effectively. On the other hand, the render tool might be sufficient for the projects that consist of few inner parts.

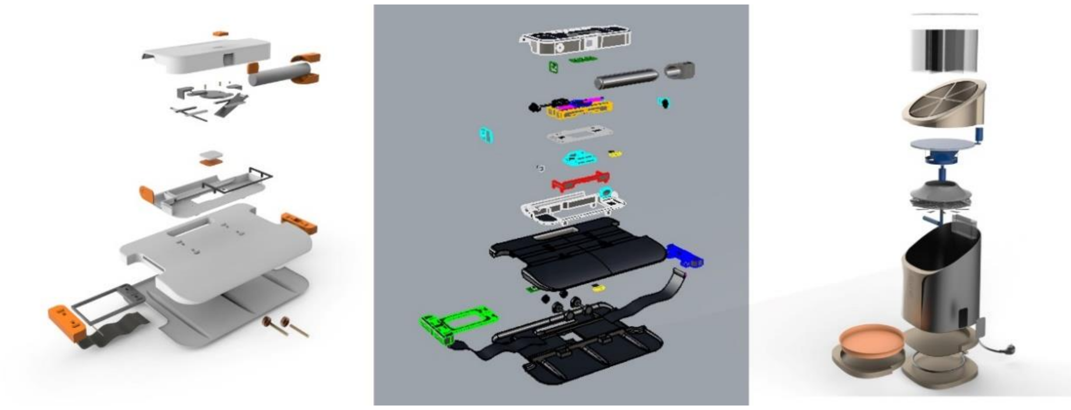


Figure 4.58. Inner parts representation examples. Left: Inner part representation with 3D-model and render (Student 1) and Right: Inner part representation with render (Student 2)

4.7.3.17. Technology

Technology is very similar to inner parts; this is because this product aspect is mainly related to the parts inside the product. Perspective views and exploded views were mainly used to represent technology without giving any reference during studio sessions (Figure 4.59). Plan views, zoom views and ghosted views were also used to explain technology, though at a lesser degree. In addition, the product was represented either completely or by showing the parts while explaining technology. Figure 4.59 shows that the direct inferences are more than indirect inferences, resulting in 3D-model and render tools being the main design representation tools used in explaining technology during studio sessions.

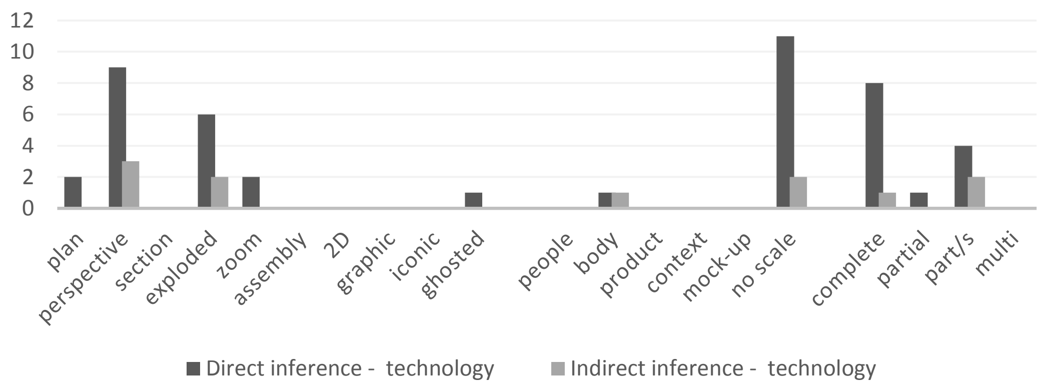


Figure 4.59. Direct inferences and indirect inferences about technology

Figure 4.60 shows technology representation examples of two different students. While a student represented technology with renders supported with writing to label in the sixth session and with only render in the ninth session, another student represented with a 3D-model and renders with labels supporting each other (Figure 4.60). When the students used 3D-models to represent technology, they did not label the parts related to technology. On the other hand, when they used renders to represent technology, they mainly labelled the parts. Although 3D-models enable the students to highlight or zoom into the related technological parts and increase the interactivity of the studio session, labelling parts seems to be essential while explaining technology during studio sessions.

Figure 4.60. Technology representation examples. Left: Inner part representation with 3D-model and renders (Student 5) and Right: Inner part representation with 3D-model and renders (Student 13)

4.7.3.18. Maintenance

Maintenance is one of the rarely seen product aspects during the studio sessions. This product aspect was considered only by one of the students and explained during the ninth session. This is why Figure 4.61 shows little information about maintenance of the product. As it can be seen in the figure, perspective views were used to explain maintenance without giving any reference by showing the parts of the product. Figure 4.62 shows maintenance representation used in the ninth session. The student represented maintenance of the product with a 3D-model. There is no other representation used for maintenance during the product development process.

Therefore, it is not possible to draw much insight about the interactivity of the sessions related to the design representation tools.

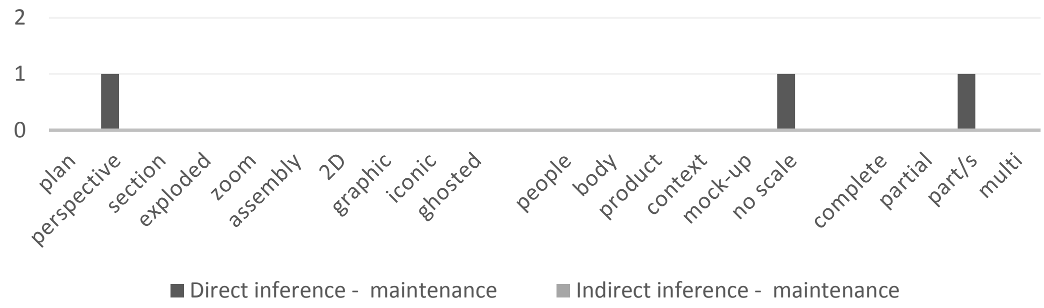


Figure 4.61. Direct inferences and indirect inferences about maintenance

Figure 4.62. Maintenance representation example, 3D-model (Student 2)

4.7.4. Insights from the documentation

The documentation for this study can be categorized as;

1) information that was used by the students to give direction to their product design during the product development process,
2) re-mentioned product aspects by referring to previous studio sessions, and
3) design representation tools that were used to re-mention these product aspects.

The first category is information giving direction to product design during the product development process. This was mentioned during studio sessions, such as product examples, research findings and user groups. This information is vital for the students to keep record in order to reuse or re-mention this knowledge in different stages of the product development process. Figure 4.63 shows the information that the students needed to re-use during the studio session. Product examples, project statements, problems, research findings, and user groups were the most re-used information in studio sessions, including the preliminary jury. In addition to this information, moodboards, keywords, critiques (feedback from tutors) and evaluations (evaluation of students about own design) were re-mentioned in studio sessions, including the preliminary jury. In the preliminary jury, the students re-mentioned project statements, problems, research findings, user groups, product examples, moodboards and keywords. During the other studio sessions, product examples, critiques, research findings, evaluations and project statements were the most re-mentioned information. The students also re-mentioned problems, user groups and keywords, but needed this group of information less.

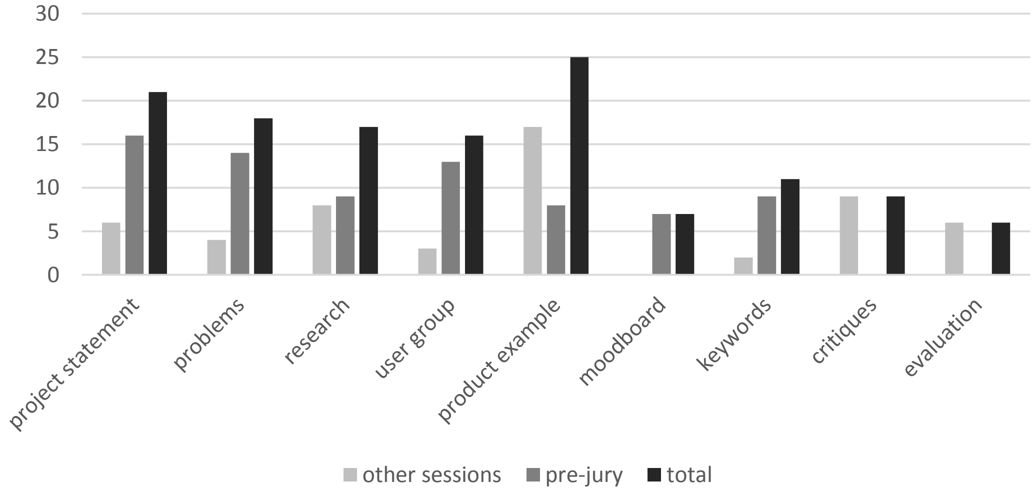


Figure 4.63. Information to give direction to product design during the product development process

When looking at the design representation tools that the students used in representing this information, photos and writing were the main tools. Considering AR as a supportive design representation tool for studio sessions, this information might not be much relevant to include in the development of an AR tool, because of the fact that AR is mostly related to 3D-modelling. However, keeping record of this information in one design representation tool is more practical. As shown in Figure

4.22 (Section 4.7.1), physical and virtual tools were more used when the students re-used this information; thus, AR may have the potential to provide documentation as a virtual tool in addition to representing product aspects with 3D-models.

The second category is the product aspects that the students re-mentioned by referring to previous sessions. Figure 4.64 shows that usage scenario was the most re-mentioned product aspect. In addition to usage scenario, the other product aspects mentioned by referring to previous versions were user interaction, user interface, feature/function, parts, aesthetics/form, size and context/environment (Figure 4.64).

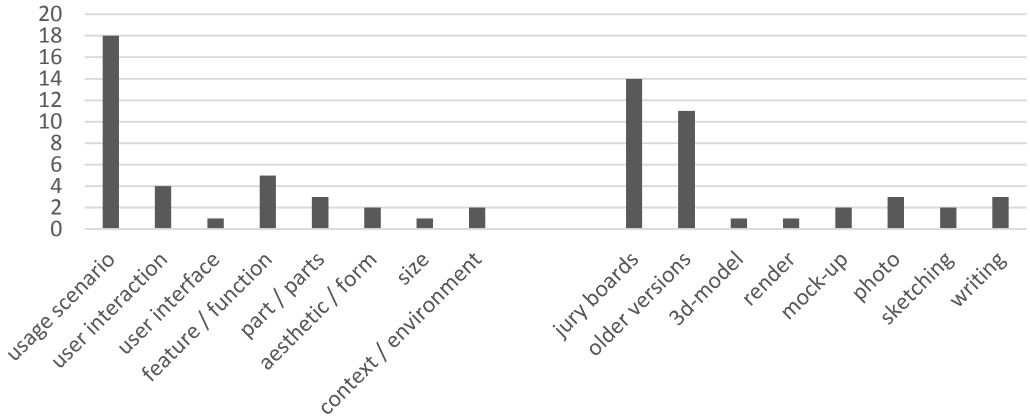


Figure 4.64. Re-mentioned product aspects and re-used design representation tools

The third category is the design representation tools used in explaining re-mentioned product aspects. These design representation tools were mainly jury boards and earlier versions of the other tools, which included 3D-models, renders, mock-ups, photos, sketching, and writing (Figure 4.64). Similar to the information used in giving direction to product design during the product development process, it is essential to document jury boards and older versions of design representation tools in order to re-use them in the following studio sessions when required. Although the number of re-mentioned product aspects seem to be less, except usage scenarios, documenting properly can provide the students the opportunity to re-use or re-inject the knowledge in different phases of the product development process in necessary sessions. This may enhance the recall of knowledge from previous sessions to re-mention when needed.

4.7.5. Insights from the preparation

Preparation can be considered as using AR technology to prepare design representations in order to use these in studio sessions. When looking at the data from this perspective, the most obvious findings are usage scenario preparations made for the preliminary jury. To represent usage scenarios together with user experience, user interaction and feature/function, the students prepared step by step explanations like a scenario board, showing product interaction with user, with the product in its context (Figure 4.65). While explaining these product aspects, complete product or partial product presentations were preferred with mostly perspective views and less plan views, zoom views and iconic views. Preparing step by step explanations like a scenario board including user and context needs much time, such that these representations are mainly seen in the preliminary jury and final jury. The students do not prefer to prepare such representations for other studio sessions. Considering from this perspective, AR technology can help the students prepare these representations easier. Although the quality of the representation prepared with AR might not be as good as those that students prepare with other tools, AR as a supportive design representation tool may have the potential to increase the making of these preparations. The findings show that AR has the potential to help the students prepare usage scenarios and related product aspects for the preliminary jury but it can also be used for other sessions.

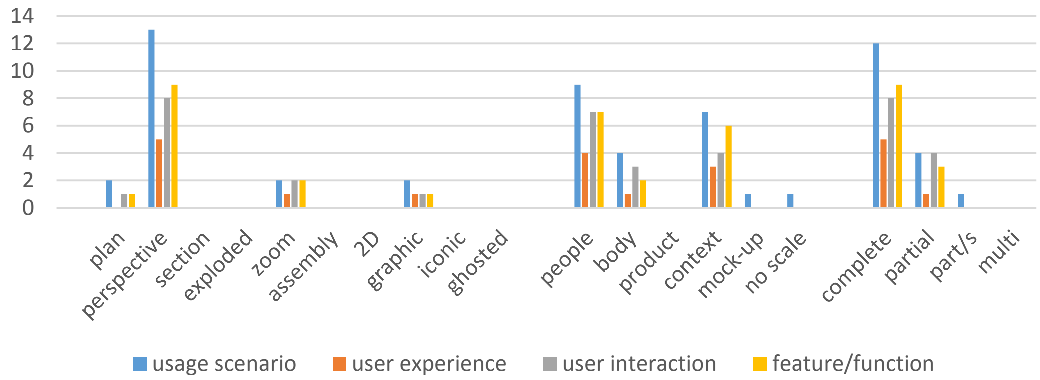


Figure 4.65. Findings related to preparation of design representations made for studio sessions

Similarly, AR technology can also be used to prepare user-product interaction and to explain physical ergonomics, which might increase the ratio of this product aspect mentioned in studio sessions. The students could easily use AR to show their product on users or body parts and could use these preparations during studio sessions. This representation for physical ergonomics could also be done interactively during studio sessions. There are also other product aspects for which it is not possible to use AR interactively during studio sessions, such as context/environment. On the other hand, AR could also make preparation for context/environment easier to show this product aspect in studio sessions. Such a preparation would enable the student to show how the product will look in context/environment and relatively to show aesthetics/form and size of the product in its context/environment. The students can easily use AR technology to prepare these design representations to use in studio sessions. Therefore, these aspects may be considered more by the students during the product development process and mentioned more during the studio sessions.

4.7.6. Insights from the challenges

The challenges can be considered as the findings that might have potential for AR but might be difficult to develop when compared to other findings. The challenges are mainly about real time demonstration of the product aspects, which can be seen in Table 4.15. The most noticeable ones that the students might need during the product development process are usage scenarios, user interface and mechanisms. Demonstrating usage scenarios with AR technology could strongly support explanations of scenarios during studio sessions, and be more effective in terms of showing how to use the product and how the human-product interaction takes place. Similarly, a video demonstration for the usage scenario prepared by AR could also help the students explain this product aspect effectively. In addition to usage scenarios, user interface and mechanisms were the most noticeable product aspects that may be represented with a real time demonstration.

While an interactive user interface could enhance the step by step explanations of the students, a real time demonstration showing how a mechanism works could also help the students explain effectively. Real time demonstrations could enhance the explanations of the students, resulting in better feedback from tutors and increase in the interactivity of the studio sessions. Representing physical ergonomics interactively to show the user-product interaction, changing the material/color of the product in real time and a real time demonstration showing how the product is assembled are the other challenges that the students might also need during studio sessions but to a lesser degree when compared to other product aspects. In addition to these product aspects, sketching and taking notes on AR screen might have the potential for students during studio sessions.

Table 4.15. The challenges of the product aspects

Product aspects	**AR challenges**
usage scenario	Real time demonstration about how the product is used, or Preparation of a video demonstration of usage scenario
user interface	An interactive user interface that can be shown during studio sessions
physical ergonomics	Showing interactively the user-product interaction
material/color	Changing the material/color of the product in real time
mechanism	Real time demonstration showing how mechanism works
assembly /set-up	Real time demonstration showing how product is assembled
sketching	Although sketching and taking notes seemed less, they might be needed during studio sessions
taking notes	

4.7.7. Findings from the insights

When looking at the use of design representation tools utilized during the product development process, using different tools at the same time that support each other supports both the students' product development process in terms of development of product aspects and explanation of these product aspects during studio session, and the studio sessions in terms of the interaction with the tutors and the feedback given by the tutors during studio sessions (Figure 4.66). As explained in Section 4.7.3, using different design representation tools is an effective way for students to explain a product aspect during studio sessions. In addition, using different design representation tools together increases the interactivity of the studio session. Explaining a product aspect with the tools supporting each other also enhances the feedback given by tutors. In addition to the feedback, students can make more informed decisions about their product development process when they use different tools together.

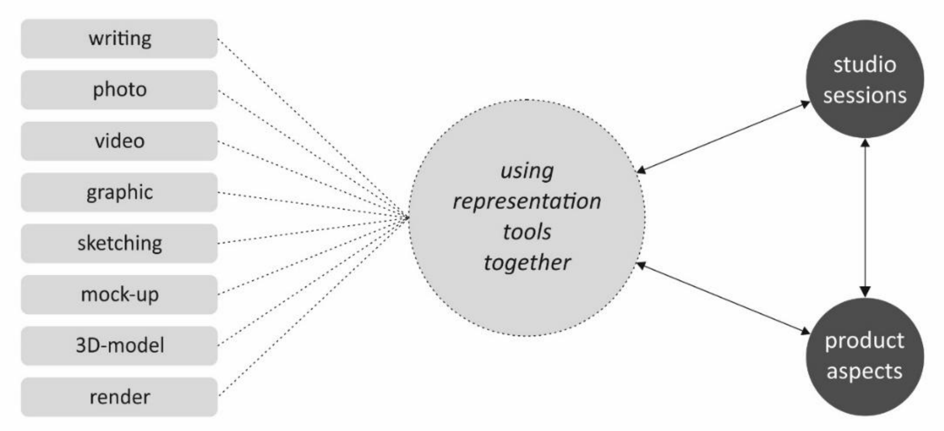


Figure 4.66. Using design representation tools together

The relation between design representation tools is briefly given in Figure 4.67 without looking at the product aspects separately. This relation is based on the use of these tools of the students during design studio sessions including desk crits and preliminary jury. This relation can be divided into three levels, *main tools, supportive tools* and *supplementary tools.* Main tools are the first level design representation tools that are required to explain a product aspect and need to be used with supportive tools. Main tools are 3D-models, visual mock-ups, working mock-ups, graphics and renders. Supportive tools are the second level design representation tools that support these main tools, and these tools are renders, renders + graphics, 3D-models, sketching, visual mock-ups, graphics, writing and photos. In addition, supplementary tools are the third level design representation tools that the students use in necessary representations. These tools are photos, videos and writing.

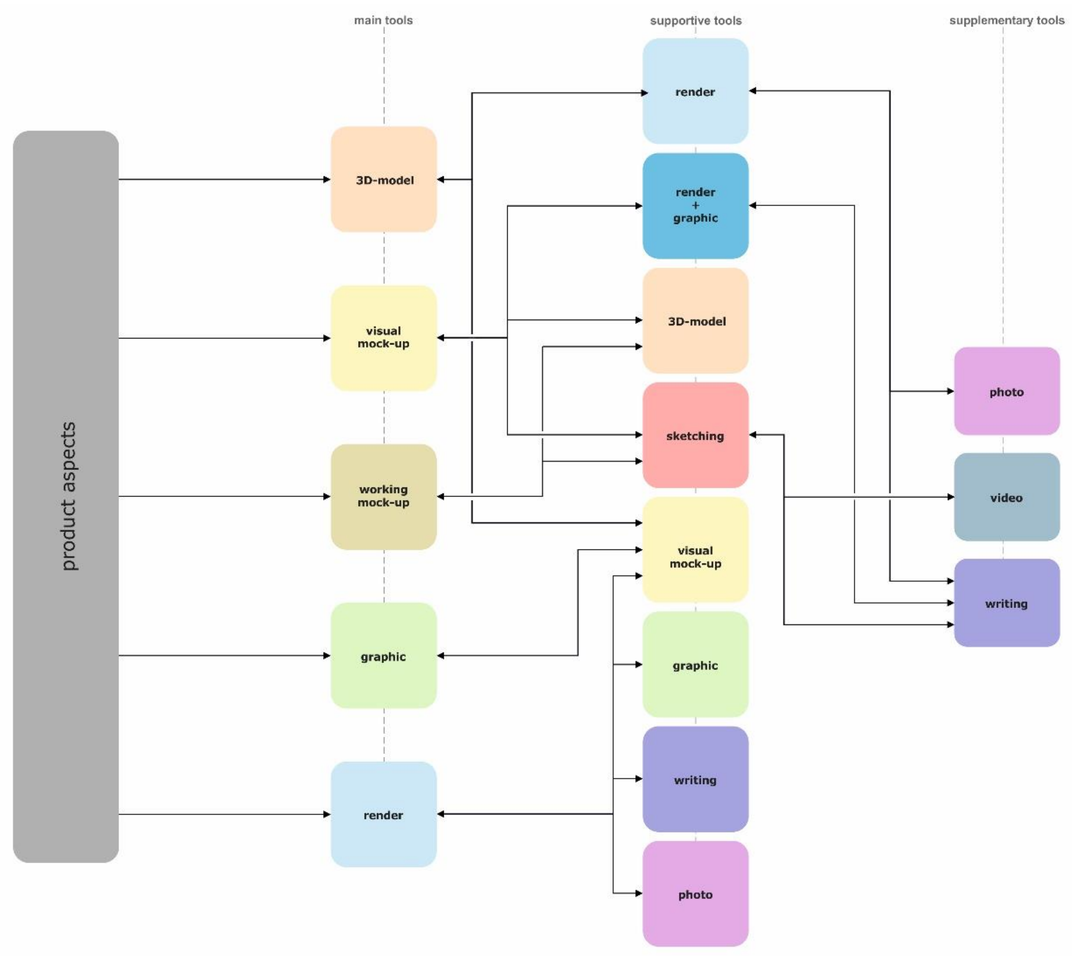


Figure 4.67. The relation between design representation tools

The relations between these design representation tools in different levels can be explained through main tools.

- 3D-models are supported with renders and visual mock-ups. Renders are also supplemented with photos and writing.

- Visual mock-ups are supported with renders + graphics, 3D-models and sketching. Renders + graphics are supplemented with writing. Sketching is supplemented with writing and videos. 3D-models are supplemented with videos.
- Working mock-ups are supported with 3D-models and sketching.
- Graphics are supported with visual mock-ups.
- Renders are supported with visual mock-ups, graphics, writing and photos.

These are the relations between different design representation tools that were used by the students during the product development process to support each other without looking at each product aspect separately. Table 4.16 summarizes the relations between different design representation tools supporting each other for each product aspect. These relations are illustrated in the DRT (Design Representation Tool) framework (Figure 4.68) that shows the suggested effective use of the design representation tools during the product development process. This suggested use of design representation tools is based on the different design representation tools, which were used by the students during studio sessions (given in Table 4.14). These relations for each product aspect illustrated in the framework are:

- **Usage scenario** can be represented with *visual mock-ups*, which can be supported with *3D-models*, *sketching* and *renders+graphics*. Sketching and renders+graphics can be supplemented with *writing*. In addition, usage scenario can be represented with *working mock-ups,* which can be supported with *3D-models* and *sketching*.
- **User experience** is mainly related to presentation of usage scenario. This product aspect was explained by the students together with usage scenario.
- **User interaction** is mainly related to presentation of usage scenario and user interface. This product aspect was explained by the students together with usage scenario or user interface.
- **Emotion** is mainly related presentation to usage scenario. This product aspect was explained by the students together with usage scenario.

- **User interface** can be represented with *graphics,* which can be supported with *visual mock-ups*.
- **Feature/function** is related to user interface, parts and mechanism.
- **Parts** can be represented with *3D-models,* which can be supported with *renders.* In addition, parts can be represented with *renders,* which can be supported with *writing.*
- **Physical ergonomics** can be represented with *visual mock-ups,* which can be supported with *3D-models* and *sketching.* In addition, this product aspect can be represented with *working mock-ups,* which can be supported with *3D-models* and *sketching,* which can be supplemented with *video.* Moreover, physical ergonomics can be represented with *renders,* which can be supported with *graphics.*
- **Aesthetics/form** can be represented with *3D-models,* which can be supported with *visual mock-ups.* In addition, aesthetic can be represented with *renders*, which can be supported with *visual mock-ups.*
- **Size** can be represented with *visual mock-ups,* which can be supported with *3D-models, renders* and *sketching.* Renders can be supplemented with *photos*.
- **Material/color** can be represented with *renders,* which can be supported with *photo.*
- **Product configuration** can be represented with *3D-models,* which can be supported with *mock-ups* and *renders.* In addition, product configuration can be represented with *renders,* which can be supported with *mock-ups.*
- **Context/environment** can be represented with *renders,* which can be supported with *photos.*
- **Mechanism** can be represented with *working mock-ups,* which can be supported with *3D-models* and *sketchings.*
- **Detail** can be represented with *3D-models,* which can be supported with *mock-ups.* In addition, detail can be represented with *renders,* which can be supported with *mock-ups.*

- **Technical standards** have limited information to define the relation between design representation tools.
- **Assembly/set-up** has limited information to define the relation between design representation tools.
- **Inner parts** can be represented with *3D-models,* which can be supported with *renders.* In addition, inner parts can be represented with *renders*, which can be supported with *writing.*
- **Technology** can be represented with *3D-models,* which can be supported with *renders.* Renders can be supplemented with *writing*. In addition, technology can be represented with *renders,* which can be supported with *writing.*
- **Maintenance** has limited information to define the relation between design representation tools.

The DRT framework showing relations between different design representation tools is important to support the students' product development processes. In addition, finding out the effectiveness of these design representation tools is helpful to explore how AR could be used for the product aspects and also to explore the possibilities that can be used with AR.

Table 4.16. Relations between design representation tools for each product aspect

product aspects	**main tools**	**supportive tools**	**supplementary tools**
usage scenario*	visual mock-up	3D-model	
		sketching	writing
		render+graphic	writing
	working mock-up	3D-model	
		sketching	
user experience*	*is related to usage scenario*		
user interaction*	*is related to usage scenario and user interface*		
emotion*	*is related to usage scenario*		
user interface	graphic	visual mock-up	
feature/function	*is related to user interface, parts and mechanism*		
parts	3D-model	render	
	render	writing	
physical ergonomics	visual mock-up	3D-model	
		sketching	
	working mock-up	3D-model	
		sketching	video
	render	graphic	
aesthetics/form	3D-model	visual mock-up	
	render	visual mock-up	
size	visual mock-up	3D-model	
		render	photo
		sketching	
material/color	render	photo	
product configuration	3D-model	mock-up	
		render	
	render	mock-up	
context/environment	render	photo	
mechanism	working mock-up	3D-model	
		sketching	
detail	3D-model	mock-up	
	render	mock-up	
technical standards	*limited information to conclude*		
assembly/set-up	*limited information to conclude*		
inner parts	3D-model	render	
	render	writing	
technology	3D-model	render	writing
	render	writing	
maintenance	*limited information to conclude*		
** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*			

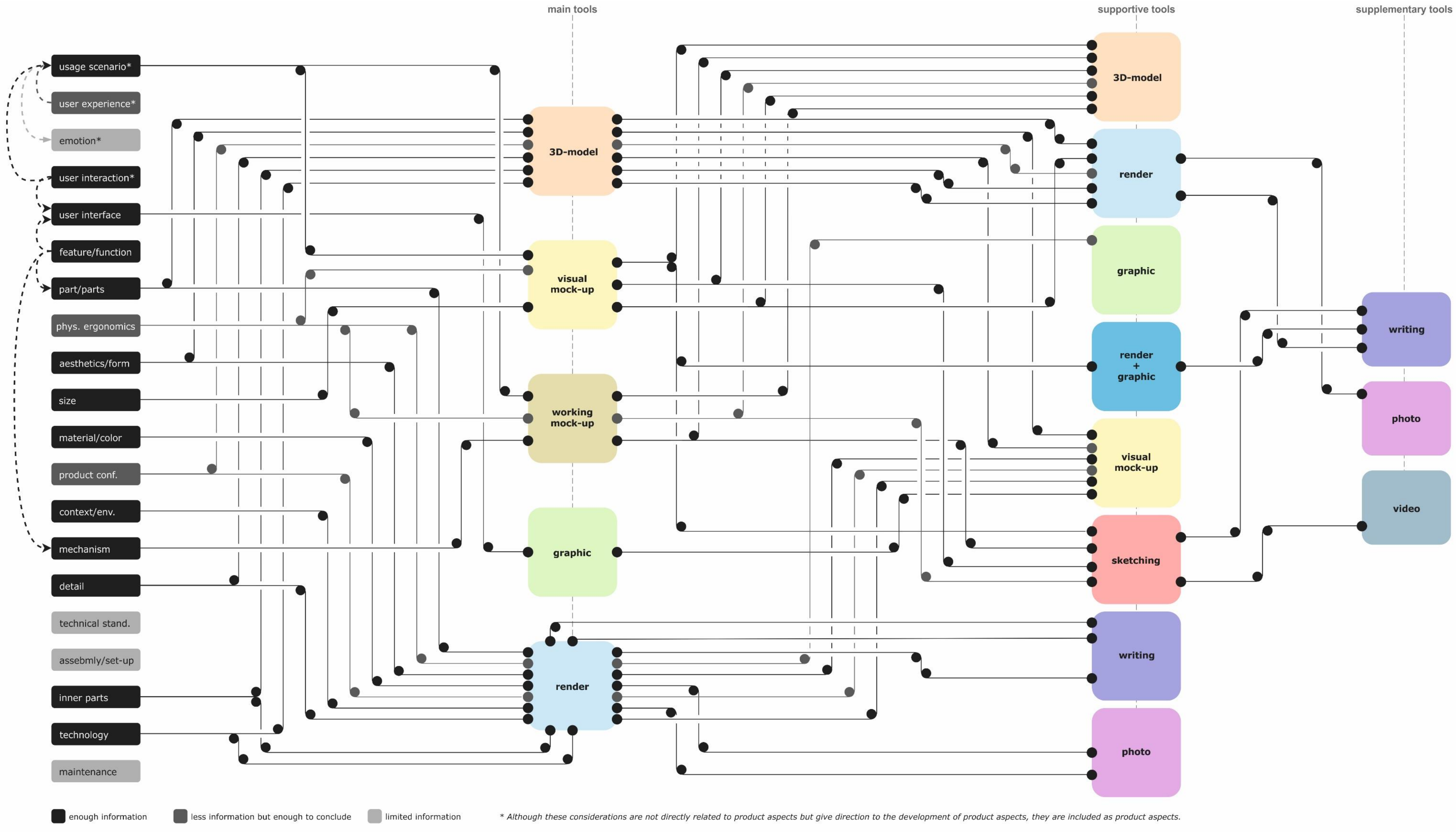


Figure 4.68. The DRT (Design Representation Tool) framework showing relations between design representation tools for each product aspect

4.7.8. *Evaluation of the product aspects with the design representation tools used during desk crits*

The students made an evaluation of how well they explained the product aspects during desk crits, using the design representation tools. They were asked to evaluate each product aspect on a Likert scale, from 1-point (not very well) to 7-point (very well) considering the design representation tools; writing, photo, graphic, sketching, mock-up, 3D-model, and render. Based on the students' evaluations, the average value over 5 is considered as important to explain the product aspects with these tools. In addition, if more than half of the students evaluated a product aspect as not applicable for a design representation tool, this evaluation was excluded. For instance, although the average value of technology is higher than 5, this product aspect was evaluated by less than half of the students and the other students evaluated as not applicable. Thus, similar evaluations were excluded. Table 4.17 shows the findings of the students' evaluations of the product aspects with the design representation tools used during desk crits. Detailed evaluation can be seen in Appendix F.

Similar to the DRT framework, physical ergonomics and mechanism is better explained with mock-ups, which is illustrated as a main tool in the DRT framework. To give another example, students' evaluations shows that form and details are better explained with 3D-models and renders, which are also illustrated as main tools in the framework. Similarly, parts and inner parts are better explained with 3D-models, which is also illustrated as one of the main tools in the DRT framework. It is evident that the findings of this evaluation support the DRT framework.

Table 4.17. Evaluation of the product aspects with the design representation tools used during desk crits

Product aspects	W - Writing, P - Photo, G - Graphic, S - Sketching, M - Mock-up, 3D - 3D-model, R - Render						
	W	***P***	***G***	***S***	***M***	***3D***	***R***
usage scenario*							
user experience*							
user interaction*							
user interface							
feature/function							
parts							
physical ergonomics							
form							
size							
material/color							
context/environment							
mechanism							
details							
technical standards							
inner parts							
technology							
maintenance							
** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*							

4.7.9. Evaluation of the product aspects of the final product

The final designs were evaluated by the students right after completing their product development processes, to find out their thoughts about how well they reached a point in terms of the product aspects. They were asked to evaluate from 1-point (not very well) to 7-point (very well). Figure 4.69 shows the students' evaluation about their product aspects. This evaluation is to illustrate descriptive statistics to explore specific information in order to support the framework of relation between different representation tools. Although the average value of the evaluations of the product aspects are above the medium value (4-point), none of them is evaluated above 5,5 or close to the highest value (7-point). However, the evaluations differ according to the design representation tools that the students used during the product development process. For instance, when looking at mechanism, the student that used working mock-ups supported with 3D-modelling or sketching during her product development process rated mechanism with 6 points, which is above average. On the other hand, another student who used sketching and 3D-modellig to develop mechanism during the product development process rated this product aspect with 1 point. For the project for which user interface is important, one of the students that used graphics and mock-ups rated user interface with 6 points, higher than other students and close to the highest value.

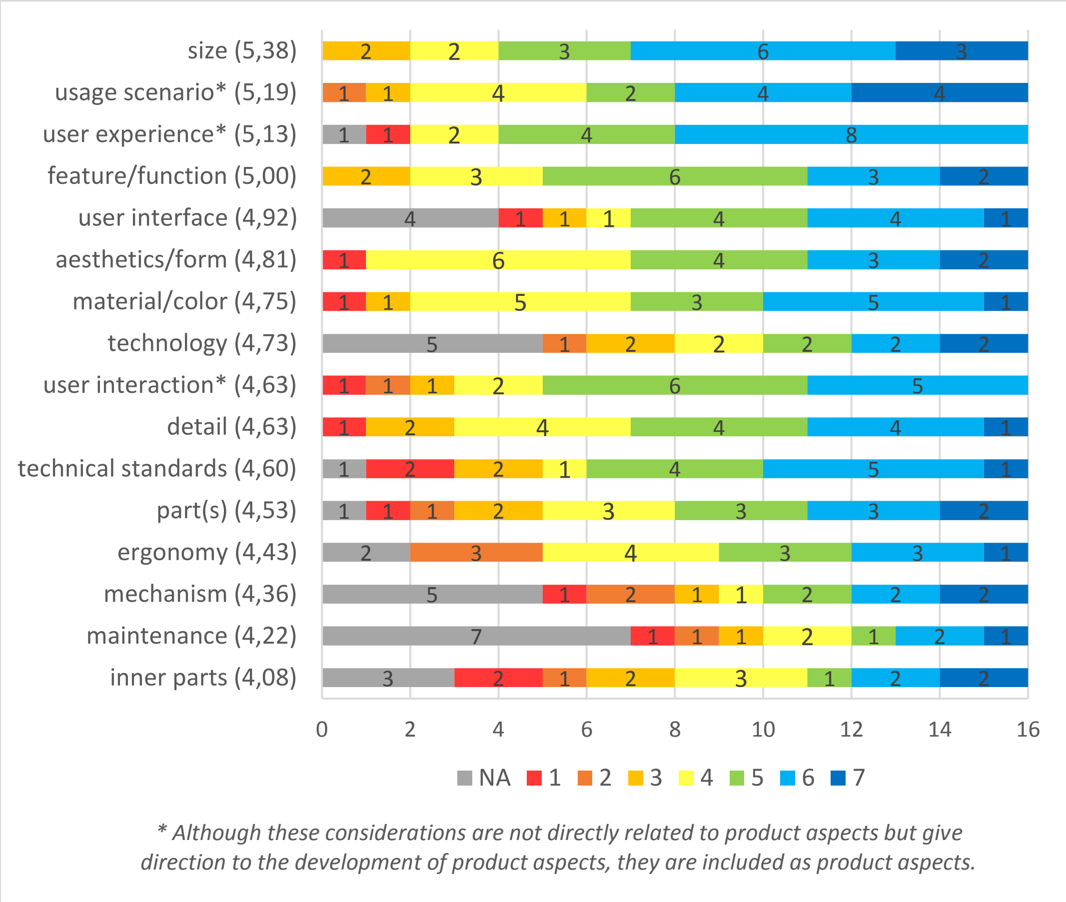


Figure 4.69. Evaluation of the product aspects of the final product

The student that used 3D-modelling supported by visual mock-ups and sketching to develop his product form rated this product aspect with 6 points. In addition, the same student rated size with 7 points and he used visual mock-ups and 3D-modelling supporting each other. On the other hand, the student who made few mock-ups during her product development process rated form with 1 point and size with 3 points. Similarly, another student who also made few mock-ups rated form with 5 points and size with 4 points. Using the tools suggested in the relations of the design representation tools during the product development process does not mean that the students were definitely more satisfied about their final product. However, using the suggested tools together supporting each other could enhance the students' development process by explaining the product aspects during the studio session, increasing the interactivity of the studio sessions and having better feedback from tutors. The reasons why the students evaluated these product aspects lower might be related to the insights from group sessions, which are mentioned in Section 4.7.10.

4.7.10. Insights from focus group sessions

In focus group sessions, the students were asked to discuss desk crits and 3D modelling process, as mentioned in the Sections 4.4.3 (procedure) and 4.4.4 (questions and materials). The data collected in this group discussion part was to make further exploration about desk crits and 3D-modelling process during the students' product development processes. The related data, which was transcribed from the recorded sessions, was coded based on both open and axial coding (Corbin and Strauss, 1990) under different categories; *desk crits, design representation tools, product development process* and *3D-modelling*. The insights about these categories will be presented. Table 4.18 briefly summarizes these insights.

Table 4.18. Insights about desk crits, design representation tools, product development process and 3D-modelling process

Desk crits	- limited time during desk crits - not enough feedback because of limited time - the problem in tracking the projects by tutors - not following the students' blog to track the projects
Design representation tools	- the negative effects of different design representation tools - the positive effects of different design representation tools - interactive representation - quality of the presentations - early use of different design representation tools
Product development process	- specific guidance to the projects - specific product development process of the students - too late to productize the design concept - bad timing of workshops - specific workshops for the students' projects
3D-modelling process	***The advantages of 3D-modelling*** - better interaction with 3D-model - effective explanations of the product aspects - more realistic and professional explanation - better personal product development process - better and common understandability of the project - better feedback given by the tutor - better and faster solving process when compared to other tools
	The disadvantages of 3D-modelling - differences in the students' 3D-modelling skills - perceiving the 3D-model as the final product - inadequate education about 3D-modelling
	The suggestions to start 3D-modelling - start 3D-modelling process earlier (after initial idea jury, between initial idea and preliminary juries, before preliminary jury) - different for everyone

4.7.10.1. Insights about desk crits

The insights about desk crits are mainly negative issues that the students encountered; limited time during desk crits, not enough feedback because of limited time, the problem in tracking the project by tutors and not following the students' blog to track the projects (Table 4.18). All these negative issues are related with each other. Most of the students mentioned limited time during desk crits to explain their process and to get feedback from the tutor. The reason is that they were paired with different tutors in desk crits but the students came across with the same tutor two or three weeks later. They had to remind their process since their last meeting in desk crit so that most of the time during desk crits passed by reminding and explaining what has been done. One of the students stated that "*meeting with the same tutor every two weeks withholds us from making explanations about the product, and we need to remind. The tutors should be able to follow better or we should meet the same tutor*". Similarly, another student stated that "*it takes time to remind and explain the process each time in table critics. A large part of the desk crits passes by reminding and telling what we have done*". Although one of the students mentioned that it is more effective to explain one's process including what is done and why it is done because the tutors could not remember, this took much time during desk crits and was a waste of time in order to get enough feedback from them. Seeing the students' project after a long time period leads to problems in remembering their projects and makes the students have to remind and explain the process so far. This leads to not enough feedback given by the tutors because of limited time. One of the students stated that "*most of the time was spent while trying to remind and explain to the tutors about our projects instead of getting enough feedback during desk crits*".

As mentioned by the students, they spent most of the time during desk crits reminding and explaining the process since they had last met with the tutor. This leads to not enough feedback given by tutors. Another negative issue related to limited time and feedback is the problems in tracking the projects by tutors. One of the students stated that "*desk crits are not efficient because we could not get enough feedback. The reason is that they could not follow our projects. We have limited time, some of which passes by reminding our projects. It is important for the tutors to follow our projects better*". In addition, it was mentioned that there is a blog that the students wrote about their process, but these blogs were not followed by the tutors regularly enough to track the students' projects. However, the students questioned why they were writing these blogs unless the tutors followed their project properly. They considered these blogs to be a waste of time for their process. On the other hand, although it was rarely mentioned by the students that when the blogs were followed by the tutors, this positively affected the desk crit session. One of the students mentioned that "*I did not get feedback from one of the tutors for the last three weeks and she remembered what I had developed before and gave feedback based on the process. I was very impressed*". Tracking the students' project in a better way contributes to efficient use of time during desk crits and efficient feedback given by the tutors.

4.7.10.2. Insights about design representation tools

Looking at the insights about design representation tools, it is seen that the negative and positive effects of different representation tools become important during desk crits. One of the students mentioned that he had problems with the drawings during desk crits because he had drawn at a level that he could can understand but it could be misunderstood or understood incompletely while trying to explain. Similarly, one of the students considered mock-ups insignificant when mock-ups were requested by the tutors, because he believed that 3D-models would be better to explain his project. He thought that he lost time by preparing mock-ups instead of making better presentations with 3D-modelling.

On the other hand, the positive effects of different design representation tools are related to the use of effective tools according to the students' projects. One of the students stated that she would have spent more time on mock-ups but she realized the positive effects of mock-ups on her project, later on in the process. Another student started preparing mock-ups for desk crits earlier than others when she realized that she could not explain her problems with her sketches very well. By this way, she expressed herself better in desk crits. Similarly, one of the students mentioned that she had to make a working prototype to see whether the mechanism worked, and she made prototypes step by step several times, which was very helpful for her product development process. Although it took much time, it was easier and more useful to explain the product but this process should have started earlier. It was too late, two weeks after preliminary jury, for her to start working prototype in order to make decisions about her project and advance her process.

Similarly, 3D-models, renders and video tools are very effective in explaining different product aspects during desk crits. For instance, as mentioned by the students, they started thinking on some of the product aspects too late, such as inner parts, materials and mechanism, and it was difficult to solve the problems of the product at later stages. In addition, one of the students stated that explaining the interface when prepared with graphic tools was very effective during desk crits. Furthermore, interactivity of the interface was missing due her skills but it would have been different if she had been able to show it. The students used the advantages of different design representation tools but mostly in the later stages of the product development process.

In addition to these advantages, interactive presentations during desk crits is an important factor that enhances the effectiveness of desk crits. One of the students stated that "*it was easier to explain the product with a 3D-model and to support this explanation with movements and interaction by taking any object around, which I discovered later*". Similarly, other student mentioned that when interactivity is involved in desk crits, this makes both the tutors and the students excited. The tutors follow the project process better and remember what was done before in the next desk crit. They are more aware of the level that the product reaches. However, they could not remember that well, when the students explained with sketches and writing. Interactivity of desk crits becomes an important asset for design representation tools that can support the desk crits in terms of students' explanations, tracking of the projects by the tutors, communication between the student and tutor, and receiving of sufficient feedback. In addition, interactivity could solve the negative issues that the students encountered during desk crits. Similarly, the quality of the presentations affects the students' motivation during desk crits. When the quality of design representation tools is good enough, the students enthusiastically explain their projects. As mentioned before, the students started to use different design representation tools at later stages, which they would have preferred to use earlier. This is because when they started to use these design representation tools to further develop the product aspects related to their projects, they used the advantages of these tools for their projects. As a result, it is essential to start using different design representation tools earlier in the product development process depending on the type of projects and the students' skills.

4.7.10.3. Insights about the product development process

Looking at the insights about the product development process, these are related to *specific guidance to the projects, specific product development process of the students, being late in productizing the design concept, bad timing of workshops* and *specific workshops for the students' projects*. All these insights can be considered as suggestions that could enhance the product development process of the students. The first insight is about specific guidance to the project rather than general. For instance, one of the students stated that the tutor needs to direct them about the expectations from mock-ups. While the tutors need to direct the students to focus on the mechanism if the project is mainly based on mechanism, they need to direct the students to focus on visual mock-ups if the project requires work on the product form. The students feel that there is a lack of specific guidance to each project. They mostly feel that they are getting general guidance instead of specific. Similarly, one of the students mentioned that students need to be guided according to their project because for example, she did not consider mechanism and interface in her project. Therefore, their expectation is to get specific guidance related to their projects.

Similarly, the second insight is about the specific product development process of the students. They feel that the tutors make reflections on each project in the same way, which makes the product development process difficult for the students. One of the students mentioned that he felt that he lost time while preparing mock-ups when it was requested. To prepare better presentations with mock-ups, he had to make small details in order to increase the understandability of the product otherwise the tutors could not understand his project without seeing these details. He placed a lot of effort in preparing mock-ups but he would have preferred working on a 3D-model to explain his project instead. This necessity to prepare mock-ups made him waste time and prevented him from preparing better presentations with other design representation tools in less time. Similarly, one of the students stated “*I think that each student’s process should be directed differently. My forms will be developed after my scenarios, then I have to figure out the details. However, the form should be made according to the ability to fly in a drone project. Everyone's process may differ*”. Similarly, another student mentioned that it was proceeded with the understanding that each student’s project should follow the same progress. However, it was difficult to continue her product development process without solving the mechanism but she spent too much time on building scenarios, which leaded to confusion for her and late decisions about her project. Therefore, students’ expectation was that the product development process might differ in the projects. Similarly, it is mentioned that the students can carry out unique project development processes starting from the conceptualization phase to the final presentation phase in the 4th and final year of the undergraduate programme. The projects could be proceeded differently by considering different product aspects from the very beginning of the process. Some of the students considered this process slow when compared to their own product development process. In addition, it was stated that the students could proceed faster if the product development process was different for each project.

The third insight about the product development process is being too late in productizing the design concept. In other words, the process followed until the preliminary jury was considered as a scenario-based process and the process that followed after the preliminary jury was considered as productization of the design concept. However, it was frequently stated by the students that it was too late to productize their projects. One of the students mentioned that they lost a lot of time at the beginning of the process and it was too late to productize. Similarly, this process made many students spend most of their time on scenario building and they could not put enough effort in developing technical parts of the products, such as details and manufacturing, because of spending too much time on the scenario. During and after the two final screenings of the students’ projects, until which they normally had to finalize their projects, they mentioned that they had to continue the product development process. There was less time remaining for the students to productize their projects between the preliminary jury and the final screenings. It was mentioned that the students continued their product development process after final screenings. In addition, limited time and productizing the projects at these stages put pressure on the students. On the other hand, one of the students stated that "*the fact that I started to work on the details earlier in the process made the product development process easier for me*". Similarly, it was also an advantage for one of the students to determine the technology and inner parts of his project at the earlier phases. It can be said that starting to productize the projects earlier could enhance the students' product development process. As a suggestion made by the students, the stages that they went through before the preliminary jury should be accelerated because the things they do, such as developing the project statement and design research, were changing and developing throughout the process. It was considered as a waste of time for the students to clarify these aspects at those stages because they went back to the related data that they already worked on during product development in order to look over again and to develop these data. It is also suggested that while the scenario-based process should be shortened, the productization of the projects should start earlier and these two processes should overlap with each other.

Other insights about the product development process were related to the workshops; bad timing of workshops, and specific workshops for the students' projects as a suggestion. It was stated that some workshops, idea generation workshop and definition of project requirements workshop, could start earlier because the students revised the workshop results later in the process; thus, conducting these workshops later was a waste of time for them. For instance, it was suggested that the workshop conducted for defining the constraints, objectives and directives of the project should start at the beginning of the project together with the problem statement workshop, and not intervene with the process. In addition, it was suggested that specific workshops for the students' projects should be done according to the major product aspects that they work on, instead of same workshops for everyone. One of the students suggested that the students who will develop an interface or the students who work on mechanisms could be divided into groups and the tutors could organize workshops accordingly. If the students could get something that they could use for their own projects during the process, they would not think that they would waste time.

4.7.10.4. Insights about the 3D-modelling process

The 3D-modelling process was also discussed by the students in the focus group sessions. This process was asked to the students because it is directly related to AR. In addition to the insights presented earlier in this section, the insights about 3D-modelling can be presented under three subcategories; *advantages of 3D-modelling, disadvantages of 3D-modelling* and *suggestions to start 3D-modelling during the product development process*.

There are several advantages of 3D-modelling. The first one is that 3D-models provide better interaction. It is stated by the students that they could zoom into the product details and show different configurations by hiding/unhiding the layers with a 3D-model. In addition, it is more effective to show the product by using layers. Furthermore, the product is easily understood when the angle is changed in a 3D-model. The second advantage of 3D-modelling is to support effective explanations of the product aspects, resulting in more realistic and professional explanations. It was stated that the students could easily explain many product aspects such as details, inner parts, size, mechanism, form, and section. In addition, showing and explaining the product with a 3D-model is faster for them. By this way, 3D-models provide the students more realistic and professional explanations. The third advantage is that 3D-modelling supports a better personal product development process for the students. As stated by the students, they could think about the product aspects better, develop these product aspects better and solve the problems easily with 3D-models. The students mentioned that they could easily develop the product form and details by considering manufacturing. Although this takes much more time than sketching, they could consider more issues related to manufacturing with a 3D-model. In addition, they could easily develop solutions for mechanism, moving parts and product aspects that need calculation. Moreover, 3D-models are more useful for students to develop the product aspects related to technical parts of the product.

The fourth advantage of 3D-modelling is to support better and common understandability of the project resulting in better feedback given by the tutor. The students stated that their projects were better understood with 3D-models. In addition, 3D models can provide a common understanding of the students' projects. The students also mentioned that seeing their project in 3D can support the tutors in giving better feedback. The fifth advantage is that 3D-modelling supports a better and faster solving process when compared to other tools. For instance, one of the students stated that it was hard to make his project with mock-ups in order to explain during desk crits but utilizing 3D-models could be better at many phases of the process. On the other hand, although other students mentioned that using mock-ups could sometimes be useful, it required more effort. 3D-models support a faster solving process but it is essential to know modelling software better. Similarly, one of the students stated that if she had had better modelling skills, she could have tried out different solutions about her project. She prepared many prototypes instead of 3D-models during the product development process. However, if she had modelled better, building several prototypes might have not been necessary because the prototypes took much time. 3D-models can support a better and faster solving process for the projects of students with better 3D-modelling skills.

When looking at the disadvantages of 3D-modelling, the first one is the differences in the students' 3D-modelling skills. As stated by the students, 3D-modelling software limited them because of their skills. They could not easily work with 3D-models since they did not know the software well. For instance, one of the students stated "*if I use a 3D-model in the early stages, it restricts me since I am not good at 3D-modelling*". On the other hand, she mentioned about how her friends could easily prepare 3D-models. Thus, it is seen that the students' skills about 3D-modelling becomes important in utilizing this tool in the earlier stages of the product development process. The second disadvantage of 3D-modelling is to perceive the 3D-model as the final product. One of the students stated that the tutors perceived the 3D-model as if it were the final product. The reason might be that the students use 3D-models during desk crits at later stages of the product development process. However, it is also mentioned that 3D-models can be used in the design development process even though it is perceived as the finalized product. In addition, it is stated that 3D-models should be a little detailed in desk crits otherwise the rough model might not be clearly understood. The third disadvantage for the students is inadequate training about 3D-modelling. As stated by the students, they did not think that they had enough lectures about 3D-modelling, resulting in their lack of skills. In addition, they believed that students with better skills improved themselves apart from 3D-modelling training. They wanted to utilize 3D-modelling earlier in the product development process but they could not use software due to insufficient skills and experience.

There are suggestions made by the students regarding when starting 3D-modelling would be helpful for them. The main idea is to start 3D modelling in the earlier stages of the product development process. As a reason given by the one of the students, she stated "*I had difficulties in my project while modelling the external form and had to model the details in the final stages, which was too late. I could not model as well as I wanted*". The reasons to start 3D-modelling process earlier are related to the insights about the product development process; namely, being too late to productize the design concept, and the specific product development process of each student, as mentioned in Section 4.7.10.3. It is suggested that starting 3D-modelling between the initial idea jury and the preliminary jury can be helpful for the students to develop the project and to find solutions. The suggested stages are between the initial idea jury and the preliminary jury. In addition, 3D-models can be used as a presentation tool during desk crits after the 3D-modelling process has started. On the other hand, it is also suggested that starting 3D-modelling should be different for everyone due to different skills. For instance, one of the students mentioned that she could not use

3D-modelling starting from the earlier stages because of her lack of skills. Similarly, another student stated "*this process can be different for everyone because I cannot model but I can prototype*". However, it is also stated that some of the students express themselves better with 3D-models and so they start using 3D-models from the beginning of the process, but they do not show them in desk crits at earlier stages, because it is considered forbidden.

4.7.11. Integration of design representation tools into the product development process

Based on the insights from focus group sessions mentioned in Section 4.7.10, the integration of design representation tools into the product development process is suggested. As mentioned in Section 4.7.1, knowledge representations used in the product development process are pictorial, linguistic, physical and virtual. While pictorial and linguistic representations were predominantly used in the early stages of the product design process until the preliminary jury, knowledge representation was predominantly physical and virtual after the preliminary jury (Figure 4.70). These knowledge representations were supported with pictorial and linguistic tools. It can be seen that there is a transition between different design representation tools starting from the preliminary jury. Based on the insights about desk crits, design representation tools, product development process, and 3D-modelling, this transition should start earlier in the product development process, between the initial ideas jury and the preliminary jury, to use physical and virtual tools effectively. When the students utilize these tools according to their product aspects, they make considerable progress in their product development process. This leads to better results in their final design solution regarding the product aspects, which can be seen from their self-evaluations. Therefore, physical and virtual representation tools should start to be used after an evaluation of initial ideas, when students are at the stage of giving direction to their ideas and working them into design concepts. When they turn these ideas into design concepts, they can validate these concepts with different tools by using them during studio sessions to get better feedback from tutors with more interactive studio sessions. This results in better progress for the students' product development process. Based on the suggestion, AR technology is mainly related to the use of 3D-models and therefore can be integrated into the process when 3D-modelling starts to be used (Figure 4.70).

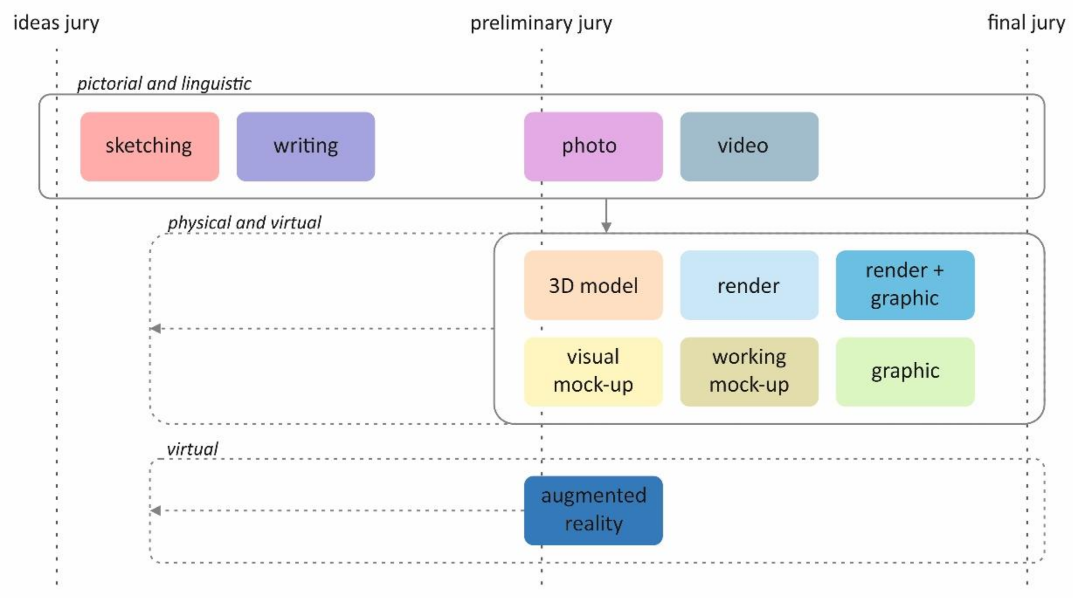


Figure 4.70. Suggested integration of design representation tools and AR technology into the product development process

4.8. Augmented reality possibilities

Researches were conducted to reveal potential implementations of AR into the product development process even though the current technology at that time had not allow to develop AR applications for design process. For example, a study conducted by Topal (2015) suggested future potentials of AR that can support product surface creation, material considerations, 3D visualization of 2D drawings, display and feedback interfaces, and mechanical and structural considerations. These suggestions were made in relation to different design stages; idea generation, preliminary jury, development of design concepts, user testing and final presentation. Beyond different design stages of product development process, this section present AR possibilities for each product aspect. These possibilities can be potential future use of AR technology for the students when they develop product aspects related to their projects.

4.8.1. Augmented reality possibilities for each product aspect

In this section, AR possibilities for each product aspect will be explained in order to define the requirements that need to be considered while developing AR technology that can be used in the product development process of industrial design students.

4.8.1.1. Usage scenario

Usage scenarios could be better presented with a real-time demonstration by using AR technology. However, this real-time demonstration needs to be easily prepared in order to show this representation while explaining during a studio session. In addition, usage scenarios could be represented with real-time interaction, by using AR and adjusting each step while explaining. Considering the time required to adjust such steps during studio sessions, if this will take some time to adjust and lead to a decrease in the interactivity of the studio session, a step by step representation could be preferred to show both the usage scenario and the human-product interaction in real size with pre-sets that are defined before studio sessions. When considering the time required to prepare human-product interaction with the other design representation tools, AR might offer a more practical way to present usage scenarios. The students could define some pre-sets before studio sessions and then use these pre-sets during the sessions. In the projects that require the context/environment aspect together with the usage scenario, students can use AR before the studio session to prepare design presentations and then they can use these representations to explain these aspects together. In addition, students can also use AR as a supportive tool in preparing design representations that are used in studio sessions.

4.8.1.2. User experience, user interaction and emotion

The possibilities of user experience and user interaction mainly come from usage scenario and user interface. The possibilities of emotion come from usage scenario or the product aspect related to emotion.

4.8.1.3. User interface

The most beneficial possibility for user interface is the one that is mentioned in Section 4.7.6, Insights from the Challenges, an interactive user interface that the students can show how it is used interactively during studio sessions. Real-time interaction can enhance the students' explanations about user interface, leading to an increase in the interactivity of the studio session and better feedback from tutors. However, interactive user interface might be harder to develop when compared to other possibilities. Considering this difficulty, a static user interface changing with pre-sets could also be really useful for the students to explain this product aspect. In other words, the students can use step by step representations that are prepared before studio sessions. This static user interface could be either hand sketching or user interface developed with graphic tools. For both design representation tools, it is really important to show user interface on the product.

4.8.1.4. Feature/function

Feature/function might be related to user interface, parts, mechanism or any other related product aspect. Product feature/function mainly requires pre-sets that are defined according to these features. This might be highlighting a part of the 3D-model related to feature, or a step of mechanism prepared before the studio session. These pre-sets could be a representation related to product parts, representation of the interaction when the product functions, or representation of the product feature in context. Therefore, these pre-sets could be prepared before the studio session and then could be used while explaining this product aspect during the studio session. According to the feature/function, the students might need to show their product partially and AR could offer the potential of showing the product partially as it is intended with pre-sets in a practical way. In addition, feature/function could be represented with real-time interaction, by transforming the concept/product while explaining. However, using pre-sets for step by step representation or preferring real-time interaction for feature/function depends on the related product aspect. For instance, if the product feature/function is related to mechanism and the transition between pre-sets is important, real-time interaction could be more helpful. On the other hand, if the feature is related to the product part, step by step representation could be more useful.

4.8.1.5. Parts

Without considering the scale factor whether to represent in real size or not, it is more important to show parts in a more understandable way by exploding or zooming the related parts that the students explain during the studio session. Therefore, this can be represented with real-time interaction, or step by step representation, or single representation according to the student's need. Step by step representation or single representation might be more beneficial than real-time interaction. This is because the representation of adjustment during real-time interaction is not necessary for parts and might be time consuming, which might decrease interactivity. However, real-time interaction, which allows to transform the concept/product, can also be used according to the requirements of the design project. In addition, the students need to highlight the parts with keywords and to label them while explaining this product aspect. AR needs to offer these possibilities to help the student explain product parts effectively.

4.8.1.6. Physical ergonomics

For physical ergonomics, it is important to show human-product interaction or product relation with part of the body. This representation could be either real-time interaction during the studio session or with pre-sets that could be prepared before the studio session. If the transition between pre-sets is important to represent, real-time interaction is more effective. On the other hand, if transition between pre-sets is not important, step by step representations with pre-sets could be helpful for the students to explain this product aspect during the studio session. In addition to these representations, this product aspect can be represented with a single representation for the projects which the students need to show with just one pre-set. Depending on the projects, the need to represent physical ergonomics might change and AR could offer these representations in a practical way, which might enhance the interactivity of the studio session. During the study, it was seen that students presented different versions of the product together or separately, as they explained their considerations related to physical ergonomics. Therefore, it is helpful for the students to show this product aspect with different alternatives together or one by one while using AR technology.

4.8.1.7. Aesthetics/form

Representing different alternatives together or separately is essential for aesthetics/form. The students need to show different alternatives, either new form generations or forms generated previously, during studio sessions. Presenting these alternatives either together or one by one is required according to the students' need. Single representation, which allows the students to show aesthetics/form from different views, could be useful for their explanations. On the other hand, if the students need to show aesthetics of their concept/product in context/environment, they need to use AR technology before the studio session and they can use this representation during studio sessions. AR technology could easily offer these possibilities.

4.8.1.8. Size

Size is mainly used by the students to give an idea about the product dimensions during studio sessions, mostly by using mock-ups, which take time to prepare. AR could have the potential to be easily used in order to give an idea about size and proportions. In addition, it can be also used to show different size alternatives with pre-sets easily. Although AR is not a physical tool that can be held, it is a more practical way to represent size considering time requirements to prepare mock-ups. Adjusting size interactively during studio sessions, which AR could easily provide, could be a possibility for the students but it seems they do not need such adjustments frequently.

4.8.1.9. Material/color

Material/color aspect can be considered similar to aesthetics/form. Although the students rarely needed to show different alternatives during studio sessions, representing different alternatives together or separately might be helpful for material/color. The students can show different alternatives, either new material/color options or the ones generated previously. Presenting these alternatives either together or separately is required according to the students' need. Single representation, which allows the students to show material/color from different views, could be useful for their explanations. On the other hand, if the students need to show material/color of their concept/product in context/environment, they need to use AR technology before the studio session and they can use this representation during the studio session. AR could easily offer these possibilities to represent material/color with different alternatives if required.

4.8.1.10. Product configuration

Product configuration can be either related to modular parts that can form different versions of the product, or a product that can be extended with parts. Product configurations need to be presented with different versions together or one by one. This representation could be adjusted interactively during studio sessions with AR application by hiding/unhiding parts. Considering the time required to adjust such steps during studio sessions, if this will take some time to adjust and lead to decrease in interactivity in the studio session, step by step representations could be preferred to show different configurations with pre-sets that are defined before the studio session. In addition, the transition between pre-sets is not important to show during studio sessions, as it might be time consuming. Step by step representations with pre-sets could be more beneficial for the students to explain this product aspect during studio sessions. In addition, a single representation for each configuration could be used with pre-sets defined before studio sessions and could be easily shown during studio sessions.

4.8.1.11. Context/environment

Considering context/environment, it is really difficult to use AR during the studio session. However, the potential is that the students can use AR before the studio session to prepare the context/environment in order to explain this product aspect during the studio session by using this design representation.

4.8.1.12. Mechanism

As it is explained among the challenges, mechanism could be presented effectively with a real-time demonstration that shows how it works, if it is easier to develop considering AR technology. When the students presented mechanism with a working mock-up, this increased the interactivity of the studio session. If real-time demonstration is not possible, step by step explanation either by adjusting real time or with pre-sets could also enhance the effectiveness of mechanism explanation. If the transition between pre-sets is important to represent, real-time interaction is more effective. For real-time interaction, exploding some parts or section views by cutting the parts could be helpful to explain mechanism in addition to other transformations; hiding/unhiding and zooming in/out. On the other hand, if transition between pre-sets is not important, step by step representations with pre-sets could be more helpful for the students explain this product aspect during studio sessions. In addition, highlighting and labelling the parts related to mechanism might be helpful for the students while explaining during studio sessions.

4.8.1.13. Details

Similar to mechanism, it could be beneficial for students to show detail effectively with a real-time demonstration of how the detail works. This product aspect can also be represented by moving/rotating/zooming into the parts related to detail interactively during studio sessions. If transition between pre-sets is not important, step by step representations with pre-sets could also be useful for the students to explain this product aspect during studio sessions. While presenting detail with real-time interaction, exploding some parts or section views by cutting the parts could enhance the explanation of the students. Similar to mechanism, hiding/unhiding, zooming in/out, highlighting and labelling the parts related to details could also be helpful for the students while explaining this product aspect during studio sessions. AR needs to offer these possibilities to help the design students explain details in a better way.

4.8.1.14. Technical standards

There is insufficient information to draw insights about technical standards but this product aspect might mainly be related to mechanism, detail, inner parts or technology.

4.8.1.15. Assembly/set-up

There is insufficient information for insights about assembly/set-up but assembly could be presented with a real-time demonstration that shows how the product is assembled. However, the need for a real-time demonstration might not be necessary so that it could be very beneficial for the students to explain assembly/set-up with a step by step representation instead of real-time demonstration. Pre-sets showing how the product is assembled might enhance the explanation of the students.

4.8.1.16. Inner parts

It is essential to show inner parts of the product with an exploded view, by highlighting, labelling and hiding/unhiding while explaining the inner parts. The inner parts could also be represented in different views, such as ghosted and section. AR could offer these possibilities in practical ways, which can show all inner parts together and how they are placed in the product with or without exploding parts. While the students are explaining the inner parts, different ways of presentation could be supported by AR technology according to the students' needs.

4.8.1.17. Technology

Similar to the inner parts, technology explained by the students were mostly related to the parts placed inside of the product. Therefore, showing the technology of the product with an exploded view by hiding/unhiding parts is necessary for the students while explaining this product aspect. In addition, highlighting or labelling parts could be beneficial for students to refer to the parts while explaining during studio sessions.

4.8.1.18. Maintenance

There is insufficient information to draw insights regarding maintenance, which is about how to clean or change the parts of a product. It is not a product aspect that the students mentioned often. AR could also offer maintenance possibilities according to a related product aspect. For instance, if maintenance is mainly related to the inner part, the possibilities mentioned for inner parts can be applicable for maintenance as well.

Table 4.19 summarizes AR possibilities for each product aspect.

Table 4.19. AR possibilities for each product aspect

Product Aspects	**AR possibilities**
*usage scenario**	• Real-time demonstration • Real-time interaction • Step by step representation • Human-product interaction in real size • Pre-sets to show during studio session • Preparation before studio session
*user experience**	The possibilities mainly come from usage scenario and user interface.
*user interaction**	The possibilities mainly come from usage scenario and user interface.
*emotion**	The possibilities come from usage scenario or the product aspect related to emotion.
user interface	• Interactive user interface • Static user interface changing with pre-sets • User interface (either hand sketching or graphics) on the product
feature/function	• Step by step representation with pre-sets according to feature/function • Single representation • Real-time interaction if necessary • Showing related parts by hiding/unhiding • Showing related parts by zooming in/out • Highlighting a part related to feature/function • Showing product partially with pre-sets
parts	• Step by step representation with pre-sets • Single representation • Real-time interaction if necessary • Showing parts by exploding or zooming in/out • Moving/rotating or hiding/unhiding • Highlighting them • Labeling the parts with keywords
physical ergonomics	• Showing interactively human-product interaction • Step by step representation with pre-sets • Single representation if necessary • Showing different versions of the product
aesthetics/form	• Showing different alternatives separately or together
size	• Showing different size alternatives separately or together
material/color	• Showing different alternatives separately or together

Table 4.19 continued. AR possibilities for each product aspect

Product Aspects	**AR possibilities**
product configuration	• Step by step representation with presets • Single representation • Real-time interaction if necessary • Adjusting versions by hiding/unhiding parts • Pre-sets to show different versions
context/environment	• Preparing context aspect to show during studio session
mechanism	• Real-time demonstration of how mechanism works • Real-time interaction • Step by step representations with pre-sets • Exploding or cutting parts related to mechanism • Representing the parts related to details by moving/rotating or hiding/unhiding • Highlighting and labelling parts to specify • Pre-sets to show during studio session
details	• Real-time demonstration of how detail works • Real-time interaction by exploding or cutting related parts • Step by step representation with presets • Representing the parts related to details by moving/rotating or hiding/unhiding • Highlighting and labelling parts to specify • Pre-sets to show during studio session • Showing section view
technical standards	There is limited information but the possibilities might mainly come from mechanism, detail, inner parts or technology.
assembly/set-up	There is limited information but the possibilities might be, • Real-time demonstration how the product is assembled • Step by step representations
inner parts	• Showing inner part with exploded view or ghosted view or section view • Showing inner parts by hiding/unhiding • Highlighting and labelling them
technology	• Showing technology with exploded view or ghosted view or section view • Showing technology by hiding/unhiding • Highlighting and labeling parts related to technology with keywords
maintenance	There is limited information but the possibilities might mainly come from inner parts or product parts.
** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*	

4.8.2. AR requirements for product aspects

By looking at the possibilities mentioned in Section 4.8.1, six levels of AR requirements for product aspects are defined; these are, *interaction, transformation, specification, reference, display,* and *preparation* (Figure 4.71).

Interaction;

1. *Real-time demonstration* can be considered as automatic representation that is saved beforehand. There is no need to use AR but it will demonstrate according to the representation prepared before the studio session.
2. *Real-time interaction* can be considered as adjusting the concept/product according to the students' needs during studio session. Instead of real-time demonstration, the student can change settings according to questions or reflections of the tutors.
3. *Step by step representation* can be considered as using presets that are defined beforehand. With a click, the students can arrange what they want to present instead of adjusting; thus, this is more practical than real-time interaction.
4. *Single representation* can be considered as no need to represent different steps. Only single representations can help students in accordance with their needs.

Transformation;

5. *Exploding/cutting the parts* can be considered as the parts of the concept/product that need to be separated from the rest by exploding or shown in relation to each other by cutting for a section view.
6. *Moving/rotating parts* can be considered when there is a need to spatially manipulate parts while explaining.
7. *Hiding/unhiding parts* can be considered when the parts need to be focused on while explaining.

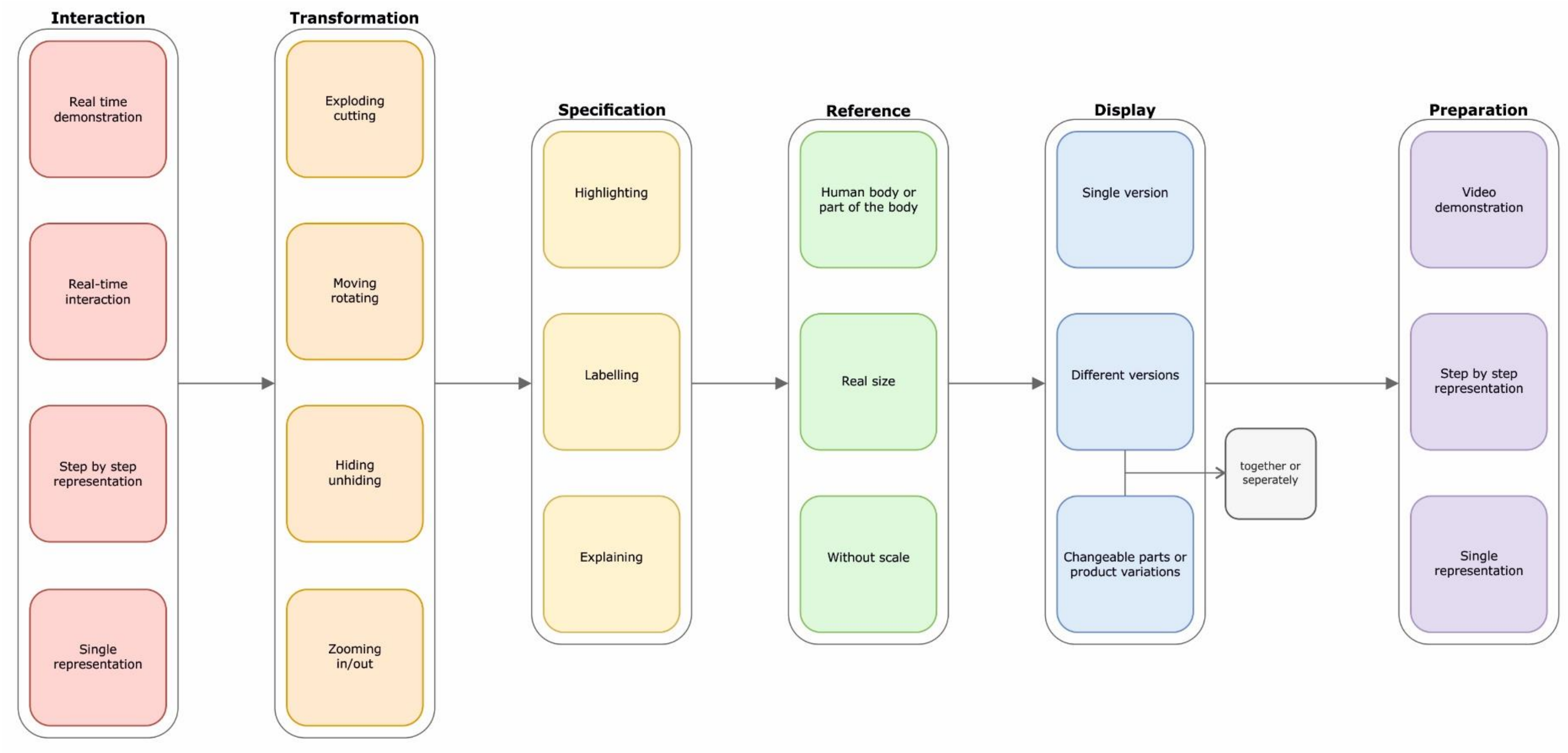


Figure 4.71. Six levels of AR requirements for product aspects

8. *Zooming in/out* can be considered when there is a need to show the representation bigger than the actual size in order to increase the visibility of the parts while explaining.

Specification;

9. *Highlighting* can be considered when the parts should be brought forth and drawn attention to while explaining.
10. *Labelling* can be considered when the parts need to be named with keywords beforehand, so that students can easily explain with verbal reference during studio sessions.
11. *Explaining* can be considered when the students need to note down explanations beforehand to use them during studio sessions.

Reference;

12. *Representing on human body or part of the body* can be considered when the concept/product needs to be presented in reference to the human body or body part.
13. *Representing in real size* can be considered when the concept/product needs to be presented in real size without using any other reference.
14. *Representing without scale* can be considered when the concept/product does not need to be presented in its actual size.

Display;

15. *Single version* can be considered when a single concept/product needs to be represented.
16. *Different versions* can be considered when there is a need to represent different versions of the concept/product.
17. *Changeable parts or product variations* can be considered when there is a need to represent different variations or modularity and configuration of components.

Preparation;

18. *Video demonstration* can be considered when the students need to prepare an explanatory video with AR technology to show in studio sessions.
19. *Step by step representation* can be considered when the students need to prepare design representations with AR technology by taking print screens of their concept/product to show these representations in studio sessions.
20. *Single representation* can be considered when the students need to prepare design representation about a product with AR technology to show this representation in studio sessions.

Documentation;

In addition, there might be a need for the students to document,

21. *earlier versions* of product aspects in order to re-mention them during the students' product development process, and
22. *information*, such as project statement, user group and product examples.

The design representation tools to re-mention information and product aspects are photos, writing, sketching, 3D-models, renders and jury boards. Although these representation tools, except 3D-models, are not directly related to the use of AR, the technology can also be used to document the process. For instance, students can document their product development process; the information about their project, sketching, mock-ups, 3D-models, etc., by uploading the documents to their tablet in which AR is used. Then, they can re-use these documents during studio sessions when needed together with or without the AR representation tool. It is also important for the students to document their product development processes considering the design representation tools.

Table 4.20 represents requirements of product aspects for AR technology to integrate into AR application, which could be used by students during their product development processes. In addition, it illustrates which requirements the eDrawings application fulfills and whether it is answering this requirement directly or indirectly.

Table 4.20. Product aspects' requirements for AR technology

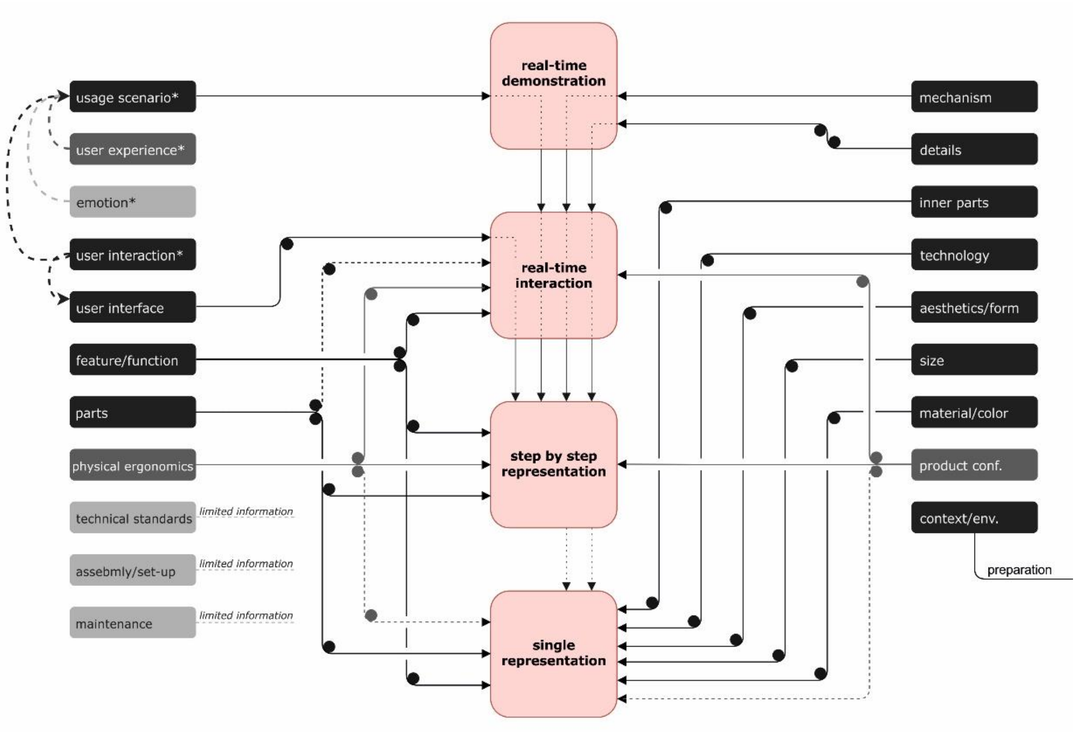
	Interaction				Transform				Specification			Reference			Display			Preparation			Documentation	
	Real-time demonstration	*Real-time interaction*	*Step by step representation*	*Single representation*	*Exploding/cutting*	*Moving/rotating*	*Hiding/unhiding*	*zooming in/out*	*Highlighting*	*Labelling*	*Explaining*	*human body or part of the body*	*real size*	*without scale*	*Single version*	*Different versions*	*Changeable parts or product variations*	*Video demonstration*	*Step by step representation*	*Single representation*	*Earlier versions*	*Information*
Product Aspects	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***
usage scenario*	■											■	■		■			■			*Earlier versions of each product aspect might be needed during the students' product development process.*	project statement
		■				■						■	■		■				■			
			■				■				■	■	■		■					■		
user experience*	*is related to usage scenario*																					problems
user interaction*	*is related to usage scenario and user interface*																					
emotion*	*is related to usage scenario*																					research
user interface		■											■		■	■			■			
			■								■		■		■	■			■			user group
feature/function			■						■					■	■				■			
				■		■	■	■	■					■	■				■			product examples
		■				■	■	■	■					■	■				■			
parts			■						■	■				■	■		■		■			moodboard
				■	■	■	■	■	■	■				■	■		■		■			
		■			■	■	■	■	■	■				■	■		■		■			keywords
physical ergonomics		■				■						■			■	■			■			
			■									■			■	■			■			critiques
				■								■			■	■			■			
aesthetics/form				■				■					■	■	■	■				■		self-evaluation
size				■									■	■	■	■				■		
material/color				■											■	■				■		product analysis
product configuration			■													■	■			■		
				■			■	■								■	■			■		current situation
		■					■	■								■	■			■		
context/environment															■					■		user needs
mechanism	■								■	■				■	■			■				
		■			■	■	■	■	■	■				■	■				■			
			■						■	■				■	■				■			
details	■								■	■				■	■			■				
		■			■	■	■	■	■	■				■	■				■			*and similar information*
			■						■	■				■	■				■			
technical standards	*limited information to conclude*																					
assembly/set-up	*limited information to conclude*																					
inner parts				■	■		■	■	■	■				■	■					■		
technology				■	■		■	■	■	■				■	■					■		
maintenance	*limited information to conclude*																					
eDrawings		■	▨	■	▨	▨	■	■	■	▨			■	▨	■	▨	▨		▨	■	▨	
■	eDrawings has the feature ***directly*** answering this requirement.																					
▨	eDrawings has the feature ***indirectly*** answering this requirement.																					

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*

For instance, the application supports real-time interaction directly but supports step by step representation indirectly. Step by step representation requires different configurations that need to be prepared before the presentation of the student during desk crits. It cannot be prepared by using the application. To give another example, a part can be highlighted by selecting this part but the layers feature of the application needs to be on to see the label, which should be done before the presentation. In general, the eDrawings application includes several requirements either directly or indirectly.

4.8.3. Suggested AR Interaction framework for product aspects

Although AR requirements for product aspects are given in Section 4.8.2, interaction hierarchy can be considered as a framework for each product aspect (Figure 4.72).



* Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.

Figure 4.72. AR Interaction framework for product aspects

- *Usage scenario* can be effectively represented with real-time demonstration, which can be the first option. If this demonstration takes considerable time for the students to prepare, then real-time interaction can be the second option to represent this product aspect. If interactive adjustment of the concept/product to explain usage scenario during studio sessions is time consuming, which decreases the interactivity of the session, step by step representation with pre-sets defined before studio sessions can be used.
- *User experience* and *emotion* is related to usage scenario.
- *User interaction* is related to usage scenario and user interface.
- *User interface* can be effectively represented with real-time interaction, showing how the user can interact. However, development of such interaction with AR technology could be harder when compared to other possibilities. Representation with pre-sets, which shows each step of the user interface, is the alternative representation if real-time interaction is not possible.
- *Feature/function* has no hierarchical order between the interaction options. It depends on both the students' need and the product aspect in relation to feature/function. Real-time interaction, step by step representation and single representation are the options that can be preferred to explain feature/function during studio sessions.
- *Parts* as a product aspect has also no hierarchical order between the interaction options. It can be represented with both step by step representation and single representation according to the students' need. In addition, it might be represented with real-time interaction but the students might rarely need this representation. This is because the transition while adjusting the concept/product might not be necessary for this product aspect but still real-time interaction is a minor option.
- *Physical ergonomics* has no hierarchical order between the interaction options. It depends on the students' need and real-time interaction, step by step representation and single representation are the options that can be used to explain this product aspect during studio sessions. If it is important to show

transitions while adjusting the concept/product, real-time interaction is a better option to use. If the transitions are not essential to show during studio sessions, step by step representation with pre-sets provides the ideal interaction. If there is no need for different pre-sets to show during studio sessions, single representation is the better option.

- *Mechanism* can be effectively represented with real-time demonstration, which can be the first option to show how it works. If this demonstration requires considerable time for the students to prepare, then real-time interaction can be the second option to represent this product aspect. If interactive adjustment of the concept/product to explain mechanism during studio sessions is time consuming, which decreases the interactivity of the session, step by step representation with pre-sets defined before studio sessions can be used. In addition, if the transitions between the adjustments of mechanism with real-time interaction are not important, step by step representation provides better interaction to explain this product aspect during studio sessions. Moreover, in cases where there might be a need for the students to show only one step of mechanism, single representation can be used.
- *Details* can be effectively represented with real-time demonstration, which can be the first option. If this demonstration takes considerable time to prepare, then real-time interaction can be the second option to represent this product aspect. If interactive adjustment to explain detail is time consuming and decreases the interactivity of the session, step by step representation with pre-sets can be used. In addition, if the transitions between the adjustments to explain detail are not important, step by step representation is a better option in explaining this product aspect during studio sessions. Moreover, there might be a need for the students to show only one step of detail; in this case, single representation can be used.
- *Inner parts* and *technology* can be effectively represented with single representation.

- *Aesthetics/form, size* and *material/color* can be effectively represented with single representation.
- *Product configuration* has no hierarchical order between the interaction options. It depends on the students' need and real-time interaction; step by step representation and single representation are the options that can be used to explain product configuration during studio sessions. If it is important to show transitions while adjusting different product configurations, real-time interaction is a better option to use. If the transitions are not important to show during studio sessions, step by step representation with pre-sets is the better option to explain this product aspect. In addition, each configuration can also be shown with single representation without making any adjustments during studio sessions.
- *Context/environment* has no interaction option but it can be prepared by using AR technology before the studio session. This design representation can be used to show and explain context/environment during studio session.
- *Technical standards, assembly/set-up* and *maintenance* have limited information to suggest interaction possibilities.

4.8.4. Evaluation of the design considerations to be represented with AR technology

Although AR requirements for product aspects are defined according to the insights, it is also important to find out the importance of the design considerations to be represented with AR application. In other words, knowing which design considerations including product aspects and research related information the students need to represent with AR application during the product development process is necessary. The design considerations were evaluated by the students to find out their importance to be represented with AR technology. They were asked to evaluate each design consideration from 1-point (not very important to represent) to 7-point (very important to represent). Figure 4.73 shows the students' evaluation of the design considerations that can be represented with AR technology and the average values. This evaluation is to illustrate descriptive statistics to explore which product aspects have potential for AR technology. The product aspects that have an average value lower than medium value (4) of the evaluation and the product aspects that have an average value closer to medium value, even though higher than medium, can be considered as less important to be represented with AR.

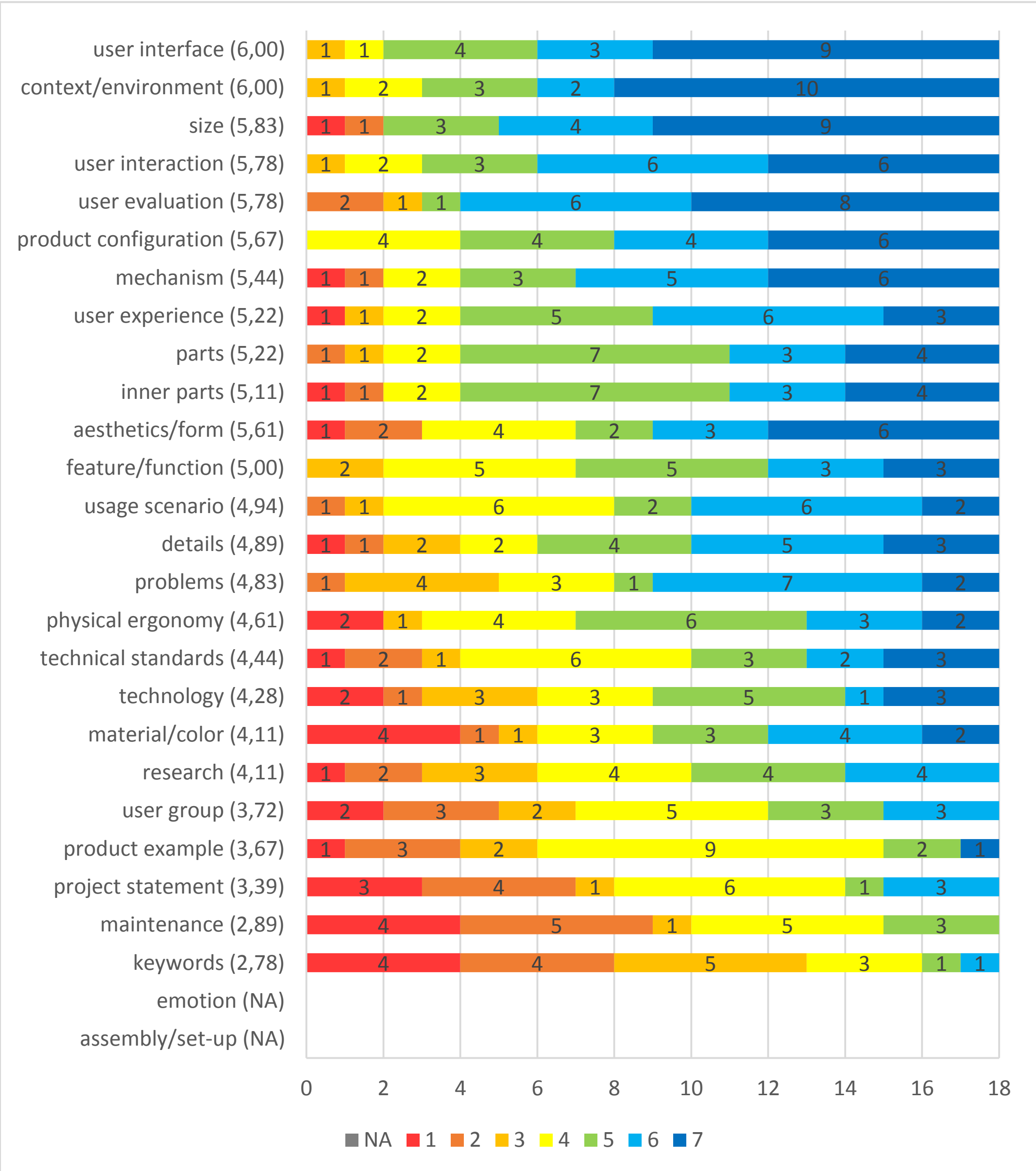


Figure 4.73. Evaluation of the design considerations to be represented with AR technology

The design considerations that have an average value higher than 4,5 have more potential to be represented with AR technology. When looking at these design considerations, they were evaluated with 5-point or higher by more than half of the students. These product aspects ranging from higher to lower average value are *user interface, context/environment, size, user interaction, user evaluation, product configuration, mechanism, user experience, parts, inner parts, aesthetics/form, feature/function, usage scenario, details, problems* and *physical ergonomics*. In addition, the evaluation of the students shows that the product aspects *material/ color, technology, technical standards* and *maintenance* are less important to be represented with AR technology.

On the other hand, the evaluation of the students about design considerations related to documentation shows that the design considerations, except user evaluation and problems, have less importance to be re-used during the product development process. Considering this, AR technology can also be used to test the students' concept/product with the users in order to get feedback from them, which is important for the students to make progress during their product development process. Other considerations related to documentation, namely *user group, product examples, project statement* and *keywords*, did not seem important to be used in an AR technology. Although the considerations related to documentation did not seem important for the students, a study about the product development process including AR as a design representation tool during the process can provide further information on whether they will need these product aspects. In general, this evaluation shows that most of the design considerations, except those related to documentation, are important to be represented with AR technology.

4.8.5. Forming groups of the design considerations

The design considerations are grouped according to the findings about how they were presented during studio sessions, AR possibilities and requirements for the product aspects and by looking at the similarities between them based on these findings.

Grouping the design considerations including product aspects can help AR developers to make relation between them for developing new AR applications. In addition, it can be helpful for designers to understand which design considerations can relatively be presented in an AR application. This grouping was also taken into consideration to decide a project brief for the study to explore the effects and potentials as a supportive tool during product development process.

The product aspects can be divided into four groups (Table 4.21); *user oriented, visual oriented, technical oriented* and *research oriented* group. User oriented group includes *usage scenario, user experience, user interaction, user interface, emotion* and *physical ergonomics*. In this group, there are also relations between them, such as user experience and emotion being related to usage scenario, or user interaction being related to usage scenario and user interface. In addition, this group requires explaining these product aspects on the human body or body part to show user product interaction. Similarly, using AR technology to show user interface on the product is important to be able to demonstrate with interaction.

Table 4.21. Grouping of the design considerations

Design considerations			
User oriented	*Visual oriented*	*Technical oriented*	*Research oriented*
usage scenario* user experience* user interaction* emotion* user interface physical ergonomics	aesthetics/form size material/color product configuration context/environment feature/function parts	mechanism details inner parts technology technical standards assembly/set-up maintenance	project statement** problems** research** user group** product example** moodboard** keywords** critiques** user evaluation**
** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.* *** These considerations are research related information that gives direction to the product development process.*			

Visual oriented group consists of *aesthetics/form, size, material/color, product configuration, context/environment, feature/function* and *parts.* This group requires showing different versions of the product, either together or one by one. Although it is not possible to use AR for context/environment during studio sessions, context/environment is somehow related to aesthetics/form and material/color in order to represent these product aspects in context/environment.

Technic oriented group includes *mechanism, details, inner parts, technology, technical standards, assembly/set-up* and *maintenance*. While the insights and possibilities for mechanism and detail are similar, inner parts and technology have similar insights and possibilities. These product aspects might be related to each other; for instance, mechanism could be the inner parts of a product or inner parts could be directly the technological parts. In addition, although there is limited information about technical standards, assembly/set-up and maintenance, these product aspects are mainly related to the aspects in this group.

Research oriented group is the product aspects related to research findings conducted by the students and its documentation during the product development process, namely, *project statement, problems, research, user group, product examples, moodboard, keywords, critiques* and *evaluation*. These product aspects were not seen as important to be represented with AR technology as the others.

Among these groups, the second and the third group seem to have the most potential to be represented with AR technology. The product aspects in these groups need to be further explored to draw insights on how AR technology can be used to enhance their representation during the product development process.

4.9. Summary of the findings and discussion

The study including observation and focus group as data collection methods was conducted to explore the current product development process of industrial design students in order to understand how AR technology can be integrated into the product development process. Based on the findings of the study, it is seen that using different design representation tools at the same time supporting each other enhances the students' product development process in terms of development of product aspects, explanation of them during desk crits, interaction between the students and the tutors, and the feedback given by the tutors. Based on the insight and findings drawn from this study, a framework, the Design Representation Tool (DRT) framework, is suggested to effectively use the design representation tools supporting each other during the product development process according to the product aspects that the students need to develop related to their projects. This framework is significant because the students expect to lead specific product development processes according to their projects. Instead of following a common and similar process to all, they prefer following their own process with specific guidance of the tutors based on the specific requirements of their projects.

In addition, they would prefer to use different design representation tools earlier in the process in order to take advantage of these tools. This is mainly because it is too late to productize the design concept when these tools are used in the later stages. Based on the findings of the study, the use of design representation tools and the integration of AR technology is suggested. The integration of virtual and physical tools should start earlier in the product development process to effectively use them, and ideally this should be between an initial ideas jury, where students present various alternatives for determining the main design concept, and the preliminary jury, for which the students need to make critical decisions for their design development,.

Product aspects' requirements for AR technology and AR Interaction framework is illustrated to guide AR researchers and developers in order to better develop applications for industrial design field and to guide the students and the tutors in how AR can be used during the product development process. Product aspects' requirements for AR technology is illustrated under six levels; *interaction*, *transformation*, *specification*, *reference*, *display* and *preparation*. Although AR Interaction framework for product aspects is suggested under four main interaction types, it might be difficult to develop real-time demonstrations with the current state of AR technology. However, this will also be possible with the development of the technology. Product aspects' requirements for AR technology and the AR Interaction framework are the first versions and they are illustrated based on the findings of the study that explored the current product development process of industrial design students.

A further study was planned and carried out in order to validate the findings from this study, as well as to explore the effects and potentials AR as a supportive tool in addition to the validation of the benefits of AR, which is presented in Section 3.3.3, for the product development process in industrial design education. While planning the study, the findings taken into consideration can be summarized as follows:

- Using different design representation tools together supporting each other,
- Insights about desk crits, design representation tools, product development process and 3D-modelling,
- Suggested integration of design representation tools into the product development process, and
- Findings about the importance of product aspects that can be represented with AR technology.

This study was carried out as a project in an elective course given in METU Department of Industrial Design. The course was an elective course about digital modelling and fabrication, and the students carried out a project given to them. The project in this course was not as comprehensive as the design studio projects, but it included many project aspects, which were mainly from technic and visual oriented product aspects (mentioned in Section 4.8.5), to be considered during product development process. For the project given for the course, AR technology was integrated as a supportive design representation tool and the other design representation tools were also integrated at earlier stages of the product development process.

CHAPTER 5

EXPLORING AUGMENTED REALITY AS A SUPPORTIVE DESIGN REPRESENTATION TOOL IN PRODUCT DEVELOPMENT PROCESS

Based on the findings of the previous study, this study aims to make exploration about the effects and potentials of AR technology as a supportive design representation tool during the product development process of industrial design students. In addition, it aims to validate the benefits of AR, which are mentioned in Section 3.2, as advantages of AR for education, for product development process in industrial design education. Therefore, a study was planned in which industrial design students carried out a project in an elective course and were observed during desk crit which was supported with AR technology. As suggested in the previous study, using different design representation tools together supporting each other has power to enhance the students' product development process. AR technology was integrated into the product development process as a supportive design representation tool in addition to other tools; sketching, mock-ups, 3D-models and render. Utilizing different tools together with AR technology is important to find out the effects and potentials of AR for design process. To do so, desk crit session was evaluated with a survey. This chapter mainly presents how this study is conducted and the insights gained from the study.

5.1. Proposed methodology to explore AR experience during the desk crit in industrial design education

After exploring the product development process of industrial design students that aimed to have a well-grounded understanding of their process based on design representation tools and the product aspects, this study focused on the integration of

AR technology into the desk crits based on the findings of the previous study in order to make validation and to further explore the effects and potentials of AR for the product development process. The study is conducted in an elective course with 12 students, third and fourth year undergraduate level industrial design students, in the Fall semester of 2019-2020 in the Department of Industrial Design at the Faculty of Architecture at Middle East Technical University (METU) in Ankara, Turkey. The course, ID430 Digital Modelling and Fabrication, is conducted by two tutors, one full-time instructor (the researcher) and one part-time instructor.

The methodology of the study includes the collection the data through the surveys evaluated by the students and the tutor, and observation of the desk crit by the researcher. The observation was conducted in the last session of the course while the students were presenting their conceptual designs by using sketches, visual mock-ups, digital models, renders and AR applications. It was essential to use AR application to present their design concepts supported with the other design representation tools. Following the observation, the students were asked to fill in the survey about desk crit supported with AR technology, AR application and its possible use for presentations in desk crits and juries during their product development process. The course capacity was for a limited number of the students; therefore, this survey was intended to reveal descriptive statistics in order to make an exploration of the integration of AR technology into desk crits and to suggest directions for future studies.

5.1.1. Schedule of the elective course

The schedule of the elective course is given in Table 5.1. The course included 13 weeks, 4 hours per week. On the first day of the course, the researcher informed the students about the integration of AR into the process and also about the study conducted in the final project. This first week was an introduction and meeting with the students to explain the course, describe what is expected from them and to see their expectations. In addition, the sixth week of the course was national holiday;

thus, there were 11 weeks, which were divided into two parts. The first part included lectures about digital modelling methods, lectures about detailing of the project based on manufacturing methods, fabrication methods, and a small project.

Table 5.1. Schedule of the elective course, in which the study was conducted

Week	Explanations of the weeks
#1	Introduction of the course and meeting with the students
#2	Lecture about methods in a digital modelling software
#3	Lecture about methods in digital modelling software and start first project
#4	Lecture about fabrication method and preparation of the concepts for fabrication
#5	Lecture about details of the project for manufacturing and prototyping
#6	National holiday
#7	Lecture about details of the project for fabrication and start final project
#8	Form generation workshop and start concept modelling
#9	Lecture about details and preparation of the conceptual designs for fabrication
#10	Lecture on AR preparation and giving critiques on their concepts
#11	Pilot study of the study and giving critiques together with physical models
#12	Revising and detailing the model based on physical model
#13	Desk crit session by using sketching, visual mock-ups, 3D-models, renders and AR

The second part of the course, starting after the 7th week, was allocated for the final project. The students were given a consent form with brief information on the study when the project started (Appendix G). The final project started with a form generation workshop which supported the students in generating different concept alternatives quickly with mock-ups and sketching. Then they started modelling few of these concepts that they wanted to develop further. Considering different aspects of the product, such as manufacturing and aesthetics, the students were guided to decide on one of their concepts to continue working on for further developments. After that, one week was allocated to remind the details and to make preparation of the concepts for fabrication. In the 10th week of the course, a lecture was given on how to prepare eDrawings AR application with Solidworks software. On the same week, the students continued on revising and detailing the model based on physical models and tutor critiques. Until the 10th week of the course, the students had sketching, 3D-models, and physical mock-ups. In addition to these design representation tools, they prepared AR application for the following week where the researcher made a pilot study during desk crits. In the 11th week, only three students prepared AR application. The students could use any design representation tool but using AR technology together with the other design representation tools was essential. They were asked to use AR application preferably with a tablet to interact with a bigger screen. In addition, they were told that if they did not have a tablet, the researcher could provide one. However, two of them used their mobile phones instead (Figure 5.1). The tutor in the pilot study was one of the tutors conducting the course.

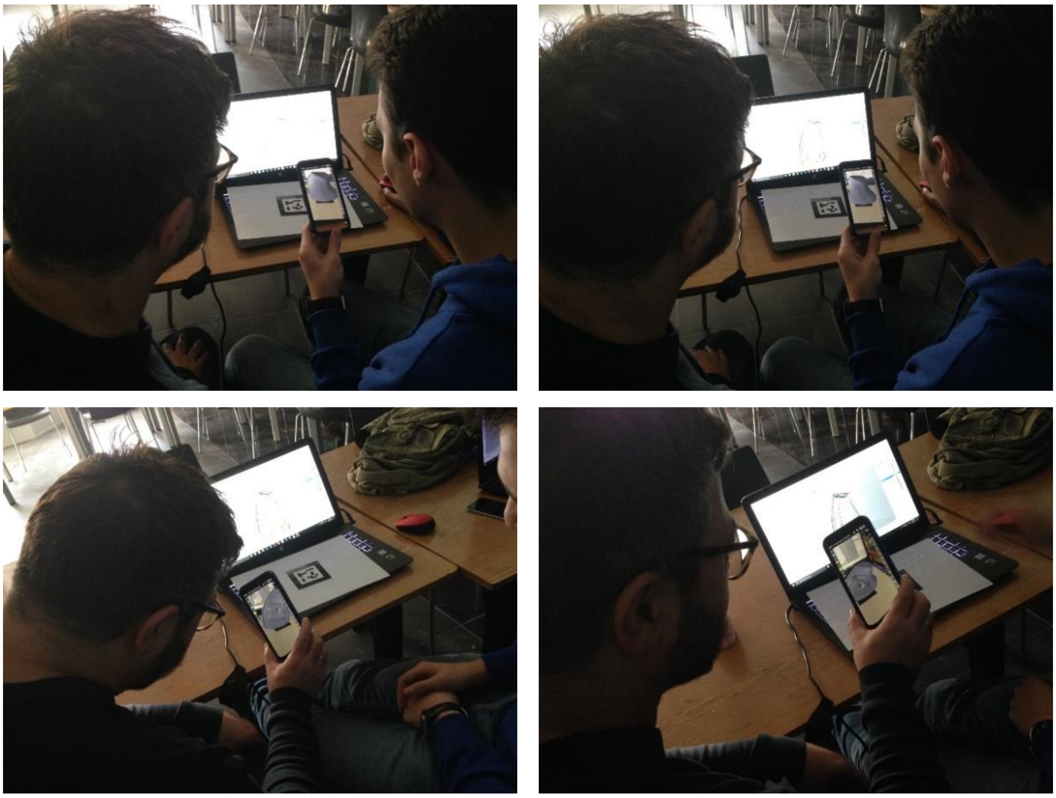


Figure 5.1. Interaction between the student and the tutor during the pilot study

After the pilot study, which the students got feedback from one of the tutors by using AR application together with other design representation tools, they made revisions and continued detailing their design concepts based on physical models and critiques.

After that, the students prepared AR application with the revisions and detailings, and renders of their concepts. All these design representation tools prepared until the final week of the course, namely, *sketching, physical mock-ups, 3D-models, renders* and *AR application,* were utilized during the desk crit session on the 13th week in order to get feedback from a guest tutor. The students made their presentations to the guest tutor from the Department of Industrial Design at METU on the 13th week. AR application was necessary to present their design concepts supported with the other design representation tools like in the pilot study. AR application was presented by using the tablet provided by the researcher. The students were asked to submit their AR applications beforehand and the researcher uploaded all their files in the tablet.

Sixteen students took the course but one of them withdrew because of the workload of other courses she had taken and one of them did not show up in second half of the second part. In addition, two students did not attend the last session. Observing the students during the desk crits took place only on the 13th and final week. The fabrication process to produce CNC models of the students’ concepts was done by the researcher to support the students and to ease the process so that they could spare this time for the preparation of eDrawings AR application of their concepts.

5.1.2. The project and integration of AR into the development process

The project given to the students in the second part of the course was to design a Bluetooth speaker. The inner parts were provided to the students in a way that they could make necessary changes. In other words, the electronic card and the button type were given as an example and they were told that they could change them according to their concepts. In addition, the battery volume was given to them and the dimensions could be changed by keeping the volume same. The dimensions of screws and inserts were standard and they could not make any changes. Furthermore, the students could include more technology or inner parts according to their concept, such as wireless or usb-type charger. The course is an elective course so the project conducted for this study was not as comprehensive as studio projects. However, the project made the students think about many product aspects during the development process considering the limited time dedicated for this course.

Bluetooth speaker project was given to the students because the product aspects that the students needed to consider were mainly technic and visual oriented product aspects, which AR has the most potential as mentioned in Section 4.8.5, such as details, inner parts, form and size. As discussed in Section 4.7.7, the power of using different design representation tools by supporting each other was taken into account. AR application was integrated into the product development process as a supportive tool instead of using this technology as the single tool. When looking at the Design Representation Tool framework, visual mock-up, 3D-model and render are the most important tools for the development of these product aspects during the students' design process. The project took six weeks so that it was an intense process. Starting from the beginning of the process, the project started with an idea generation workshop which supported the students in making quick mock-ups and sketching for concept alternatives. 3D-modelling was integrated into the process to make digital models of two selected concepts in the second week of the project. From the critiques in the third week, the students selected one concept to continue development process. In addition, the students were also taught about how to prepare eDrawings AR application with Solidworks software. The researcher provided them with a detailed guideline including step by step explanations about the preparation of the application with Solidworks and also a guideline about how to use or interact with eDrawings features.

Table 5.2. Relation between design representation tools for each product aspect

product aspects	main tools	supportive tools
usage scenario*	visual mock-up	3D-model
		sketching
		render+graphic
	working mock-up	3D-model
		sketching
user experience*	*is related to usage scenario*	
user interaction*	*is related to usage scenario and user interface*	
emotion*	*is related to usage scenario*	
user interface	graphic	visual mock-up
features/function	*is related to user interface, part(s) and mechanism*	
parts	3D-model	render
	render	writing
physical ergonomics	visual mock-up	3D-model
		sketching
	working mock-up	3D-model
		sketching
	render	graphic
aesthetics/form	3D-model	visual mock-up
	render	visual mock-up
size	visual mock-up	3D-model
		render
		sketching
material/color	render	photo
product configuration	3D-model	mock-up
		render
	render	mock-up
context/environment	render	photo
mechanism	working mock-up	3D-model
		sketching
details	3D-model	mock-up
	render	mock-up
technical standards	*limited information to conclude*	
assembly/set-up	*limited information to conclude*	
inner parts	3D-model	render
	render	writing
technology	3D-model	render
	render	writing
maintenance	*limited information to conclude*	

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*

In the fourth week, physical model of selected concept from foam material, which was machined with 3-axis CNC. The fabrication process was carried out by the researcher to make the process easier for them. AR application was also integrated into the product development process in fourth week and a pilot study was also conducted in this week with all these design representation tools except render. Until the final week, the students made revisions and detailing of their design concept. All these design representation tools were integrated into the product development process step by step considering the DRT framework and all these tools were used together supporting each other during desk crit session with the guest tutor.

Using sketching, visual mock-ups, 3D-models, renders and AR application can enhance the student's explanation of the product aspects developed during the product development process. Based on the findings from the first exploration study (Section 4.7.7), these design representation tools can cover most of the product aspects, such as inner parts, details, aesthetics/form, and size (Table 5.2). AR application can be considered as a 3D-model because it is developed with 3D-modelling.

5.2. Observation during the desk crit session with AR application

The researcher's role in the course is mainly the complete participation (according to Spradley's continuum of participation, 1980) or full membership (according to Adler and Adler's membership roles, 1987) as a full-time instructor of the course (the roles of participation were mentioned in Section 4.2.1). However, the role of the researcher during the desk crit session is moderate participation like the observation study conducted to explore the product development process. This participation is defined as where the researcher is present at the scene, visible to students and interacts with the students occasionally instead of actively participating (DeWalt and DeWalt, 2011). The researcher was also present during the desk crit session of the course to make an observation about AR technology in addition to other design representation tools and interacted with the students when necessary.

The students were observed during the 13th week of the course which was allocated to desk crits to get feedback from the guest tutor by using sketching, visual mock-ups, digital models, renders and AR application. The desk crit of each student took around 15 minutes. Each student was given approximately 8 minutes to make a presentation and the remaining 7 minutes was used for feedback from the guest tutor and his questions to be answered by the students. There was no specific order for the students to appear on desk crit. There were 16 students who took the course at the beginning but one of them withdrew one of them did not show up for the lectures in the second half of the final project and two students did not attend the 13th week. In total, 12 students (7 female and 5 male) were observed. Five students were from 3rd grade and seven students were from 4th year undergraduate level.

The data collected during the observation session are mainly the design representation tools, product aspects explained with these tools, the communication between the student and the tutor during desk crit, and the product aspects supported by AR application. An A4 size observation sheet was used by the researcher in the desk crit session (Figure 5.2), which is similar to the one used in the study for exploring the student's product development processes in the design studio. It included different sections on which to note design representation tools used in explaining the product aspects and the communication between the student and the tutor.

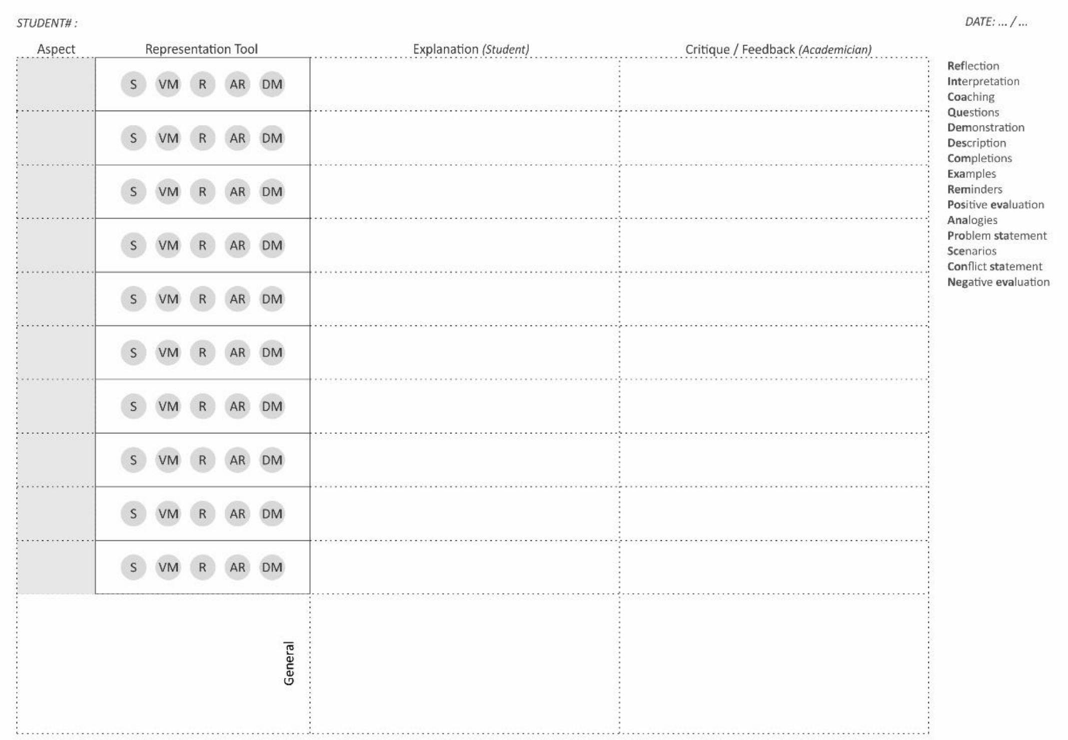


Figure 5.2. Observation sheet used by the researcher in the desk crit session

5.3. Survey: Evaluation of the desk crit session

5.3.1. Data collected with survey

A follow-up survey was conducted immediately after each desk crit with the students and the tutor in order to explore the effects of AR on desk crits and its potentials. The survey given to the students mainly included open ended questions and 5-point Likert scale evaluation. The data collected with 5-point Likert scale evaluation was to reveal descriptive statistics about the evaluation in order to make an exploration about desk crits supported with AR, AR application, and its potentials for design studio projects. Open ended questions were used to explore the benefits of AR used in desk crits, negative issues encountered during desk crits, highlights of AR technology, the advantages of AR when compared to other design representation tools, and the potential use of AR technology during the product development process in design studio projects. In addition, the students were asked to make an evaluation of each product aspect's potential considering the use of AR technology, like in the focus group study carried out in the first study. The survey given to the tutor included open ended questions to make an evaluation about the desk crit session, the students' presentations, AR application, and its use in studio projects.

5.3.2. Format of the survey given to the students

The survey given to the students included eight A4 size pages with two empty pages if the given space would not be enough for the open-ended questions and students would like to add more. This survey mainly consisted of four sections including eight questions and evaluations. The students were asked to fill in the survey by considering the previous desk crits in the course and their previous experiences in design studio sessions. The first part is about evaluation of desk crit supported with AR application. This first part includes five open ended questions;

- What do you think about presenting your design concept by using AR technology together with other design representation tools? What are your experiences? (Please briefly mention.)
- What are the advantages of using AR technology in desk crit to explain the product aspects? (Please briefly mention.)
- What are the negative sides that you experienced when using AR technology in desk crit? (Technical difficulties, difficulty of use, etc.) (Please briefly mention.)
- What are the advantages of AR technology when compared to other design representation tools (sketching, mock-ups, digital models, etc.) and which features can be used in desk crit? (Please briefly mention.)
- If any, what would you like to add about AR technology? (Please briefly mention.)

In addition to open ended questions, the students were asked to evaluate the given statements with a 5-point likert scale (*strongly disagree, disagree, neither disagree* *nor agree, agree* and *strongly agree*). The likert scale evaluation consisted of three parts, evaluation of the desk crit supported with AR application, evaluation of AR application, and the use of AR in the design studio projects. This evaluation is based on an informal version of a questionnaire suggested by Radu (2014) to evaluate AR experiences, in terms of making the representation easier to understand, easy access, directing attention to important points, making to feel immersed in and interaction. Based on his suggestion and the purpose of integration of AR technology into desk crits, the statements were defined. Statements in brief can be seen in Table 5.3. The complete statements can be seen in the complete survey given in Appendix H. In addition to the 5-point likert scale evaluation, the students were asked to briefly explain the reason behind their evaluation of each statement if they could.

Table 5.3. Statements in brief that the students evaluated on desk crit supported with AR

About desk crit	- increased motivation of the student - increased understandability of the concept - increased interaction with the tutor - better feedback during desk crit - more efficient presentation during desk crit - more fun during desk crit
About AR application	- easy to understand - easy to use - 3D realistic concept - directs the attention to important points - easily accessible - easy to interact
About studio projects	- supportive design representation tool - increased motivation during the design process - increased performance during the design process - more understandable concept in the desk crits - efficient desk crits with tutors - interactive desk crits with tutors - better feedback from tutors - positive effects on long-term memory

The third part of the survey aimed to explore the potentials of using AR technology during the product development process in design studio projects. In this part, the students were provided with the different stages of the product development process orderly and were expected to write how AR technology can be used at a specific stage (Figure 5.3). The last part is a 5-point likert scale evaluation of product aspects that can be explained by using AR technology during desk crits (Table 5.4). The complete survey can be seen in Appendix H.

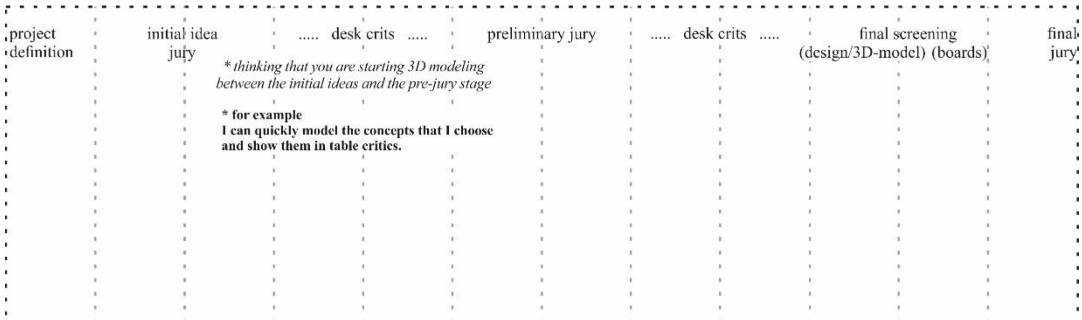


Figure 5.3. Evaluation sheet of potential usage of AR technology in the product development process

Table 5.4. A part of evaluation of product aspects that can be explained by AR application

How important do you think the product aspects given below are explained using AR technology? You are expected to make evaluation for each product aspect.						
Product aspects	*Not applicable*	Not too important			Too important	
Aesthetics/form	○	○	○	○	○	○
Size	○	○	○	○	○	○
Material/color	○	○	○	○	○	○
…	○	○	○	○	○	○

5.3.3. Format of the survey given to the tutor

The survey given to the tutor consisted of five A4 size pages including one empty page in case the given space would not be enough for the open-ended questions and the tutor would like to add more. This survey mainly consisted of three parts including 14 questions. Similar to the students’ survey, the first part was about evaluation of the desk crit supported with AR application. This part included five open ended questions:

- What do you think about the presentation of the students' design concept made by using AR technology together with other design representation tools? What are your experiences? (Please briefly mention.)
- What are the advantages of students in explaining the product by using AR technology in desk crits? (Please briefly mention.)
- What are the negative sides that you experienced when the students were using AR technology in explaining the product in desk crits? (Please briefly mention.)
- What are the advantages of AR technology when compared to other design representation tools (sketching, mock-ups, digital models, etc.) and which features can be used in desk crits? (Please briefly mention.)
- If any, what would you like to add about AR technology? (Please briefly mention.)

In the second part of the survey, the tutor was asked to make an evaluation about presentation. Open-ended questions given to the tutor was about tutor's motivation, understandability of the concept/product, interaction with the student, feedback given by the tutor, and efficiency of the presentation. In the third part of the survey, open-ended questions about AR application and studio processes were asked. These questions were about the tutor's thoughts about AR technology, its potential uses during studio projects in design education, and how AR technology can affect desk crits. The detailed survey can be seen in Appendix I.

5.4. Analysis and findings of the study

As mentioned in Section 5.2, 12 students were observed in total. While analyzing the data collected from the students, it was seen that one of them made the 5-point likert scale evaluation in the same way for all the statements. In other words, each statement and each product aspect was evaluated with the same scale. Therefore, the data of this student was excluded from the analysis. Eleven students were analyzed in total. Documentation and analysis of the data to reach the findings includes three steps; *data documentation*, *coding under categories* and *presentation of the insight* (Figure 5.4).

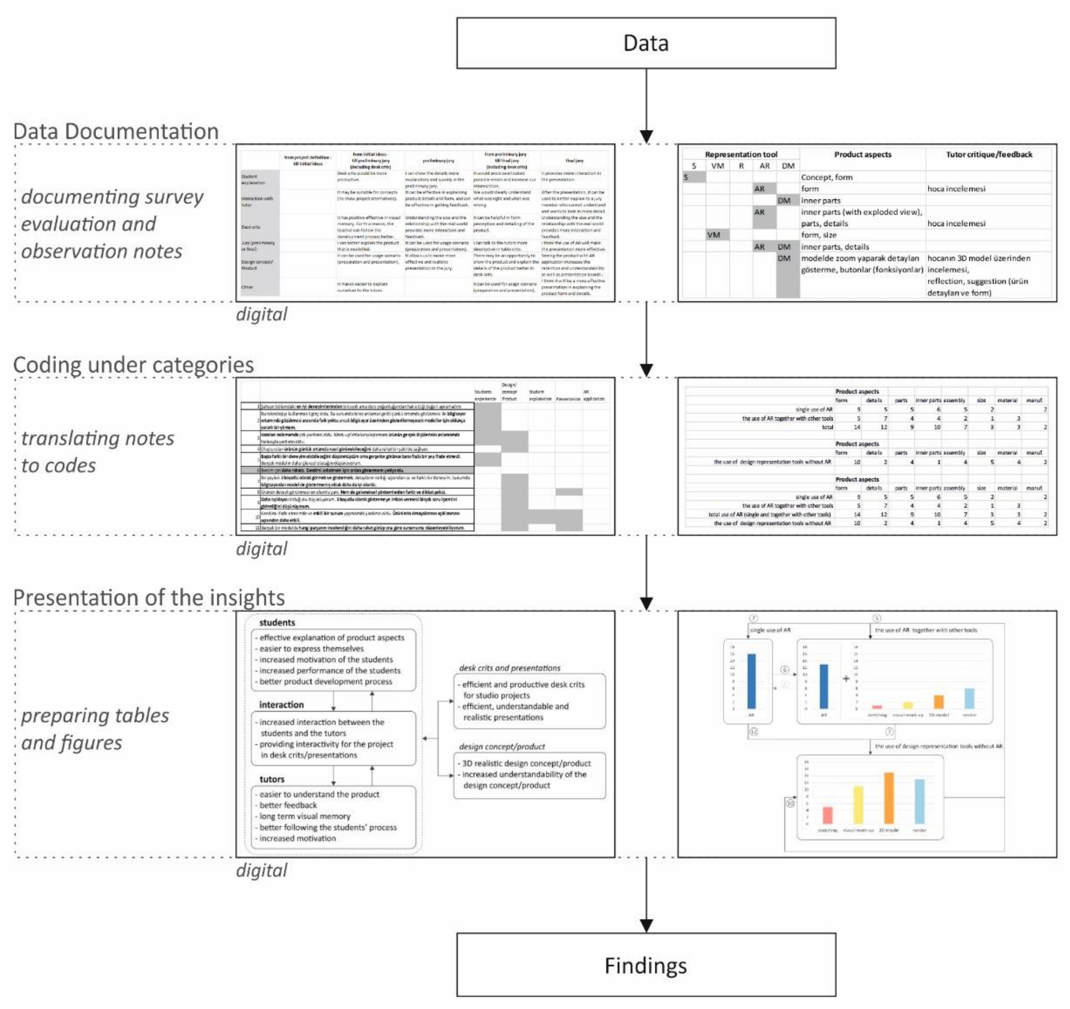


Figure 5.4. The data preparation and analysis process from data to findings

Data documentation is to transfer survey evaluation and observation notes to excel sheets. The data collected from the survey and observation includes qualitative and quantitative data, which was transferred to excel files separately. Then, the qualitative data collected from the survey and observation notes was analyzed based on both open and axial coding (Corbin and Strauss, 1990) while coding this data under categories. The purpose of open and axial coding is to gain insights with analysis of the data by breaking down according to dimensions, comparing the similarities and differences between labels to group them into categories. In addition, it is important to explore the relationship between categories during categorization process. On the other hand, the quantitative evaluation part was to reveal descriptive statistics to reach insights. In the last step, tables and figures are prepared.

The responses to open-ended questions given by the students in the survey were coded under five categories; *students experience, design concept/product, students' explanation, presentation,* and *AR application*. The category of AR application includes positive and negative issues encountered during the desk crit or the process, and advantages when compared to other design representation tools. The insights about the desk crit conducted in the final week of the course will be presented under these categories. Similarly, the evaluation of the potential usage of AR technology during the product development process in studio projects was coded under six categories; *student explanation, interaction with tutor, desk crits, jury (preliminary or final), design concept / product* and *other*. The potentials will be discussed under these categories. The comparative expressions of the students related to insights of the study in the following sections were based on their evaluation that they made by considering the previous desk crits in the course and their previous experiences in design studio sessions.

The students used a 5-point likert scale to evaluate desk crits supported with AR application, AR application, and the use of AR in design studio projects. In addition to this evaluation, they were asked to briefly explain their reasons if they could. Similarly, they used a 5-point likert scale to evaluate the importance of explaining product aspects by using AR technology.

5.4.1. Insights from the students' evaluation survey

The insights were compiled from responses given to the open-ended questions in the survey. These insights are categorized under five themes, namely, *students' experience, design concept/product, students' explanation, presentation,* and *AR application,* which are briefly summarized in Table 5.5.

Table 5.5. Insights from the responses to the open-ended questions in the survey

Students' experience	- the best experience in the department - nice experience to be more realistic with 3D view - showing in 3D removes many question marks - helping the students understand the mistakes - no difference from a digital model but very useful for models that cannot be displayed on a computer
Design concept/ Product	- seeing the product 3D realistically and more detailed - seeing the details and inner parts more clearly and in real size - easier way to see the product in environment in real size - helping the students understand the real dimensions
Students' explanation	- more descriptive/effective in showing/explaining the product and the product aspects - more effective in expressing myself - easier to express ourselves when physical model is absent
Presentation	- remarkable from traditional methods - helping the students make an effective, understandable and realistic presentation - directing my presentation by easily seeing which part is examined
AR application	***positive issues encountered during the desk crit or the process*** - quickly switching between different views - showing the details and different configurations quickly / better - perceiving the product and the parts more easily - showing the desired parts more easily - useful for understanding the details and 3D perception - simple interface
	negative issues encountered during the desk crits or the process - adjusting the angle of the product - having problems with Solidworks - having problems preparing AR application - having problems to set-up assembly for different configurations
	advantages when compared to other design representation tools - providing more visual opportunities - very useful for showing inner parts quickly - understanding/explaining form, volume without mock-up - seeing the product with different configurations (assembly, exploded, section, etc.) quickly in real size - nice to see the product in 3D and as if it is here

5.4.1.1. Students' experiences

When looking at the students' experiences with AR technology, the students, except two of them, had positive experiences during desk crits. Two of them mentioned as their best experience in the department (Table 5.5). This was the first time that the students used AR technology in a desk crit. As an observation of the researcher, utilizing AR technology, which supported their presentations, increased their motivation. This observation is also supported by the students' 5-point likert scale evaluation about the desk crits supported by AR technology. In addition, using AR application was a positive experience to be more realistic with 3D view. Showing the product in 3D view with AR technology removed many question marks during desk crits. Furthermore, this experience helped the students better understand the mistakes during desk crits. Realistic 3D view, decreased question marks and better understanding the mistakes supported the presentation of the students.

On the other hand, one of the students mentioned that she thought it would be a different experience at first, and did not mean much to her when she saw it. In addition, another student mentioned that there seemed to be no difference of AR from a computer but it would be very useful for the models that could not be displayed on a computer. While evaluating motivation in the desk crit part of the 5-likert scale evaluation, the same student mentioned that there might be a problem with AR application, related to usability or technicality. As an observation of the researcher, the student did not feel that she managed to prepare a fully working AR application. Although she had no problems with AR technology while presenting her product during the desk crit, this feeling decreased her motivation and consequently her experience.

5.4.1.2. Design concept or product

When looking at the insights about the design concept or product, it can be summarized in four main headings. Seeing the product 3D realistically and in more detail is the first one. Although a visual mock-up provides a 3D view of the product, it is not as detailed as AR application. On the other hand, a digital model is a detailed 3D view in a 2D screen, thus it does not give the same feeling as an AR application. 3D realistic and detailed view of AR application is an advantage compared to what visual mock-ups and digital models can somehow provide.

Seeing the product aspects more clearly and in real size is the second insight related to the design concept or product. The product aspects that the students mentioned were mainly product form, details, inner parts, and product size. The project given to the students for the elective course covered these product aspects more specifically. When the students will experience AR technology with different projects in which they need to consider different product aspects, they might positively experience AR for the other product aspects as well. This requires further studies to conclude the insights for other product aspects.

The third insight is that AR provides an easier way to see the product in its environment in real size. Although is not exactly clear what the students mean but this can be considered in two different ways. The first one is to see the product in the desk crit environment in its real size while explaining. The second one is that students used AR application to see the product in a real environment before the desk crit session. Both cases bring about an advantage of using AR technology.

The final insight is to help the students understand the real dimensions. When it takes too much time to prepare a visual mock-up to see the dimensions of the product, AR application can easily help students understand the real dimensions.

5.4.1.3. Students' explanations during desk crits

When looking at the insights about the students' explanations during desk crits, AR technology was considered as more descriptive and effective in showing and explaining the products or the product aspects. Like the positive effects on the design concept or product, AR application contributed positively to the students' explanations about the product and its aspects. Similarly, AR technology was also considered as more effective in students expressing themselves. In addition, it was easier for students to express themselves when a physical model was absent. As an observation of the researcher, better explanation of the product and its aspects and better self-expression of the students contributed to effective presentations.

5.4.1.4. Presentation

When looking at the insights about presentation, the students mentioned that AR technology helped them make an effective, understandable and realistic presentation. They also mentioned that they directed their presentation by easily seeing which part is examined. Furthermore, AR technology was considered as a remarkable way to make presentations compared to traditional methods.

Although the insights are presented in different categories, they cannot be considered as irrelevant from each other. The insights are somehow related to each other. For instance, one of the students responded to one of the open-ended questions related to the experience with AR technology, "AR is more effective in explaining the details of the products. It helped me better express myself and make an effective presentation". This shows that AR has a positive effect on the relationship between the product or product aspects, the students' explanation, and presentation. Another student response was "it was much more descriptive to show and explain my product. It was a nice experience to be more realistic instead of showing with a picture. It allowed me to go beyond the classical presentation methods". This response also supports this relationship between different categories.

5.4.1.5. AR application

The last category is about the insights on AR application; positive issues encountered during the desk crits or the process, negative issues encountered during the desk crits or the process, and the advantages of AR application when compared to other design representation tools. The positive issues encountered during desk crits are mainly the insights related to the usage of AR application and the insights about perception and understandability. These insights are as follows:

- AR application has a simple interface.
- The students quickly switched between different views.
- They showed the details and different configurations quickly and better.

- They showed the desired parts more easily.
- The product and its parts are perceived easily.
- AR application is useful for understanding the details and supports 3D perception.

When looking at the negative issues encountered during desk crits or the process, three of the students mentioned that they had no problems and one of the students mentioned that adjusting the angle of the product was difficult while using AR application during desk crits. The insights from the responses of other students are mainly related to software and preparation problems. One of the problems that the students encountered was related to the Solidworks software. In addition to that, they also had problems while setting up assembly for different configurations and while exporting the files to the AR application. It was the first time that most of the students used this software. Although the students were instructed about the preparation process and the necessary documents were given to them, it seems normal for them to have had problems with a new program that they had just started to use. If they had been used to use this program before, they would have had less problems.

When looking at the advantages of the AR tool over other design representation tools, the insights are as follows:

- AR application provides more visual opportunities.
- It is very useful to show inner parts quickly.
- It helps the students understand and explain form, volume and proportions without mock-ups.
- It provides to set up the products with different configurations (assembly, exploded, sections, etc.) quickly in real size.
- It is nice to see the product in 3D and as if it is here.

The insights related to product aspects seems not to cover as many aspects as mentioned in the insights of the study exploring the product development processes of industrial design students in a studio project. As mentioned in Section 5.1.2, the course, in which the study was carried out, is an elective course; thus, the project conducted for this study was not as comprehensive as studio projects. However, considering the limited time, the project all the same encouraged the students to think about the related product aspects during the development process.

5.4.2. Insights from the 5-point likert scale evaluation in the students' survey

The 5-point likert scale evaluation includes three parts, *evaluation of desk crits supported with AR application, evaluation of AR application* and *use of AR in design studio projects*. The evaluation was done based on the statements, which are already given briefly in Table 5.3 (Complete statements in Appendix H).

5.4.2.1. Evaluation of desk crits supported with AR application

The statements evaluated for the desk crit supported with AR application was about *increased motivation of the student, increased understandability of the concept, increased interaction with the tutor, better feedback during desk crit, more efficient presentation during desk crit* and *more fun during desk crit.*

Increased motivation of students: Four students strongly agreed and five students agreed that presenting the design concept with AR technology during desk crits increased their motivation (Figure 5.5). The students explained the reasons behind this as trying out a different method for the first time, and having a future-oriented experience. Similarly, using a different technology increased their motivation. In addition, it was very useful for the students to see every detail instantly. It also provided an advantage to the presentation because AR supports to show the product more realistically. On the other hand, the student who disagreed about increased motivation explained that it reduced her confidence in case there might be problem. Although she had no problems with AR technology while presenting her product during the desk crit, the feeling she had that there might be a problem at any moment decreased her motivation. She also used AR technology for the first time. It is believed that once she gains further skills in utilizing this technology, the negative feelings will disappear, resulting in better experiences.

Increased understandability of the design concept: When looking at the increased understandability of the design concept, seven students strongly agreed and three students agreed that presenting the design concept with AR technology during the desk crit increased the understandability of the design concept (Figure 5.5). The students who made an explanation for this statement told that AR enabled them to explain the product form, volume of the product and inner parts more easily. In addition, it enabled to control product form and size from different angles. Understandability also increased in terms of showing details. Seeing the model in a 3D environment was helpful to increase understandability. These were the explanations of the students supporting the increased understandability of the design concept.

Interaction with the tutor: For the statement on the interaction with the tutor, all the students, except one, either strongly agreed or agreed that presenting the design concept with AR technology during the desk crit increased the interaction with the tutor (five students strongly agreed and five students agreed) (Figure 5.5). One of the reasons that increased the interaction was that utilizing AR together with a physical model could provide direct interaction with the tutor because it became a more understandable presentation. In addition, problems about the design concept were more clearly understood, allowing the students to communicate better. One of the students explained that he was able to answer questions faster.

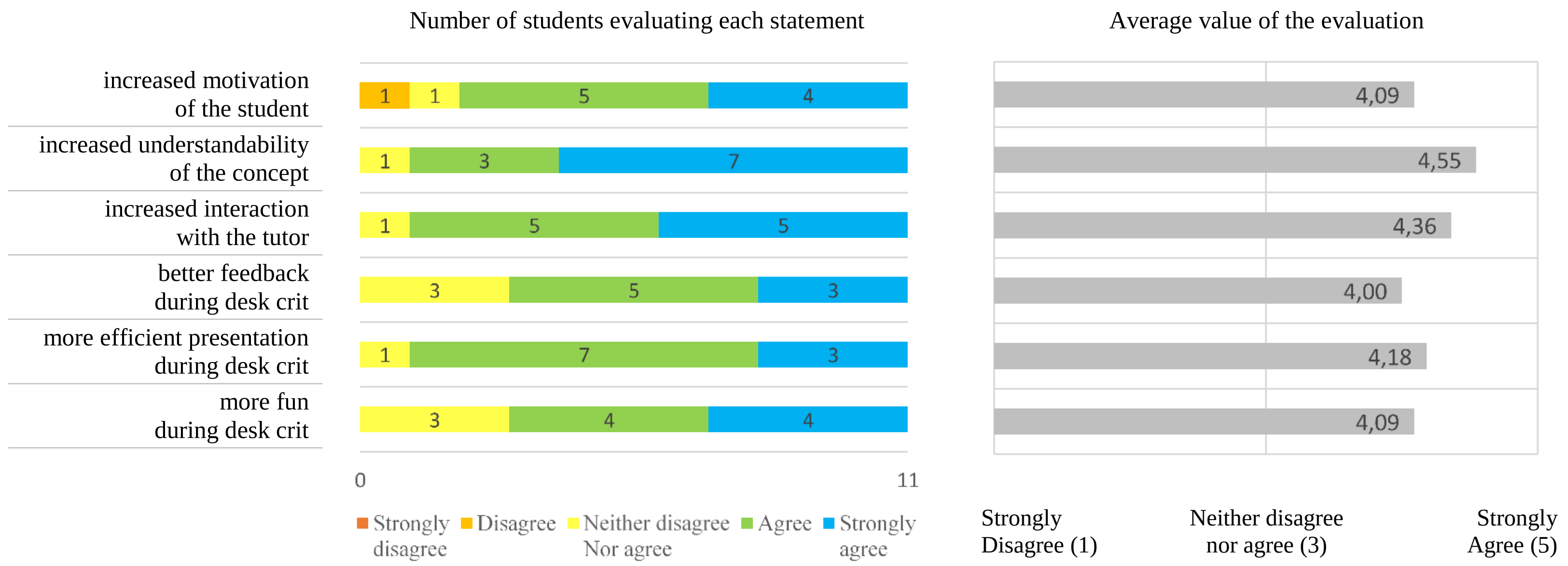


Figure 5.5. Insights of the evaluation of desk crit supported with AR application

Better feedback during the desk crit: When looking at the statement on better feedback during the desk crit, three students strongly agreed and five students agreed that presenting their design concept with AR technology during the desk crit enabled them to get better feedback. (Figure 5.5). Among these students who made an explanation, one student explained that the product was clearly discussed since the form was more easily perceived. In addition, other students explained that AR helped them see and learn the problems about their design concept more clearly and easily. On the other hand, three students neither disagreed nor agreed on better feedback. One of them mentioned that there was no comment made on the design concept. As an observation of the researcher for this student, AR increased the understandability and the design concept was successful so that the tutor did not comment as much as he did for other students.

More efficient presentation during the desk crit: For the statement on more efficient presentation during the desk crit, three students strongly agreed and seven students agreed that presenting the design concept with AR technology during the desk crit was more efficient (Figure 5.5). Apart from these, only one student explained that it has reduced time-consuming details, such as the production of the model, and shortened the presentation time.

Fun during the desk crit: As for the evaluation of students on having fun during the desk crit, four students strongly agreed and four students agreed that presenting the design concept with AR technology during the desk crit was more fun. On the other hand, three students neither disagreed nor agreed on the desk crit being fun. Similar to efficient presentation, only one student explained that it was exciting because it was different from traditional methods. For this statement, using the term “exciting” would be more proper instead of “fun”.

5.4.2.2. Evaluation of the AR application

To evaluate the AR application, the statements given to the students in the survey were: *easy to understand, easy to use, 3D realistic concept, directing the attention to important points, easily accessible* and *easy to interact with*.

Easy understandability of the AR application: One student strongly agreed and five students agreed that the AR application was easy to understand (Figure 5.6). Among these students, two of them explained that its interface was understandable and very clear for people who are used to using such programs. On the other hand, while one student disagreed on the easy understandability of the AR application, four students neither disagreed nor agreed on this statement. Among these students, it was mentioned that they had difficulty in choosing the parts that it worked slowly, and that it needed improvement. In addition, one student explained that getting used to the AR application is necessary. The researcher has a similar observation. Many students did not experience enough before the desk crit session in which the students used the AR application. Like other similar applications, it is important to gain experience in order to get used to the AR application. The results related to this statement on understandability would have been different if the students had gained experience before the desk crit session.

Easy usage of the AR application: One student strongly agreed and eight students agreed that AR application was easy to use (Figure 5.6). There was only one explanation made among these students, stating that the AR interface was easy and understandable. Similar to the statement on easy understandability, this evaluation would have been positively different if the student had gained experience and got used to using the AR application enough before the desk crit session. Although it seems be an easy-to-use AR application, more time is required for the students in order to get used to it.

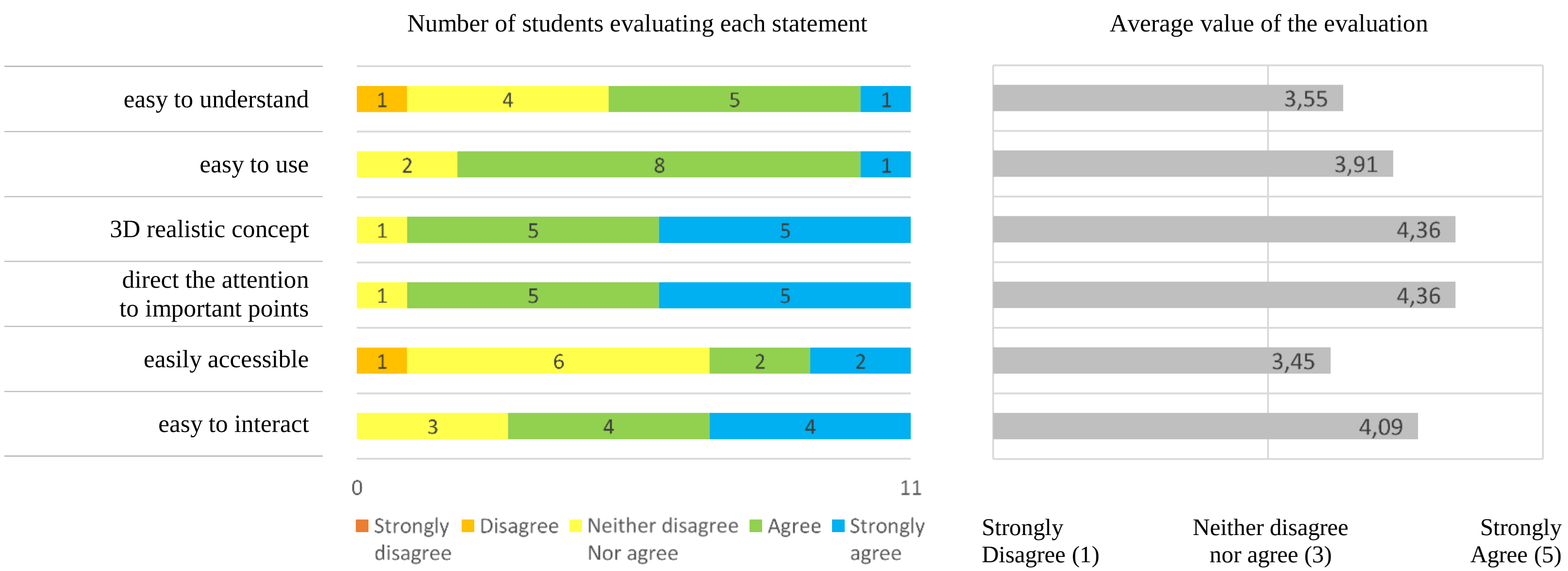


Figure 5.6. Insights of the evaluation of AR application

3D realistic concept: Five students strongly agreed and five students agreed that the AR application enabled them to feel the design concept 3D realistically. One student neither disagreed nor agreed (Figure 5.6). There was no explanation about 3D realistic concept that the students mentioned. The evaluation of the students shows that AR provides to see the design concept digitally in 3D and as it is in the desk crit environment.

Directing the attention to important points: Similarly, five students strongly agreed and five students agreed that the AR application directed the attention to important points. One student neither disagreed nor agreed (Figure 5.6). The explanations about this statement were that the section view showing the interior parts took attention and the application was very useful for focusing on a part.

These two features of the AR application (3D realistic concept; directing the attention to important points) were the best evaluated ones.

Easily accessible: The evaluation results show that the AR application is not easily accessible. One student disagreed and six students neither disagreed nor agreed with this statement (Figure 5.6). The explanations behind this evaluation were that many people do not know about AR, application is paid for albeit its small price, and it requires another software. With the development of new applications that can be used for industrial design, this application will become more accessible. In addition, using another software made it a little difficult for the students to prepare the AR application because most of them were not used to using this software. Like all other applications, an application can have a free version that supports fewer features. Therefore, investing on an AR application that can support desk crits during the product development process for a small price seems feasible. For AR developers, it would be helpful to consider developing a student version that can be used in education.

Easy to interact with: Four students strongly agreed and four students agreed that the AR application was easy to interact with (Figure 5.6). There was only one explanation made for this statement, indicating that it was very easy to use and understand during the desk crit. On the other hand, there was another explanation made by one of the students who neither disagreed nor agreed. It was about the problems with the interface while using the AR application during the desk crit. Similar to the evaluation made on the statement of easy to understand, the reason behind this might be that the students did not have enough experience with the AR application before the desk crit session. It is essential to get used to the AR application in order to be able to use it fluently during the desk crit. The evaluation of the students on interaction with AR application would have been positively different if they had gained enough experience beforehand.

5.4.2.3. Evaluation on how the AR application can affect studio projects

To evaluate how AR application can affect studio projects, the statements given to the students in the survey was about *supportive design representation tool, increased motivation during the design process, increased performance during the design process, more understandable concept in the desk crits, efficient desk crits with tutors, interactive desk crits with tutors, better feedback from tutors,* and *positive effect on long-term memory.* These statements were positively evaluated and evaluations are very close to each other, except for the two following statements; *increased motivation* and *increased performance during the design process* (Figure 5.7). These two statements were evaluated less positively than the other statements.

Motivation during the process: There are two explanations given for the statement related to motivation, one positive and one negative. While one student explained that the integration of AR and new technologies into the design studio brings new excitement, another student mentioned that it might a bit difficult process because it will take time to adapt. When the students will start to adapt AR technology, it will contribute to increased motivation.

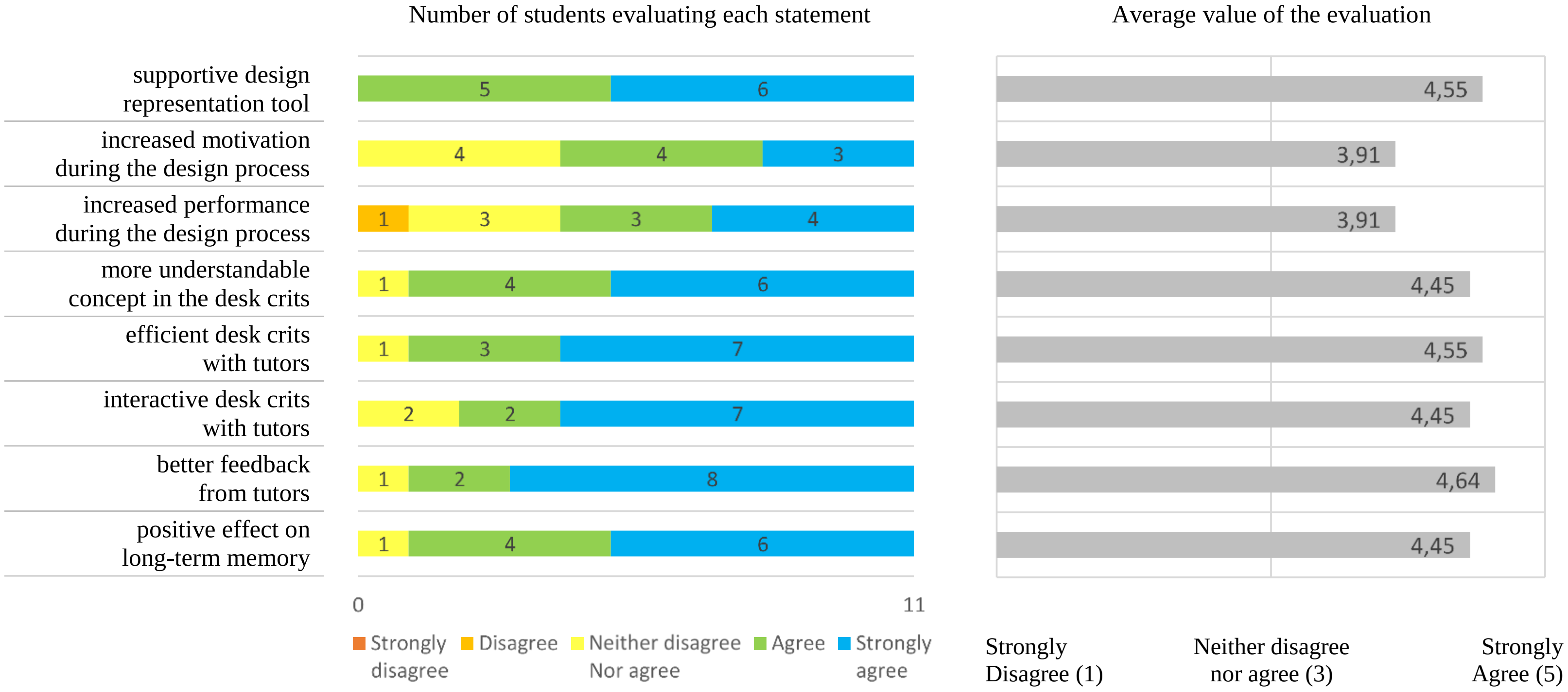


Figure 5.7. Insights of the evaluation of how AR application can affect studio projects

Performance during the process: Similarly, one positive and one negative explanation was stated about the performance by the students. While one student explained that AR can provide a faster product development process, another stated that AR will not work well if the digital model is not right. Their performance could have been affected from these aspects. It is obvious that the AR application needs a digital model and the students learn about digital modelling during their education. However, their digital skills can be different. But they manage to prepare their 3D models for digital fabrication, such as CNC machining and 3D prototyping. This shows that they can also manage to prepare 3D models for AR application.

***Supportive design representation tool and more understandable concept in desk crits*:** For these statements, more than half of the students strongly agreed. All students either strongly agreed or agreed with the statement related to supportive design representation tool whereas only one student neither disagreed nor agreed for more understandable concept in desk crits (Figure 5.7). This shows that AR technology has great potentials for these statements. AR technology can be a supportive design representation tool that can be used in desk critics. According to an explanation of a student, AR accelerated the process by removing many question marks to be asked during the desk crit. In addition, it was also mentioned that using AR technology in studio projects could make the design concept more understandable during the desk crits with tutors. The explanations show that AR supports to consider product form, size and details, as sometimes mock-ups cannot be made. Usage scenario implementation with AR can improve this process.

Efficiency and interactivity of the desk crits: Similarly, more than half of the students strongly agreed for these statements. Only one student neither disagreed nor agreed for efficiency whereas two students neither disagreed nor agreed with the statement related to interactive desk crits with tutors (Figure 5.7). The evaluations and explanations show that using AR technology in studio projects can make the desk crits with tutors more efficient and interactive. The explanations that support these statements were:

- *“I believe that it will reduce the time loss during desk crit to zero.”*
- *“It can be more efficient for tutors to understand.”*
- *“It accelerates the process.”*
- *“I think desk crits will be more understandable.”*
- *“Being able to explain a project better definitely increases the interaction.”*

Efficient and interactive desk crits can definitely improve the students’ product development process.

Better feedback from tutors **and** ***positive effect on long-term memory:*** Like other statements, more than half of the students strongly agreed for these statements. Only one student neither disagreed nor agreed for both statements (Figure 5.7). Desk crits supported with AR technology in studio projects can enable better feedback from tutors. Although there is no explanation stated by the students, their evaluation supports better feedback from tutors during desk crits. In addition, desk crits supported with AR technology in studio projects might have positive effects on long-term memory, which is important for tutors to remember the students’ projects. It has positive effects since most people in the department are visually improved, which is stated by one of the students. In addition, another student explained that it would be useful to see it as a real product with the environment. These were the insights about the evaluation on how AR application can affect the studio projects, resulting in great potentials of AR technology.

5.4.3. Insights on the potentials of AR for the product development process

In addition to the potentials of AR technology given in the previous section (5.4.2), the students were also asked to write about how AR technology can be used at different stages of the product development process on a sheet provided with the different stages of the product development process orderly (this sheet can be seen in Figure 5.3, in Section 5.3.2, p. 217). Similar to the responses given to open-ended questions, the responses given to this question were transferred to an excel file. The responses to this question were coded under five different categories, namely *student explanation, interaction with the tutor, presentation at desk crits and juries, design concept/product*, and *memorability and understandability*.

Student explanation: The responses of the students show that AR technology can support the students in explaining the product and product aspects better, easier and effectively. In other words, their explanations can be better and effective during desk crits by using AR. Similarly, they can talk to the tutors more descriptively during desk crits. In addition, it can also help the students better explain to a jury member during their presentations, as stated by one of the students. The quotations of the students supporting these insights can be seen in Table 5.6.

Interaction with the tutor: When the students' explanation is better and effective, this might positively contribute to the interaction with tutor. The responses support this contribution, such as "*it can be effective in getting feedback*" and "*our interaction with tutors increases …*". The potentials of AR, such as seeing as 3D in a desk environment and exploring the product form, provide better feedback and more interaction. This can occur both during desk crits and presentations, as it can be seen from the responses of the students about interactions with tutors in Table 5.6.

Efficiency of presentations at desk crits and juries: The students mentioned that desk crits will be more productive and effective with the use of AR technology. Similarly, according to them the presentations in the juries will be more effective and realistic. Showing the product aspects more explanatorily and quickly, interactivity of AR, increasing interaction with tutor by using AR, seeing the product in the desk environment and similar potentials of AR support productivity, effectiveness and being realistic (Table 5.6).

Table 5.6. Insights of AR potentials during the product development process

Student explanation	- "I can ***better explain*** the product …" - "It makes it ***easier to explain*** ourselves to the tutors" - "I can show the details ***more explanatorily and quickly*** …" - "It can be ***effective in explaining*** the product …" - "There may be an opportunity to show the product and ***explain*** the details of the product ***better*** …" - "I can talk to the tutors ***more descriptively*** in table crits" - "… the use of AR at desk crits will make the ***explanations more effective***" - "It can be ***effective in explaining*** the details, form …" - "After the presentation, it can be used to ***better explain*** to a jury member who cannot understand …"
Interaction with tutor	- "It can be effective in ***getting feedback***" - "Understanding the size and the relationship with the real world provides ***more interaction*** and ***feedback***" - "Our ***interaction*** with tutors ***increases*** and desk crits will be more productive" - "It provides ***more interaction*** in the presentation"
Presentation at desk crits and juries	- "Desk crits would be ***more productive***" - "… AR will make desk crits ***more effective***" - "Our interaction with tutors increases and desk crits will be ***more productive***" - "Seeing our product as if it were really there will ***increase the effectiveness*** of desk crits" - "I can show the details ***more explanatorily and quickly*** in the ***preliminary jury***" - "It allows us to make a ***more effective and realistic presentation*** in the jury" - "It provides ***more interaction in the presentation***" - "… the use of AR will make the ***presentation more effective***"
Design concept/ product	- "It may be suitable for concepts to show ***concept alternatives***" - "It can be used for ***usage scenario*** (***preparation and presentation***)" - "Understanding the ***size*** and the ***relationship with the real world*** …" - "It can be helpful in ***form perception*** and ***detailing*** of the product" - "It helps me explain the ***inner parts*** of the product better" - "It can be effective for the ***details, form, size***, etc."
Memorability and understandability	- "It has positive effects on ***visual memory***. For this reason, the teacher can ***follow the development process better***" - "It allows us to quickly model multiple ideas in 3D and ***understand*** which one is ***more realistic***" - "It could avoid overlooked ***possible errors*** and increase our ***intervention***" - "We could clearly ***understand*** what is ***right*** and what is ***wrong***" - "It can make us easily see the ***points*** that we need to ***improve*** …" - "Seeing the product with AR application ***increases the memorability*** and ***understandability*** …"

Design concept/product: The insights about the design concept or the product are mainly about the product aspects that the students consider during their product development process and explain during desk crits. The product aspects indicated in the responses were mainly related to the project given to the students for the course. These product aspects were product form, product size, details, inner parts and relationship with the real world, namely environment. AR can be helpful and effective for students to show and explain these product aspects (Table 5.6). In addition to these product aspects, the students also mentioned project alternatives and usage scenarios. AR can be used for concepts to show project alternatives and to prepare and present usage scenarios.

When the students were responding to the question of how AR technology can be used at different stages of the product development process, it is obvious that the responses about the design concept/product were mainly related to the project given to them for the elective course. The insights will cover more product aspects when AR is integrated into design studio projects and different projects for which the students need to consider different product aspects.

Memorability and understandability: The students also mentioned about the effect of AR on memory and personal intervention for the product development process. "*It has positive effects on visual memory. For this reason, the teacher can follow the development process better*" and "*Seeing the product with AR application increases the memorability and understandability …*" are the student responses that show the effects of AR on memory and its advantages for desk crits (Table 5.6). In addition, students mentioned about the advantages of AR for their process. AR can be used to understand which concept is more realistic among different alternatives by quickly modelling them. Similarly, one student mentioned that "*we would clearly understand what was right and what was wrong*". Furthermore, AR can help the students pay attention to the overlooked possible errors and the points that they need to improve (Table 5.6). These were the insights coded in five categories from the responses of the students.

5.4.4. Insights of the product aspects explained with AR technology

In this section, the insights of the evaluation about the importance of product aspects explained with AR technology will be presented. When looking at the insights (Figure 5.8), the product aspects can be grouped into three: product aspects with an average value over important (over 4), product aspects with an average value close to important (over 3,50 and under 4) and product aspects with an average value under important (under 3,50).

Group 1: The product aspects in the first group with an average value over important are orderly: details, size, inner parts, assembly/set-up, aesthetics/form, parts, user evaluation and mechanism (Figure 5.8). As results showed for most of these product aspects in the previous sections, AR technology has great potential in explaining these product aspects during desk crits or presentations. User evaluation and mechanism are the product aspects evaluated over important, which the students did not consider during the product development process in the project given for the course.

Group 2: The second group, which has an average value close to important, includes the product aspects for which results were not much obtained in the previous sections. These product aspects were, technical standards, usage scenario, user experience, feature/function, user interaction, physical ergonomics, environment, design concepts and user interface (Figure 5.8). Among these product aspects, there were insights about usage scenario for which AR can be used to prepare and present, product ideas to show alternatives with AR or to quickly 3D model them in order to understand which one is more realistic. In addition, environment was positively mentioned by the students in terms of both desk crit environment and real environment. Most of the product aspects in this group are those that the students did not consider much during the project given to them. Therefore, the evaluation would have been different if the students had carried out a project in which they needed to consider these product aspects. When they experience AR technology to explain these product aspects, their evaluation will definitely be clearer.

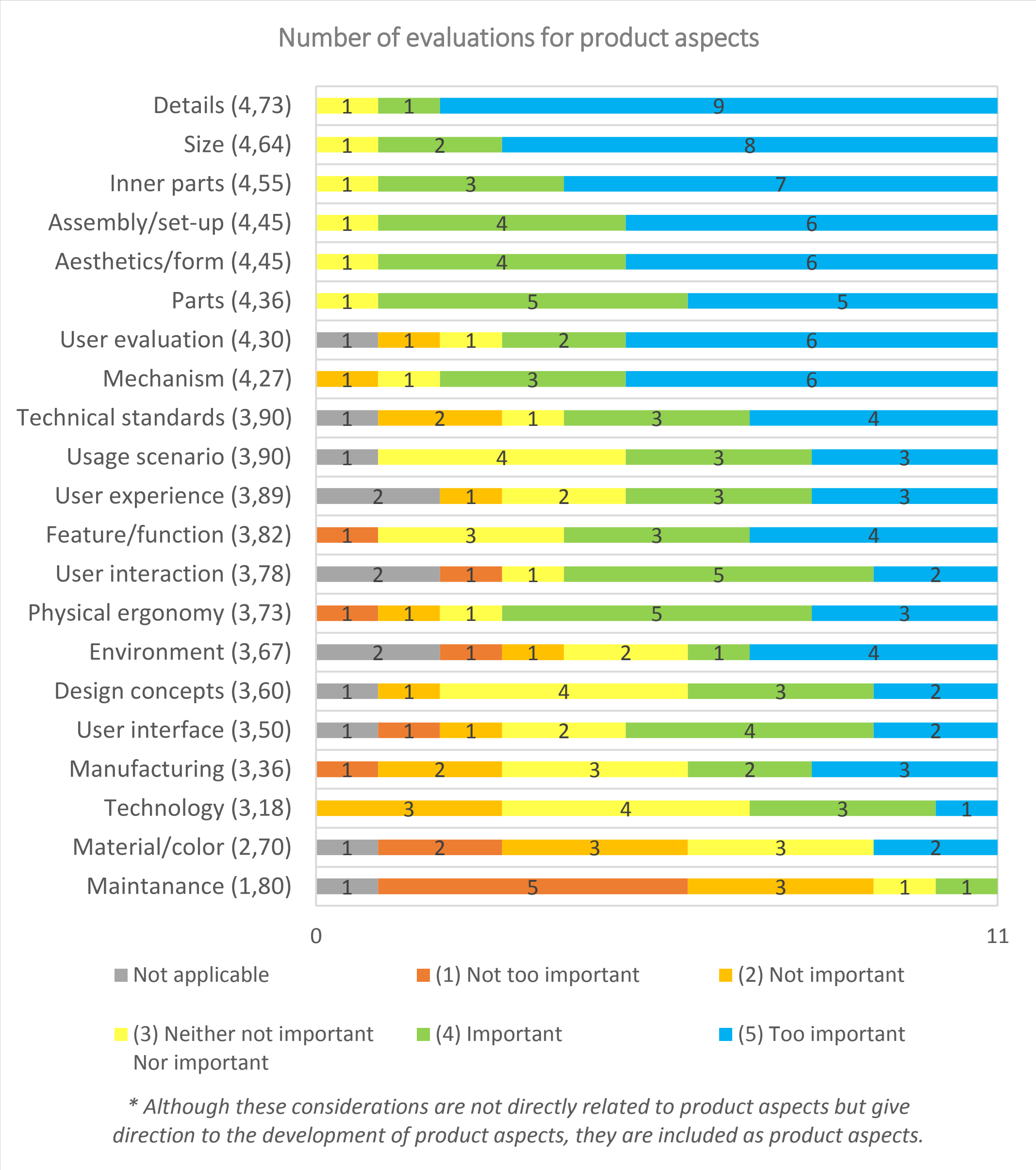


Figure 5.8. Insights of the evaluation about the importance of product aspects explained with AR technology

Group 3: The product aspects in the third group are the ones that can be considered as not important to explain with AR technology. These product aspects are, from higher to lower average value, manufacturing, technology, material and maintenance. Although material seems to have a lower average value when looking at the students' evaluation, material can also be integrated into AR applications with the development of AR technology. With this integration, the students' opinion could change with experience.

5.4.5. Insights from the observation session

Data collected during the observation session are mainly on the design representation tools, product aspects explained with these tools, and feedback given by the tutor. These data taken during desk crits, in which the research was conducted, was transferred to an excel sheet based on axial coding (Corbin and Strauss, 1990) under three categories; design representation tools, product aspects explained with these tools, and feedback given by tutor. Based on AR technology, the relationship between the design representation tools was analyzed. In addition, the product aspects explained with the single use of AR or with the use of AR together with other tools were analyzed. Similarly, product aspects explained with the use of design representation tools without AR were also analyzed. These insights will be presented in this section.

Before presenting the use relations between design representation tools based on AR technology, Figure 5.9 illustrates the number of single or multiple use of design representation tools and how many times the students switched between different design representation tools. Single use is the use of only one design representation tool to explain a product aspect while multiple use is the use of different design representation tools together to explain a product aspect. When the student changed or switched the design representation tools used during desk crits, or integrated another design representation tool to explain a product aspect, this was counted as a new use. For each student, this switch between different design representation tools or integration of other design representation tool was counted. While the average value for single use of design representation tools is 3,0, the average value for multiple use of these tools is 2,1. Single use of the design representation tools is either equal to or more than multiple use. Both uses of these tools were preferred during desk crits. While the minimum number of single and multiple uses in total was 4, the maximum number was 8 (Figure 5.9). The average value for the total switch between design representation tools is 4,1 (Figure 5.9).

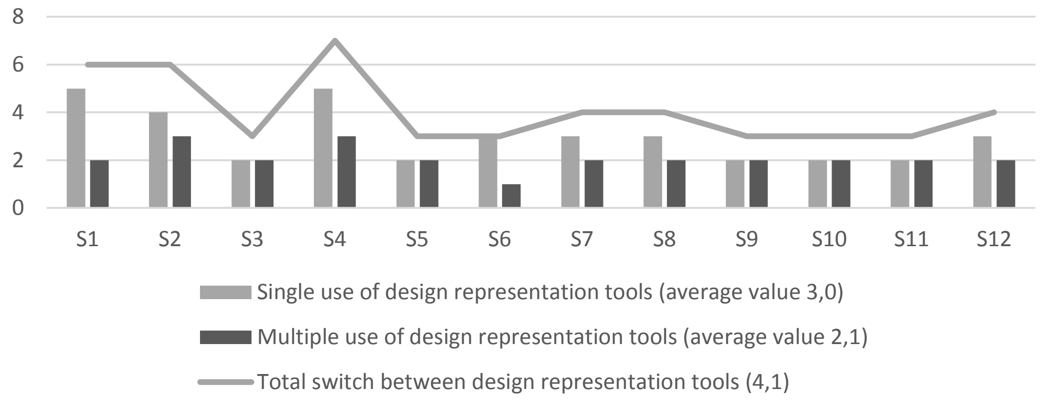


Figure 5.9. Single or multiple use of design representation tools and switches between these tools

When looking at the insights about the relationship between design representation tools based on AR technology, the use of these tools can be grouped into three; *single use of AR*, *use of AR together with other tools* and *use of design representation tools without AR*. The relations between different uses and the frequency of them is seen in Figure 5.10. Nine students started their presentation by using AR, six of them preferred single use and three of them preferred use of AR together with other tools. On the other hand, three students started their presentation by using other design representation tools, one single use and two multiple use of these tools. As a starting point for their presentation, use of AR was preferred, either as single use or together with other tools. Students switched between different uses, to support their explanations with different design representation tools, to explain a new product aspect, and to answer the question asked by the tutor. Different design representation tools gave the students flexibility in switching between different tools to support the process, which leads to many advantages as mentioned in Sections 5.4.1-5.4.4.

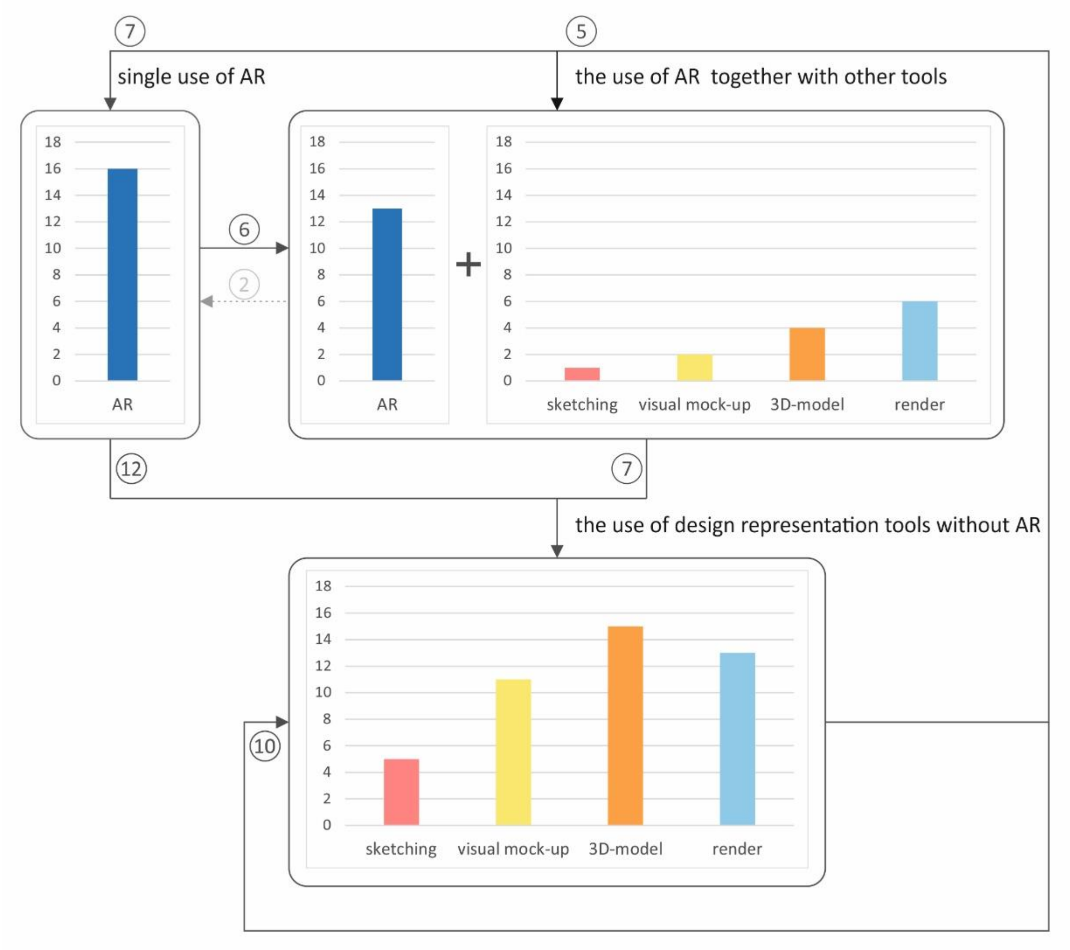


Figure 5.10. Use of design representation tools during the desk crit session

As it can be seen in Figure 5.10, when the students preferred single use of AR, they switched to different uses, by either integrating another design representation tool in addition to AR or by using other tools except AR. Although it seems to be a two-way transition between single use of AR and the use of AR together with other tools, the switch from use of AR together with other tools to single use of AR was seen only two times. From each use of AR, either single or together with other tools, the students switched to the use of design representation tools without AR.

When looking at the switches from the use of design representation tools without AR, the students switched to use of AR, either single use or together with other tools, and changed the design representation tools used during their presentation. The frequency of switching from the use of design representation tools to the use of AR (12), either single use (7) or together with other tools (5), and the frequency of changing design representation tools excluding AR (10) are very close to each other. When looking at the frequency of different uses, single use of AR was preferred 16 times and the use of AR together with other tools was preferred 13 times. While AR, either single use or together with other tools was preferred 29 times in total, the use of design representation tools without AR was preferred 32 times in total; 20 single use and 12 multiple use of these tools. Although the frequency of different uses seems to be closer each other, the difference is clearer when looking at the insights about product aspects.

The students mainly preferred the use of AR, either as single use or together with other tools, to explain most of the product aspects. In addition, when they preferred using AR together with other tools, they explained the product aspects which they did not explain with single use of AR, such as material. When the students preferred single use of AR, they explained form, details, product parts, inner parts and assembly more frequently (Figure 5.11). Size and manufacturing were also explained with single use of AR even though these product aspects were not often mentioned. When the students preferred the use of AR together with other tools, they also explained all these product aspects except manufacturing. In addition to these product aspects, material, user interaction and physical ergonomics were explained when AR was supported with other design representation tools. Single use of AR could be inefficient for some of the product aspects, such as material. Using other design representation tools to support AR could also help the students better explain product aspects.

On the other hand, the product aspects were not explained with the use of design representation tools without AR as frequent as with the use of AR, either single use or together with other tools. These product aspects were details, product parts, inner parts and assembly (Figure 5.11). When looking at form, the frequency of explaining with the tools without AR is closer. The students also used design representation tools except AR to explain product form as well as AR. When looking at the insights about product aspects explained with the use of design representation tools without AR, the students preferred these tools more to explain size and material. In addition to these product aspects, user experience was also explained without using AR even though the frequency of explaining user experience is lower.

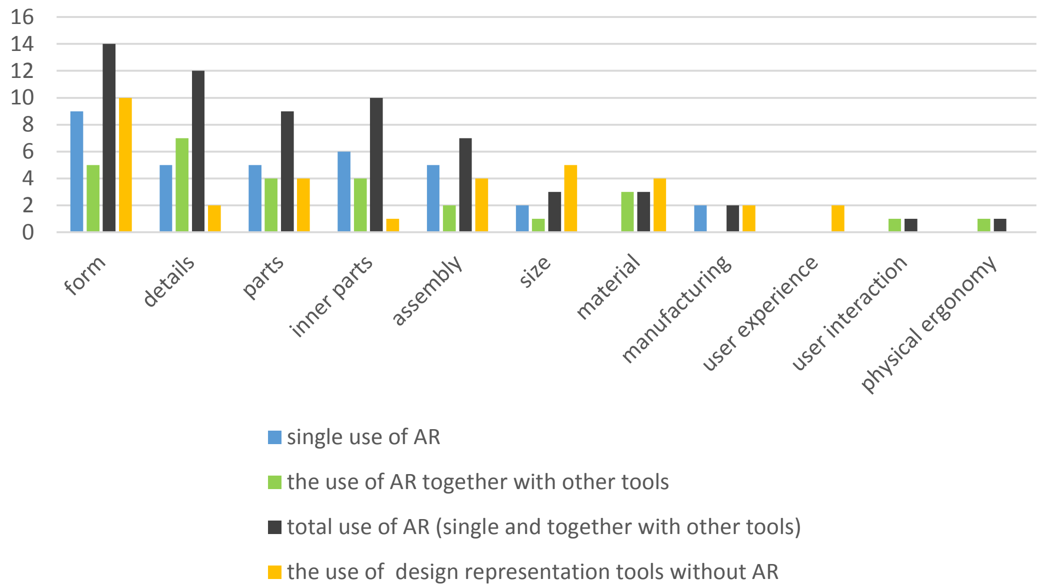


Figure 5.11. Product aspects explained with single use of AR, with the use of AR together with other tools, and with the use of design representation tools without AR

Although the frequency of different uses of design representation tools is close to each other as explained, single use of AR and the use of AR together with other tools was preferred to explain product aspects. AR supported with other design representation tools was used to explain product aspects that could not be explained with the single use of AR. On the other hand, design representation tools without AR was also used for different reasons, namely, to explain product aspects, to support explanation with AR, and to explain product aspects that could not be explained with AR. This shows that being flexible in switching between different design representation tools helps the students support and direct their presentation during desk crits. In addition, AR technology has great potential as a supportive design representation tool that can be used during the product development process of studio projects in design education.

5.4.6. Insights from the tutor's evaluation survey

Although there was only one tutor, as a guest tutor, in the desk crit session, it was important to obtain the tutor's opinions about the integration of AR technology into desk crits. The responses given to the questions in the survey are grouped under seven categories; *tutor's experience, understanding the product, feedback given by the tutor, interaction with the students, presentation, design concept/product* and *AR application*. The insights about these categories will be presented in this section. The responses of the tutor are given under these categories in Table 5.7.

Tutor's experience: When looking at the insights about the experience, the tutor indicated that AR technology is exciting and essential to integrate in the presentations since this technology is developing and becoming widespread. In addition, he mentioned that "widespread use and increased interaction of AR can contribute to more efficient results". This experience was also considered as seeing the product in 3D in a real environment without the use of a keyboard and mouse, which makes it easier and realistic.

Understanding the product: The responses of the quest tutor show that understanding the product was easier and practical. One of the reason was to see different configurations of the product, such as exploded or closed view, which might increase the understandability of the product. These diversities in the presentations could also be helpful for the tutors to easily understand the product and to be more aware of the product details.

Feedback: It is obvious that AR technology has positive effects for tutors to understand the product easier, more practical and faster. When the product is better understood, it is expected for the students to get better feedback from the tutors, which is supported by the response given by the tutor. On this issue, the tutor mentioned that "it was easier to give feedback" with AR integrated in desk crits.

Table 5.7. Tutor's responses in the survey

Tutor's experience	- "AR technology is developing and becoming widespread and I think it is exciting and necessary to make project presentations with the help of this technology." - "Widespread use and increased interaction of AR can contribute to more efficient results." - "It was like seeing the product in 3D on the computer screen in a real environment but without the use of a keyboard and mouse."
Understanding the product	- "It was easier and more practical to understand and interpret the products presented in the desk crits." - "As the products were presented in different configurations (exploded or closed), these diversities in the presentations were quite understandable." - "It can be helpful for tutors to understand the product faster and to be more aware of the products' details."
Feedback given by the tutor	- "It was easier to give feedback."
Interaction with students	- "I think it increases the interaction with the student because it helps the student show more clearly what he/she wants to talk about the product."
Presentation	- "It was exciting and increased my motivation." - "The presentation was definitely more efficient with a new dimension of technology." - "The audience could not be too involved. Supporting projection of AR will increase efficiency."
Design concept/ product	- "It is a great advantage to see the product in context from different views." - "It is a successful method giving the opportunity to experience the products in their real context."
AR application	- "It was definitely more practical, fast and easy." - "I was able to turn the model as I wanted, but could not zoom in at critical points." - "Controlling AR can work more effectively."

Interaction with students: Similarly, the tutor indicated that the interaction with the students increased since AR technology helped the students show their product more clearly in terms of what they wanted to talk about.

Presentations: In addition, the tutor described the presentations of the students as exciting and more efficient with a new dimension of AR technology, which increased his motivation. On the other hand, the tutor suggested to project AR in order to involve the audience. This suggestion could be helpful for the presentations in juries because the setting of the desk crits is different than those of jury presentations.

Design concept/product: In terms of the design concept/product, the tutor indicated that seeing the product in the context from different views was a great advantage. In addition, the tutor mentioned that "it is a successful method to give the opportunity to experience the products in their context". This response shows that the students can also use AR technology to see their product not only in a desk crit environment but also in a real environment during the product development process. This could help the students make decisions about their progress by experiencing the product in its real environment.

AR application: The positive side of AR application for the tutor was the experience being more practical, fast and easy. On the other hand, the negative side was that he could not zoom in at critical points. As a suggestion, he mentioned that controlling AR needs to work more effectively. The tutor also mentioned the importance of experiencing with the AR application in order to get used to it. In addition, AR application needs to work efficiently with minimum errors in order not to distract the communication during desk crits. In general, the tutor had a positive approach towards AR technology and believed that AR needs to be integrated into the desk crits and presentations, leading to more efficient results for both the students and the tutors.

5.4.7. Discussion of the findings

When compared to the other design representation tools, AR technology has advantageous interactional features and qualities that bring about the positive effects and potentials of the integration of AR technology into the product development process. Realistic 3D presentation of a design concept/product in the learning environment, showing the design concept/product interactively by exploding, cutting, zooming in/out, hiding/unhiding which is easier than it is for digital models, and practical presentation during desk crits are the most prominent features of AR technology. Despite these interactional features and qualities, time requirement for the students to learn AR preparation process can be considered as a constraint which might lead to negative effects.

Although the findings in the previous sections are presented under different categories, they are all related to each other, which contribute positively to each other. AR technology has positive effects and potentials for the students, the tutors, the interaction between them, desk crits and presentations, and design concept/product (Figure 5.12).

The findings show that AR application was helpful for the students to show and explain several product aspects, such as form, details and inner parts. When a design concept is presented with AR technology, this support the students' explanations of the product aspects. AR technology supports the students in expressing themselves while explaining the product and the product aspects. By this way, it becomes practical way for the tutor to understand the products presented in the desk crits with the help of AR technology. Presenting the product with different configurations makes the product understandable for the tutor, resulting in increased feedback about the student's project during desk crits. The positive effects of AR technology contribute to increased interaction between the student and the tutor because AR helps the students ease the explanation of product aspects, which results in increased understandability of the product. In addition, AR technology supports the increased amount of feedback during desk crits.

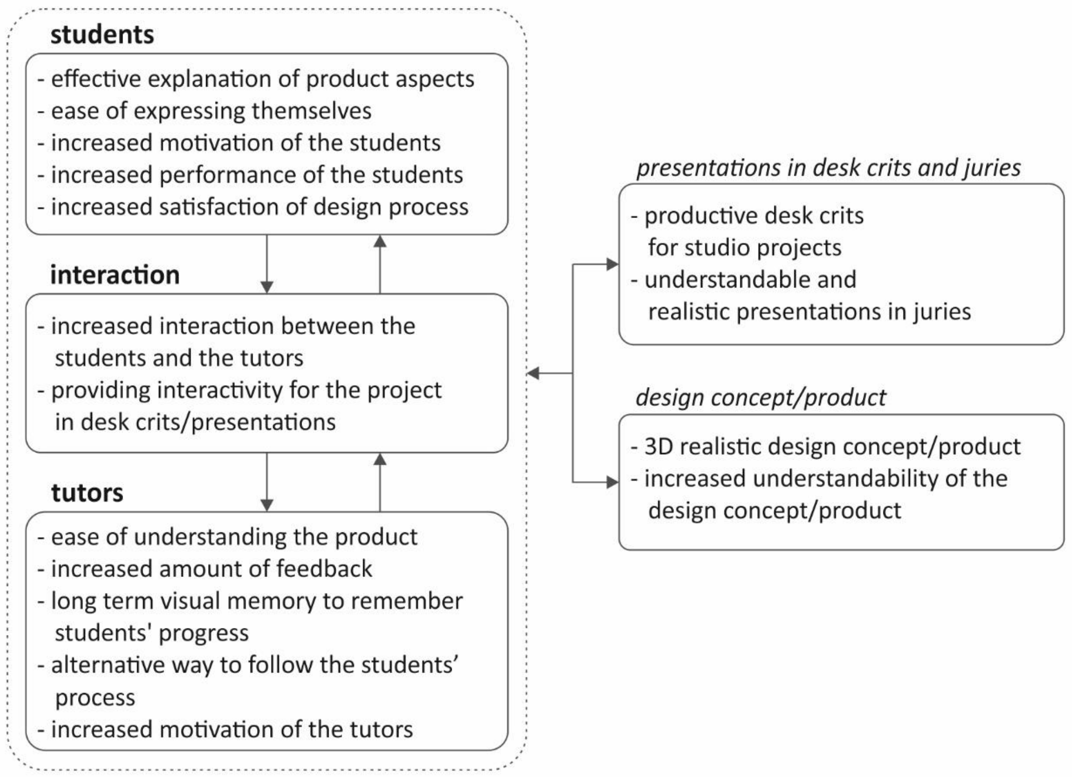


Figure 5.12. Benefits of AR technology as a supportive design representation tool for the students' product development process

The positive effects of AR benefit the students and the tutors, also affecting the interaction between them in terms of the development of the design concept/product and its presentation at desk crits and juries (Figure 5. 11). AR contributes to more productive desk crits. The productivity of the desk crits can be increased by interactive presentations, effective explanations, increased understandability of the product, increased feedback and interaction between the students and the tutors. Similarly, the presentations in juries can become understandable, realistic and interactive. AR technology could help the students make understandable and realistic presentations with its features, such as seeing the product 3D realistically and more detailed, and seeing the product in the environment in its real size. Compared to traditional methods, AR technology is considered as remarkable and exciting, which increased the students' motivation as well as the tutor's. It is also considered as a helpful means for the students to direct their presentation.

These positive effects and potentials of AR bring about positive experience for students and tutors. Being more realistic with 3D view in the environment, decreasing many question marks during desk crits, helping the students understand the mistakes and other positive effects of AR make this experience positive for the students. Seeing efficient results with the use of AR affects the tutors' experience positively. The tutor taking part in this study believes that it is necessary to integrate this technology into project presentations during desk crits and juries. Noticing overlooked possible errors that increase the students' intervention in order to improve the product, and positive effects of AR on visual memory that can help the tutor follow the product development process better, are also important findings that support the positive experiences.

These findings are grouped according to validation of the findings from literature, new findings to assess with future studies and potential findings to assess with future studies (Table 5.8). The table also shows the category of findings, which are illustrated in Figure 5.12. The findings from literature were mentioned in Sections 3.2 and 3.3. Most of them were related to education context whereas few of them were directly related to the product development process. Validated findings for the product development process are; *increased motivation of the students, increased performance of the students, increased interaction between the students and tutors, providing interactivity for the project, increased motivation of tutor, realistic presentations* and *3D realistic design concept/product*.

New findings that need to be assessed with future studies are; *effective explanation of product aspects, ease of expressing themselves (students), ease of understanding the design concept/product, increased feedback from the tutor, productive desk crits for studio projects* and *increased understandability of the design concept*. Although better content understanding was already mentioned as a benefit of AR technology, such as Sin and Zaman's (2010) study, findings related to understandability, ease of understanding the design concept/product and increased understandability of the design concept, are listed as new findings. This is because, while the content mentioned in the literature was knowledge transferred from teacher to student, the content in the study is the student’s project progress, which changes and develops during product development process. In addition, this content is different for each student. In other words, there is no specific content in each desk crit transferred from students to tutor.

Table 5.8. Grouping of the findings according to validation, new findings and potential findings to assess with future studies

	S	***I***	***T***	***P***	***D***
Validation of the findings from literature *benefits of AR for product development process validated from the literature*					
increased motivation of the students	■				
increased performance of the students	■				
increased interaction between the students and tutors		■			
providing interactivity for the project		■			
increased motivation of tutor			■		
realistic presentations				■	
3D realistic design concept/product					■
New findings to assess with future studies *benefits of AR for product development process as a new finding*					
effective explanation of product aspects	■				
ease of expressing themselves (students)	■				
ease of understanding the design concept/product			■		
increased feedback from the tutor			■		
productive desk crits for studio projects				■	
increased understandability of the design concept					■
Potential findings to assess with future studies *potentials of AR for product development process to assess with future studies*					
increased satisfaction of personal design process	■				
long term visual memory to remember students’ progress			■		
alternative way to follow the students' process			■		
realistic and understandable jury presentations				■	
S: Students, I: Interaction, T: Tutors, P: Presentations in desk crits and juries, D: Design concept/product					

Potential findings that need to be assessed with future studies are; *increased satisfaction of personal design process, long term visual memory to remember students' progress, alternative way to follow the students' process,* and *realistic and understandable jury presentations*. The study was conducted in an elective course and these findings were drawn as a potential for design studio projects. The findings except realistic and understandable jury presentations should be assessed with long-term studies to explore the effects of AR on these issues.

5.4.8. Discussion of eDrawings AR application

The AR application used in the study, eDrawings, is also considered as an effective tool in presenting the product and the product aspects. Quickly switching between different views, showing the product aspects and different configurations quickly and better, and showing the desired parts more easily with AR were among other important findings. In addition, AR helped to perceive and understand the product and the product aspects more easily. In addition, AR brings about several advantages when compared to other design representation tools; these are more visual opportunities, seeing the product in 3D and as it is in the environment, showing the inner parts quickly, seeing the product with different configurations in real size, and understanding/explaining form, volume and proportions without mock-ups. AR application supports the students in showing 3D realistic concepts and directing the attention to important points with its easy use and interaction. However, understanding and accessing the application needs to be easy for the students. On the other hand, understanding AR application is somehow related to getting used to using the application. Therefore, it is important to experience this technology by integrating it into the product development process. When the students experience AR application more, the findings will be clearer.

On the other hand, an AR application that does not work properly or meet the requirements of the students might have negative effects on the product development process. Feeling that there might be a problem with the AR application during the desk crit can lead to negative effects on students' explanation, motivation and performance during desk crits. This results in a decrease in the effectiveness of desk crits including understandability of the product, feedback given by the tutor and interaction between the student and tutor. If the students do not feel that they manage to prepare a fully working AR application, this can bring negative effects. The problems that the students faced with during the preparation of the AR application were mainly related to the Solidworks software, which most of the students used for the first time. Although they were instructed about the preparation process and the necessary documents were given to the students, it seems normal for them to have had problems with a new program that they just started to use. It is evident that it requires time for the students to learn the AR preparation process. If they had been used to using this program beforehand, they would have had less problems. Considering the studio projects, it is not possible to integrate this learning process into studio education. The learning process needs to be integrated into related courses so that the students can practice and experience with AR more and integrate this technology as a supportive design representation tool into their product development process.

5.4.9. Reflection of the researcher

As the researcher of this study presented in this chapter, my reflection about the students who experienced AR technology in their product development process is their excitement, which made them enthusiastic to learn and use this technology. On the other hand, learning and preparing AR application took time for the students because AR application was prepared with a different software, Solidworks. Although many of the students had no experience with Solidworks before, few of the students had problems with preparation of AR technology. However, the preparation process needs to be easier without learning and using another software. As suggested and explained in the next section, AR application needs to import 3D-model of the design concept/product with its layers and the students should be able to make necessary adjustments in the application.

Other reflection about the students, who used AR application to explain their products during desk crits, is that AR provides them to make their presentations interactively when compared to other design representation tools. This does not mean that they always prefer using AR rather than other tools. They use all design representation tools, either single or together, and switch between these tools during their explanation according to the tool which they feel comfortable to explain. This flexibility and seeing the product virtually as 3D in the context support both the explanation of the students and the discussions with the tutor by supporting the understandability of the product. On the other hand, if the students experience repetitive negative situations with AR during desk crits such as vibration of 3D-model and adjustment problems, this leads to decrease in the productivity of desk crit sessions. Even the anticipation that AR technology will not work properly may make the students feel uncomfortable.

Although this study was conducted in a single desk crit session of an elective course, the guest tutor, who attended this session, was eager to experience AR technology by himself. He knows this technology from beforehand and has less experience but his approach to AR technology was very positive. My reflection is that the interactivity of AR technology stands out from other tools. An important question might be what the tutors approach would be when they experience AR technology as a supportive design representation tool for a long time. Similarly, how the students approach to AR technology may change in time when their experiences with AR during desk crit sessions increase. My prediction is that the approach of the students and tutors to AR would not be the same like in the first use but this technology is desired to be used as a supportive design representation tool.

Apart from the reflections about this study, my reflection about AR technology is that it can also minimize the difficulties that are mentioned in Section 4.7.10. I do not totally argue that AR technology can eliminate all the problems and difficulties that the students experienced during the product development process and desk crits in design studio. However, AR can help decreasing these problems and difficulties. On the other hand, AR can also bring about new problems and difficulties if it is not properly integrated into the product development process or if the students experience problems while using this technology during desk crits. Whether AR can help decreasing the problems or can bring about new ones should be questioned with further studies, in which AR is integrated as a supportive design representation tool during product development process in addition to other tools.

5.5. Roadmap for the development of augmented reality applications for the product development process

The outputs that can direct the development of AR applications for the product development process are the AR Interaction framework and AR requirements for product aspects. The AR Interaction framework, which is presented in Section 4.8.3, needs to be considered based on the needs and expectations of industrial designers for the development of an AR application. In addition, this application needs to include the features or functions that were listed as AR requirements (Section 4.8.2) according to the product aspects, which will be covered with the application. However, developing a single AR application that covers all the product aspects together with all interaction types might be difficult. Then, it is suggested to consider selecting a group of product aspects based on the suggestion of product aspects groupings presented in Section 4.8.5. These are the main outputs that need to be taken into consideration during the development of an AR application for the product development process.

In addition to these outputs, some suggestions can be given for future developments of AR applications based on the study. These suggestions are *having no need for another software, eliminating the jittering or vibration of digital models, adjustment of the sensitivity* and *availability and accessibility of the AR application.*

Having no need for another software: It was required to use another software to prepare AR application, which took time to learn and prolonged the AR preparation process. In addition, preparing different pre-sets of the product, such as exploded and section, required time for the students. Although, an instruction and documentation for AR preparation process was given to the students, they faced with the problems. Therefore, it is strongly suggested that importing 3D-model with its layers directly into the AR application and making necessary adjustments in this application needs to be developed. In other words, the students should be able to adjust the exploded view of the product in the AR application instead of preparing it with another software. This makes the preparation process easier for the students.

Jittering or vibration of digital models: Although jittering or vibration of digital models happened very rarely, such a situation might make the students feel there is a problem with the AR application. This might lead to negative effects on students' presentations unless this is an instant situation. Thus, jittering or vibration of digital models need to be minimized or eliminated if possible. If such situations constantly recur during a presentation, a feedback showing the reason why this happened should be given in order not to lead to negative effects on students' presentation.

Adjustment of the sensitivity: A tablet was utilized for the study. Controlling AR application with fingers for rotating the 3D-model or zooming in/out was not as easy as using a mouse on a computer screen for each student. It is necessary for students to get used to use the application but they still might have problems in controlling with fingers, especially for the controls to move the fingers on tablet screen. The sensitivity requirement can be different for each user; thus, the sensitivity level sensitivity should be adjusted if possible.

Accessibility of the AR application: Although eDrawings AR application, which was used for the study, has a very small one-time fee, the students did not think that the application was very accessible (Section 5.4.2.2, Figure 5.6). For this reason, it is suggested that it would be beneficial to consider developing a student version so that it can be used in design education. Similarly, AR application can have a free version that supports fewer features. When the students use this free version and experience the positive effects, then they can consider paying a reasonable amount of fee for the AR application that can support their product development process.

5.6. Summary of the study

The findings of this study reveal the effects and potentials of the integration of AR technology into the desk crits during the product development process. With the integration of AR, the students presented their conceptual designs with different design representation tools including sketches, visual mock-ups, digital models, AR application and renders during the desk crit session in which the study was conducted. Using AR application was essential to present their design concepts supported with other design representation tools.

The findings show that AR technology has benefits for the students, the tutors, the interaction between them, desk crits and presentations, and design concept/product, which were summarized and discussed in Section 5.4.7. Based on the findings about eDrawings AR application, AR technology brings about several advantages for presenting the product and the product aspects when compared to other design representation tools, which were summarized and discussed in Section 5.4.8. On the other hand, AR technology can lead to negative effects due to problems that the students can face during the preparation process or presentation with AR application. These problems need to be minimized and eliminated with the development of the technology in order to increase the positive effects of AR.

The study was conducted in an elective course within a limited time for the project given to the students and took place at the final week of the product development process. Therefore, further studies are required to explore AR technology with different projects in different stages of the product development process, which is explained in Section 6.5 Potential Directions for Future Studies.

CHAPTER 6

CONCLUSION

This thesis explores the product development process of industrial design students and the integration of AR technology as a supportive design representation tool into this process in order to enhance the students' product development process.

This thesis contributes with the following outputs to the current state in industrial design education.

1. Design Representation Tool (DRT) framework for enhancing the use of the tools in order to improve the product development process and its outcome.
2. Delivery of product aspects requirements for AR technology, and an AR Interaction framework
    a. for AR researchers and developers to better develop potential applications and
    b. for academics to make decisions about whether an AR application can be integrated into the process.
3. Overview of the benefits of AR technology as a supportive design representation tool for the students' product development process.

This chapter discusses these contributions by revisiting the research questions. In addition, it presents the limitations of the studies conducted and the potential directions for future studies.

6.1. How design representation tools can be used for enhancing the product development process in industrial design education

One of the most important outputs of this thesis is the DRT (Design Representation Tool) framework (Figure 6.1) that illustrates the relationship between these tools according to the product aspects related to the students' projects. The DRT framework is based on the three-level relation of main tools, supportive tools, and supplementary tools. Using design representation tools supporting each other improves the development of the product aspects. Desk crits are the center medium of design studio education (Schön, 1991; Goldschmidt et al., 2010) and the students use design representation tools to explain their process to the tutors during desk crits. They mainly explain the product aspects that they developed to the tutors with the design representation tools. Development of the product aspects related to the students' project is as important as their explanations during desk crits. This framework provides a guidance on how to use design representation tools together in order to better develop the product aspects and to better explain them during desk crits. By this way, better development and better explanation of the product aspects by using design representation tools together can support the communication and interaction between the students and the tutors, resulting in better feedback given by the tutors. As suggested in Section 4.7.11, the integration of design representation tools, especially virtual and physical tools, should start to be used in the earlier stages of the product development process, resulting in better final products.

Considering the expectations of the students about the product development process, the guidance of the tutors should be specific and the students should follow their own process according to the nature and requirements of the project. This framework provides guidance for both the tutors and the students. For instance, if solving mechanisms is the key product aspect of a student's project to continue with the product development process, the tutor can guide the student in preparing working mock-ups supported with 3D-models or sketching for mechanisms. If a student needs to work on the product form related to the project, he/she can be guided to work with 3D-models supported with visual mock-ups for form alternatives. Similarly, students can use this framework to direct their process according to the product aspects that they need to develop.

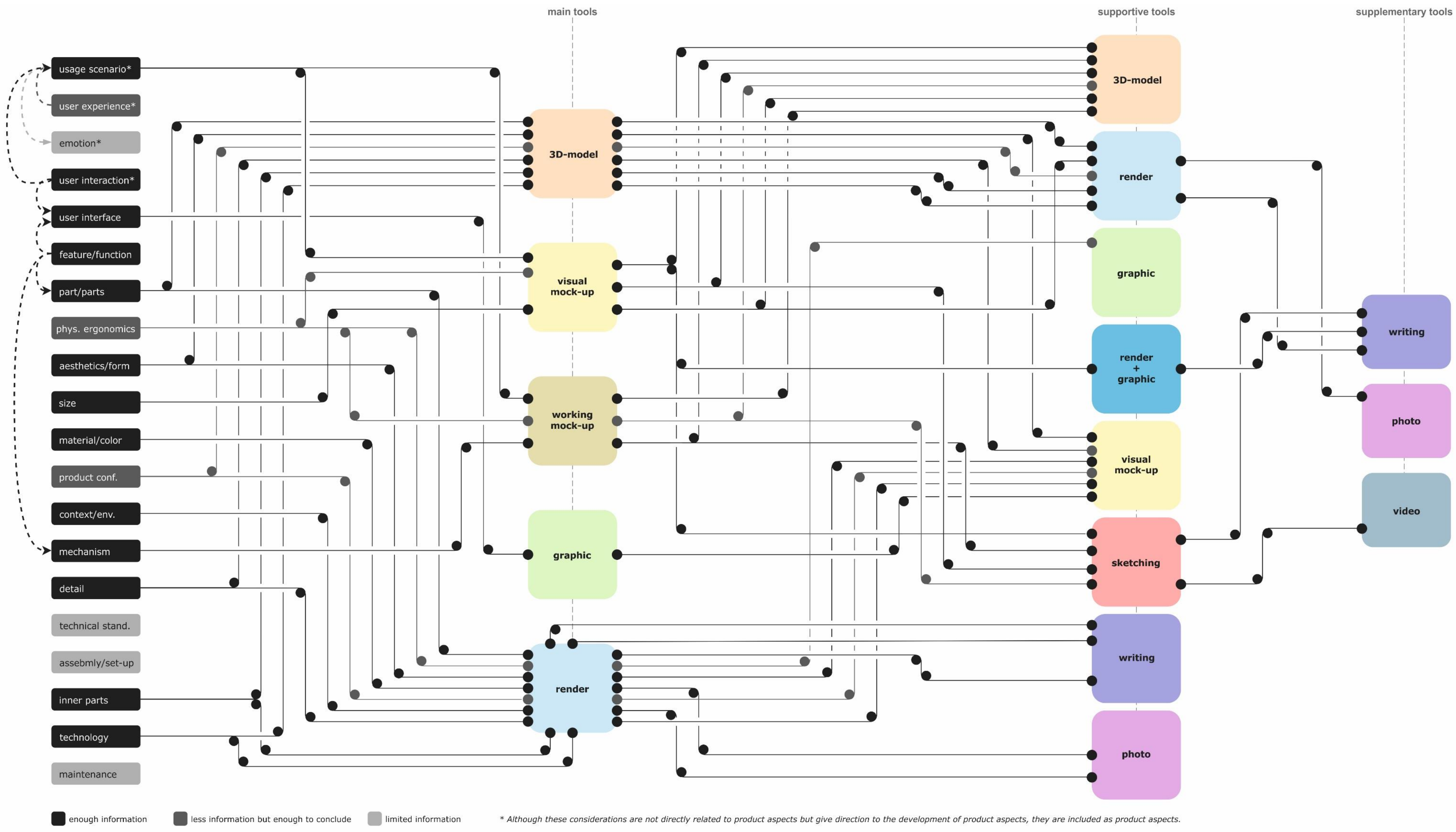


Figure 6.1. The DRT (Design Representation Tool) framework showing relations between design representation tools for each product aspect

Figure 6.2 shows an example project that a student carried out during the product development process in graduation project course. The project statement was a camera equipment that will provide stabilization and will make it easier for professional camera users to shoot in dynamic environments. After the development of initial ideas, her major considerations to continue her product development process was mechanism and physical ergonomics.

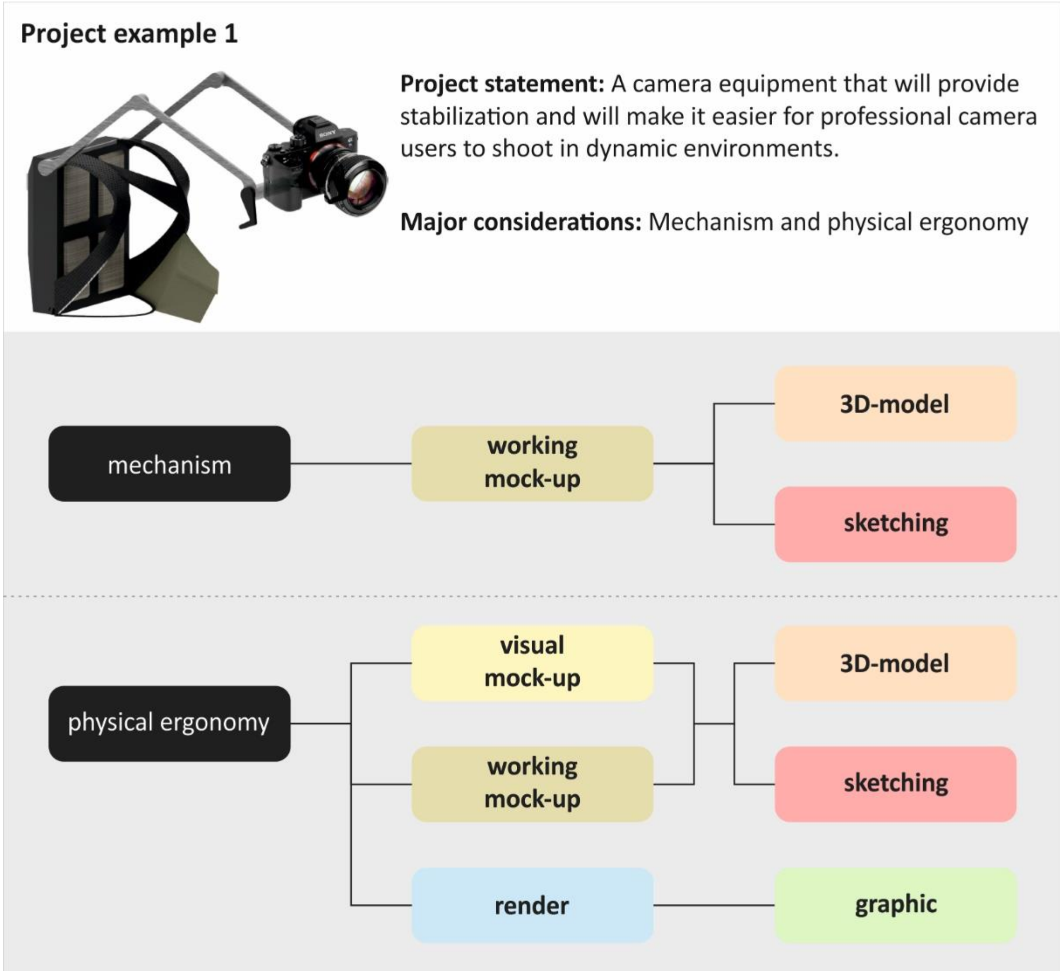


Figure 6.2. Project example to be guided with DRT framework

Considering DRT framework, the student should be guided to prepare working mock-up supported with either 3D-model or sketching between development of initial ideas and preliminary jury in order to make decisions and to improve the product development process. As it can be seen from DRT framework, working mock-up supported with either 3D-model or sketching can help the students work on both mechanism and physical ergonomics, and explain these product aspects in desk crits.

Similarly, another project example is given in Figure 6.3. The project statement was a smart guide that tracks a kid's fever regularly, collects and archives data of body temperature, and notifies emergency situations. Major considerations during the product development process were aesthetics/form, inner parts and relatively technology. Many inner parts were directly related to the technology for this project example. When looking at DRT framework, the student should be guided to work on 3D-models of the strong ideas and visual mock-ups with the help of 3D-model after the development of initial ideas. In addition to these tools, the student can use render to support these tools. Using these tools can help the students improve their product development process and express their progress in desk crits.

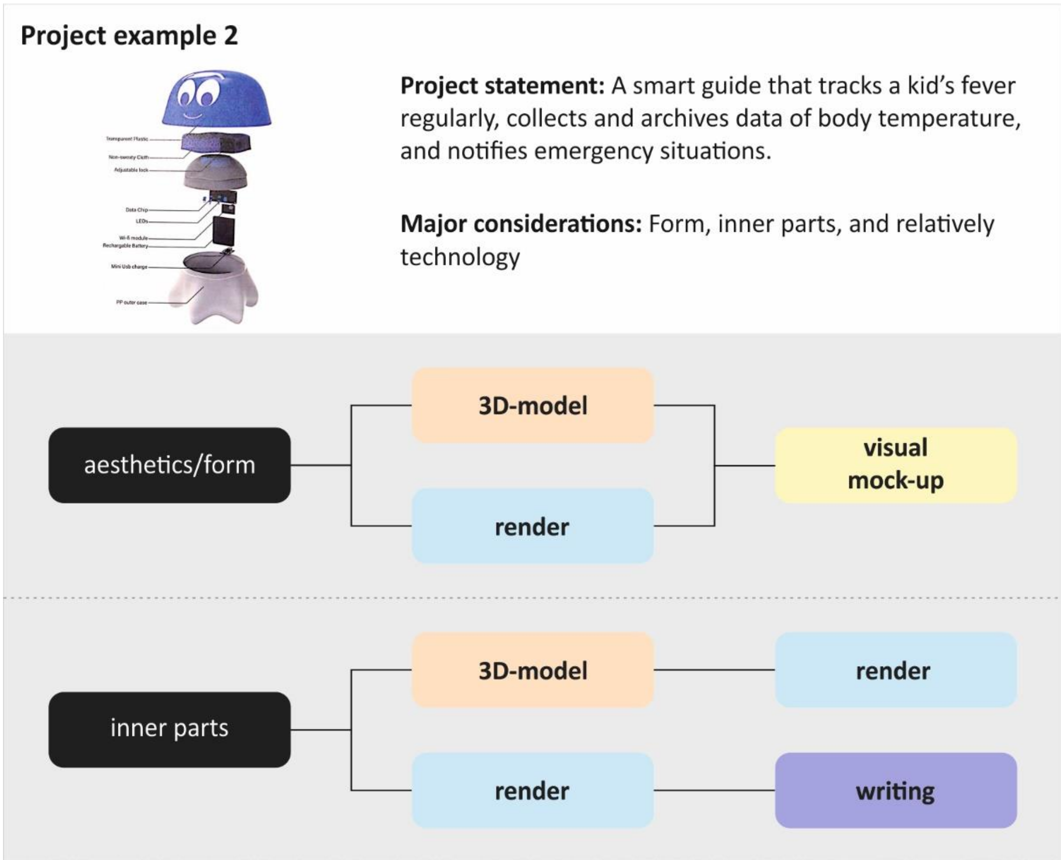
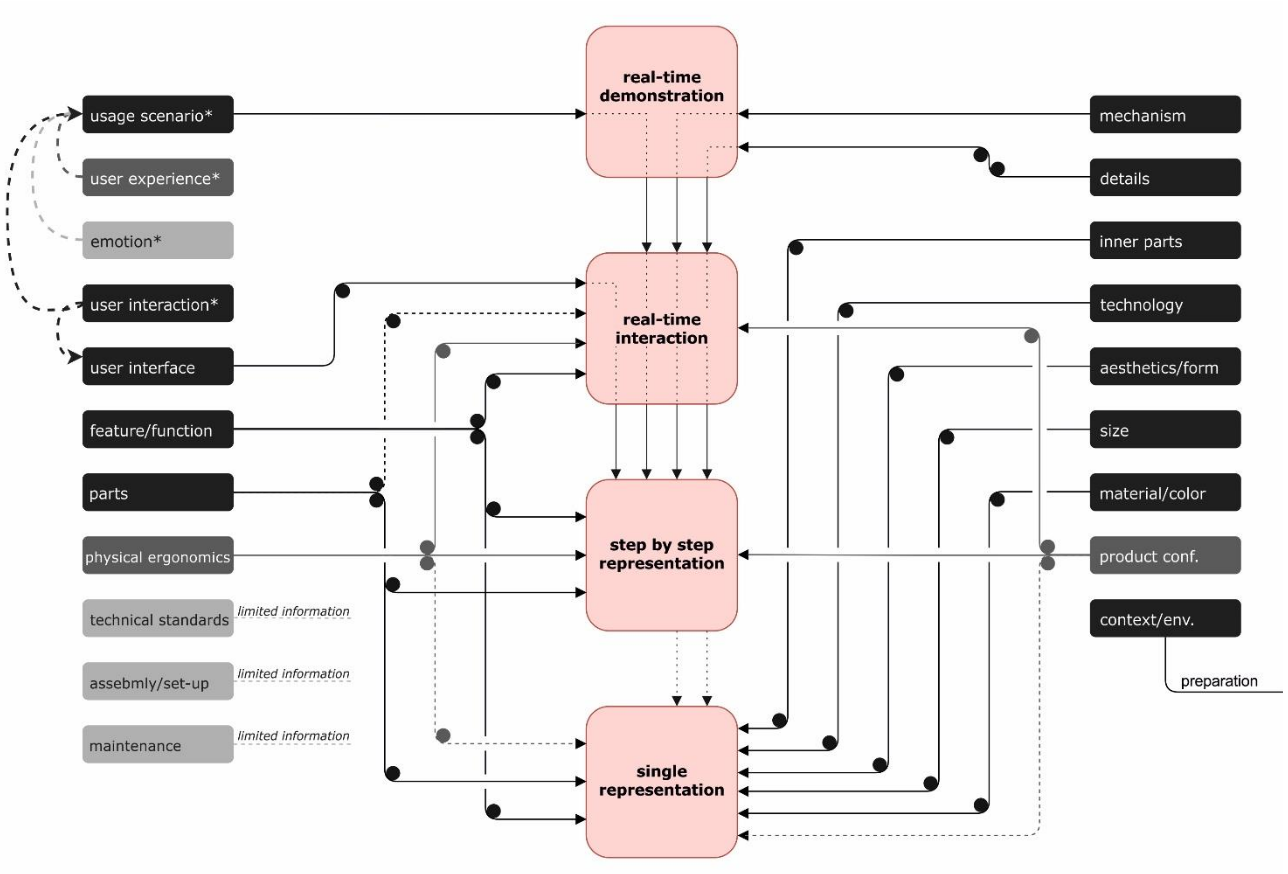


Figure 6.3. Project example to be guided with DRT framework

The major considerations can differ according to different projects and different stages of the product development process. DRT framework can guide the students to select design representation tools according to major considerations that they work on. These considerations can be more than two and if it became difficult to select the design representation tools to develop product aspects, it would be suggested to prioritize the product aspects to benefit from DRT framework.

6.2. How AR technology can be integrated into the product development process in industrial design education

Unlike most of design representation tools, AR technology provides more interactive ways of presenting the design concept or product. In addition, AR has many potentials for interactively presenting and explaining product aspects during desk crits. However, how this technology should be integrated into the product development process for enhancing the students' process is vital. Based on the findings of the design representation tools except AR technology, this thesis delivers the requirements of product aspects' for AR technology under six levels; *interaction, transformation, specification, reference, display* and *preparation*. The thesis also offers an AR Interaction framework (Figure 6.4) and AR requirements for product aspects (Table 6.1) to guide tutors and students on how to integrate and use AR technology in the product development process.



* Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.

Figure 6.4. AR Interaction framework for product aspects

Table 6.1. Product aspects' requirements for AR technology

	Interaction				**Transform**				**Specification**			**Reference**			**Display**			**Preparation**				**Documentation**	
	Real-time demonstration	*Real-time interaction*	*Step by step representation*	*Single representation*	*Exploding/cutting*	*Moving/rotating*	*Hiding/unhiding*	*zooming in/out*	*Highlighting*	*Labelling*	*Explaining*	*human body or part of the body*	*real size*	*without scale*	*Single version*	*Different versions*	*Changeable parts or product variations*	*Video demonstration*	*Step by step representation*	*Single representation*		*Earlier versions*	*Information*
Product Aspects	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***		***21***	***22***
usage scenario*																						*Earlier versions of each product aspect might be needed during the students' product development process.*	project statement
user experience*	*is related to usage scenario*																						problems
user interaction*	*is related to usage scenario and user interface*																						research
emotion*	*is related to usage scenario*																						user group
user interface																							product examples
feature/function																							moodboard
parts																							keywords
physical ergonomics																							critiques
aesthetics/form																							self-evaluation
size																							product analysis
material/color																							current situation
product configuration																							user needs
context/environment																							*and similar information*
mechanism																							
details																							
technical standards	*limited information to conclude*																						
assembly/set-up	*limited information to conclude*																						
inner parts																							
technology																							
maintenance	*limited information to conclude*																						

** Although these considerations are not directly related to product aspects but give direction to the development of product aspects, they are included as product aspects.*

AR applications for product design are constantly being developed by AR researchers and developers. This guidance can also help tutors and students determine whether and how an application can be used. According to the product aspects related to the students' projects, the requirements for AR technology can differ. Therefore, an application should include the requirements that are illustrated for the product aspects developed by the students. For instance, while a specific AR application can provide real-time interaction that helps the students show user interface interactively during desk crits, another AR application can provide real-time demonstration showing how mechanisms work. Similarly, an AR application can augment the virtual model of human posture together with the 3D virtual model of the product or can augment the 3D virtual model on a real human body. This helps the students to present and explain physical ergonomics of the product.

In addition, product aspects' requirements for AR technology and the AR Interaction framework provide guidance for AR researchers and developers to better develop AR applications for industrial design. Although it might be difficult to develop some of the requirements with the current state of AR technology, such as different versions of the product as display option, or real-time demonstration as interaction type, these will also be possible with the development of the technology. This guidance is the first version that is illustrated based on the findings of the other design representation tools. Therefore, further research that includes AR technology in addition to other tools needs to be carried out, in order to improve this guidance.

Based on these findings, suggested guidance for AR developers is illustrated in three main steps (Figure 6.5); *select product aspects, define AR interaction type,* and *look for product aspects' requirements*. First step is to select product aspects for which AR application will be developed. These product aspects can be selected according to the grouping as mentioned in Section 4.8.5, based on the presentation of product aspects, AR possibilities and the similarities between them. These groups are user oriented, visual oriented and technic oriented. Second step is to define AR interaction type according to the selected product aspects; real-time demonstration, real-time interaction, step by step representation and single representation. AR interaction type can also be decided upon according to the technology that will be used for AR application in addition to the product aspects. Third and last step of suggested guidance is to look for product aspects' requirements to decide on which features need to be developed for the defined AR interaction type (Table 6.1). This step is to review requirements for transform, specification, reference, display and preparation levels.

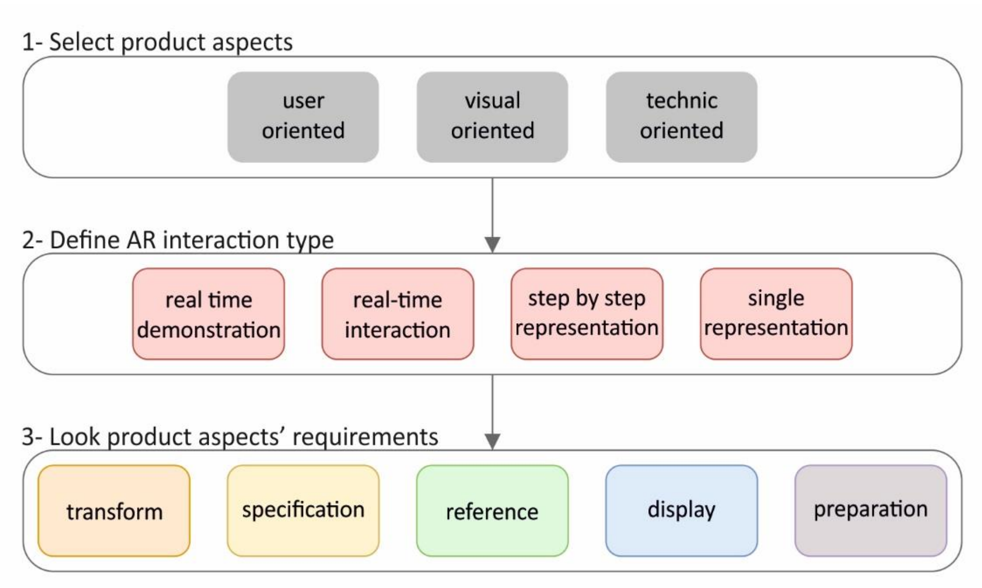


Figure 6.5. Suggested guidance for AR developers

To give an example, aesthetics/form, size, material/color, product configuration and context/environment in visual oriented group are selected to develop an AR application for the product development process. Single presentation is mainly suggested for these product aspects as AR interaction type. Zooming in/out is necessary for transform whereas there is no specification need for the selected product aspects. For aesthetics/form and size, it is important to present with real size or without scale, which should make it possible to change the scale. In addition, these product aspects should be displayed with either single version or different versions. Moreover, if product configuration is adjusted by hiding/unhiding, product variations can be displayed with changeable parts. This option can be eliminated if different versions can be enough for product configuration. Considering the use of

AR as a preparation for desk crits, single representation for these product aspects is enough by taking print screen of AR application. Then these print screens of AR can be used during desk crits. In addition, AR application can be used to show the design concept/product in context/environment as a preparation tool.

6.3. How AR technology as a supportive design representation tool can affect the product development process

AR technology as a supportive design representation tool, as discussed in Section 5.4.7, has several positive effects and potentials for the product development process. The study carried out for exploring the effects and potentials of AR technology as a supportive design representation tool during the product development process was conducted in an elective course and the project given to the students was not as comprehensive as studio projects. Considering the limited time dedicated for this course, the students considered many product aspects that have the highest potential to be represented with AR technology during the product development process.

AR technology can be very useful for the students to show and explain the product aspects, such as form, details and inner parts. AR technology can help the students to easily express themselves while explaining the product and the product aspects. Better presentation and explanation of the product with the help of AR technology leads to a better understanding of the product during desk crits, resulting in better and effective feedback. All these positive effects of AR technology can increase the interaction between the student and the tutor and provide interactivity for the project in desk crits and presentations. In addition, it can increase the motivation and performance of the students.

While the productivity of the desk crits can be increased with the use of AR technology, the presentations in juries could become more efficient, realistic and interactive with its potentials, such as seeing the product 3D realistically and more detailed, and seeing the product in its environment. These positive effects and potentials of AR can bring about a better experience for students and tutors, and can decrease question marks during desk crits. In addition, it helps the students understand mistakes and notice overlooked possible errors, resulting in the students' intervention to improve the product. Moreover, AR technology can help the tutor follow the students' product development process better, considering the positive effect on long term visual memory.

When compared to other design representation tools, AR technology can bring about several advantages:

- More visual opportunities;
- Seeing the product in 3D in real size and as it is in the environment;
- Showing different configurations of the product quickly;
- Highlighting the desired parts easily;
- Showing/explaining the product aspects quickly without other tools, such as inner parts and form without 3D-model, and form, size and proportions without mock-up;
- Increasing the understandability of the product and the product aspects, and
- Directing the attention to important points.

With its advantages, AR technology is a supportive tool that can be used during desk crits and the students' product development process. On the other hand, it is essential to get used to using AR technology because integrating and using this technology will be easier for the students when they increase their experiences with AR. However, learning how an AR application can be prepared with a software that the students are not familiar with takes time. Considering the studio projects, it is not possible to integrate this learning process into studio education. Apart from design studio education, the integration of AR learning process should be included in related courses for industrial design students to practice and experience AR technology. In this way, they can adapt this technology to integrate into their design process as a supportive design representation tool.

6.4. Limitations of the studies conducted

As mentioned in Section 4.1, the limitation of the study that explored the current product development process of industrial design students was that member check was not done for the dialogues between the students and the tutors during desk crit sessions. One of the reasons is that recording the sessions could make the students feel uncomfortable during desk crits, which might in return affect these sessions negatively. Another reason is that it was not possible to record all the sessions and to transcribe them right after, in order to cross-check with the students and the tutors because they forgot the session and also due to time limitations. However, this strategy was used to cross-check visual data of design representation tools observed during desk crit sessions with digital data of these tools supported by the students. Background, qualifications and experience of the researcher as a strategy suggested by Shenton (2004) could compensate member check of the dialogues between the students and the tutors during desk crit sessions. As the researcher has the same industrial design education background like the students and similar experiences about the product development process in industrial design, he can easily understand the students' and tutors' intentions from the dialogues.

In addition, time that the students spent for preparing design representation tools and development of product aspects were not observed to measure or asked from the students to note down. Time spent for preparing a tool and developing product aspects might differ according to the students' skills, which were not observed and measured. This is because the students might need different amounts of time and effort to reach same level. Nonetheless, differences in time spent and the students' skills could be seen as a limitation of the study. On the other hand, the students were selected based on their levels and the sectors of their projects to make it homogenous, as explained in Section 4.1.2, in order to enrich the data from different levels of students and different sectors. In addition, the coding process was carefully carried out by controlling the data several times during the analysis process in order to minimize this limitation.

It is also important to mention the critical points of the studies that should be taken into consideration for future studies. For the study that explored the current product development process of the students, they were asked to send the design representation tools digitally to the researcher regularly by taking photos of these tools or sending the digital versions. However, although this requires less time for the students, it was hard to collect these tools from the students digitally without reminding them multiple times. Collecting these tools took a while.

The limitation of the study that explored the integration of AR technology was that, the study was conducted in an elective course, which was not as comprehensive as the graduation project course. Conducting the study in an elective course with limited time for a project might be a limitation for the study, compared to the graduation project or other projects in design studios where more time is dedicated for design development. If the study was conducted in a design studio project, the exploration would be more efficient and productive for the findings.

For the study that explored the effects and potentials of AR technology as a supportive design representation tool during the product development process, learning an AR application, preparing with an unfamiliar software and getting used to using it could take time for the students. This time requirement should be considered while planning a study with students who are not familiar with such technology. As a suggestion, a four-hour lecture to show how to prepare AR application, a four-hour lecture to go through their problems and a last four-hour to finalize their applications together with the tutor of the course can be an ideal planning if the students will use AR technology for the first time. If possible, this time management can be extended by increasing the students’ experience.

6.5. Potential directions for future studies

6.5.1. Assessing the Design Representation Tool (DRT) framework with students and tutors

One possible direction for future studies could be to conduct studies in which the first version of the DRT framework is used to guide the product development process of the students. Although, the study that explored this process was conducted in a graduation project course with fourth year undergraduate industrial design students, future studies can be carried out with students from different years, namely students in the second, third and fourth years, as well as graduate students. This study aimed to provide a well-grounded understanding of the students' product development processes, represented with the DRT framework that shows the relation between the design representation tools for product aspects. Future studies can be conducted to improve this framework. Conducting future studies with different level students can both validate the DRT framework and provide new findings about the relation between the design representation tools.

In future studies, the use of the DRT framework can be evaluated either with the tutors to guide the students during desk crits or with the students to direct their product development process. For this reason, DRT framework cards can be prepared for each aspect that shows the relation between design representation tools. In addition, examples can be added to these cards. In this way, this framework can be used easily during product development process.

The study that explored the current product development process investigated the most common design representation tools that the students used during this process. With the development of technologies, different design representation tools can be integrated into the product development process in design education, such as VR and AR. With the integration of developing technologies, future studies can explore their impacts and potentials in order to extend the DRT framework with these technologies. Assessing the DRT framework in terms of the developing technologies that can be integrated into the product development process of the students as a supportive tool would help to both better understand the potentials of these technologies and obtain valuable insights for further developing this framework.

6.5.2. Assessing the early integration of different design representation tools into the product development process

Based on the findings of the study that was conducted to explore the product development process of industrial design students, it is suggested to integrate different design representation tools, especially virtual and physical tools, at earlier stages of the product development process. As mentioned in Section 4.7.11, this integration should start between the early ideas jury and preliminary jury according to the students' projects and progresses. This integration can help the students make considerable progress during their product development process, resulting in better outcomes for their final product. Future studies, in which different design representation tools are integrated into the design development process at earlier stages, can be conducted in order to assess the effects of this integration on the product development process in terms of the progress of the students, the outcomes of these earlier stages, and the end results of this process.

6.5.3. Assessing AR technology with different projects at different stages of the product development process

The study that explored the effects and potentials of AR technology as a supportive tool during product development was carried out with a single project. The project given to the students was a Bluetooth speaker, for which the students needed to consider product aspects from technic and visual oriented groups. Different design representation tools such as sketching and visual mock-ups were integrated into the design process starting from early stages. However, due to the schedule of this course and time limitation of the project, AR technology was integrated at later stages and the study was conducted in the final week of the project. Thus, a potential direction for future studies would be to assess the effects and potentials of AR technology with different projects at different stages of the product development process. Although it would be expected to arrive at findings similar to those presented in Section 5.4 with these studies, they could also provide additional valuable insights about AR technology.

6.5.4. Using AR Interaction framework and requirements for product aspects to develop AR applications that can be used in design education

Although there are some AR applications developed for the design context, there is a lack of AR applications that can be used in the product design or industrial design context, both in the educational and the professional fields. Considering the product development process, the product aspects' requirements for AR technology and the AR Interaction framework can guide AR developers and researchers in developing better AR applications that can be integrated into the process of design students and professionals. In addition, AR applications including all these requirements and interaction types might eventually be developed with the development of the technology in the future, but it should be questioned whether this is necessary. If a single AR application that covers all the product aspects together with all interaction types is not possible, it would be better to consider developing an application for a group of product aspects based on the suggestion of the product aspects' groupings (Section 4.8.5). It is more important to develop AR applications that can be easily integrated into the product development process in order to enhance this process. The new AR applications developed for the product development process should also be assessed to improve the product aspects' requirements and the AR Interaction framework.

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APPENDICES

A. CONSENT FORM FOR THE OBSERVATION STUDY

A.1. Consent form given to the students for the observation study (in Turkish)

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
Mimarlık Fakültesi, Endüstri Ürünleri Tasarımı Bölümü
Dersin Adı: ID402 Mezuniyet Projesi

Mart, 2017

Gözlem için katılımcı izin formu:

Araştırmacının doktora tezi, Endüstri Ürünleri Tasarımı eğitiminde artırılmış gerçeklik (AG) teknolojisi kullanarak interaktif ve etkili ortamlar oluşturmak üzerine yaptığı bir araştırmayı içermektedir. AG teknolojisiyle geliştirilecek olan uygulamaların, endüstriyel tasarım öğrencilerine ürün geliştirme sürecinde nasıl destekleyici bir katkı sağlayabileceği yaklaşımını ortaya çıkarması hedeflenmektedir.

Bu çalışmanın amacı ise, Endüstri Ürünleri Tasarımı bölümü öğrencilerinin stüdyo projelerinde, yeni ürün geliştirme sürecinin başından sonuna hangi aşamaları nasıl gerçekleştirdiklerini gözlemlemektir. Kullandıkları çizim, mock-up, model, ve benzeri araçları hangi aşamalarda, ne için ve nasıl kullandıklarını gözlemlemek, gerektiği durumlarda katılımcılara sorulacak sorularla desteklemektir. Gözlemler ders saatleri süresinde yapılacak, katılımcının ekstra zamanını almayacaktır. Katılımcılardan ID402 Mezuniyet Projeleri dersi kapsamında, kendi ürün geliştirme sürecini gerçekleştirmesi, bunları belgeleyerek düzenli bir şekilde dijital olarak göndermesi, ve gerekli durumlarda sorulacak sorulara cevap vermesi beklenmektedir. Gerekli görülen durumlarda gözlem sırasında fotoğraf çekilebilecektir.

Araştırma, katılımcılar açısından herhangi bir risk içer<u>memek</u>tedir. Katılımcılar, bu araştırmada kendi çalışmaları ile ilgili doğru ya da yanlış gibi herhangi bir şekilde değerlendirilmeyeceklerdir. Araştırma süresince toplanacak olan verilerden elde edilecek bilgiler, yalnızca bilimsel amaçlarla, tez araştırmasında ve araştırma sonucunda ortaya çıkabilecek bilimsel yayın ve sunuşlarda kullanılacak olup, veriler hiçbir şekilde 3. kişilerle paylaşılmayacaktır. İstenildiği takdirde çalışma sonucunda ortaya çıkan bilgi katılımcılarla paylaşılacaktır. Çalışma katılımcılar için gönüllülük esasına bağlı olup, çalışmanın herhangi bir aşamasında çalışmadan çekilebilme özgürlüğüne sahiptirler. Araştırmaya katkıda bulunduğunuz için teşekkür ederiz.

Yapılacak araştırmayla ilgili yukarıda yazılmış olan açıklamayı anladım ve gönüllü olarak çalışmaya katılmayı kabul ediyorum.

Araştırmacının;
Adı Soyadı : Alper KARADOĞANER
İmza :

Tarih :

İletişim bilgileri;
E-mail : alperkaradoganer@gmail.com
Telefon : 0312 210 6241
Adres : Endüstri Ürünleri Tasarımı Bölümü, ODTÜ

Danışmanın;
Adı Soyadı : Yrd. Doç. Dr. Naz BÖREKÇİ
E-mail : nborekci@metu.edu.tr

Katılımcının;
Adı Soyadı :
İmza :
(zorunlu değil)
Tarih :

İletişim bilgileri;
E-mail :
Telefon :

A.2. Consent form given to the students for the observation study (in English)

MIDDLE EAST TECHNICAL UNIVERSITY
Faculty of Architecture, Department of Industrial Design
Course Name: ID402 Graduation Project

March, 2017

Participant consent form for observation:

The researcher's doctoral thesis aims to explore on creating interactive and effective environments in Industrial Design education with the integration of augmented reality (AR) technology. It aims to reveal an approach how applications developed with AR technology can support industrial design students in the product development process.

The aim of this study is to observe how industrial design students follow a design process in their studio projects from the beginning to the end of the product development process. Sketchings, mock-ups, 3D-models and similar design representation tools that they use will be observed in terms of in which stage, for what purpose and how they use. The participants will be asked questions to support observations if necessary. Observations will be made during studio hours and will not take the participant's extra time. Participants are expected to carry out their own product development process within the scope of the ID402 Graduation Projects course. In addition, they are expected to document their process and regularly submit them digitally, and to answer questions that the researcher will ask when necessary. Photographs can be taken during observation in necessary situations.

The research does not involve any risk for the participants. Participants will not be evaluated somehow as right or wrong regarding their own work and process in this study. The findings that will be drawn from the data collected during the study will only be used for scientific purposes, for the thesis research and for scientific publications and presentations. The data will not be shared with third parties in any way. The findings from the study will be shared with the participants, if requested. The study is voluntary for the participants and they have the freedom to withdraw from the study at any stage of the study. Thank you for contributing to the research.

I understand the explanation written above about the study and I agree to participate in the study voluntarily.

Researcher;
Name Surname: Alper KARADOĞANER
Signature :

Date :

Contact information;
E-mail : alperkaradoganer@gmail.com
Phone : 0312 210 6241
Address : Department of Industrial Design, METU

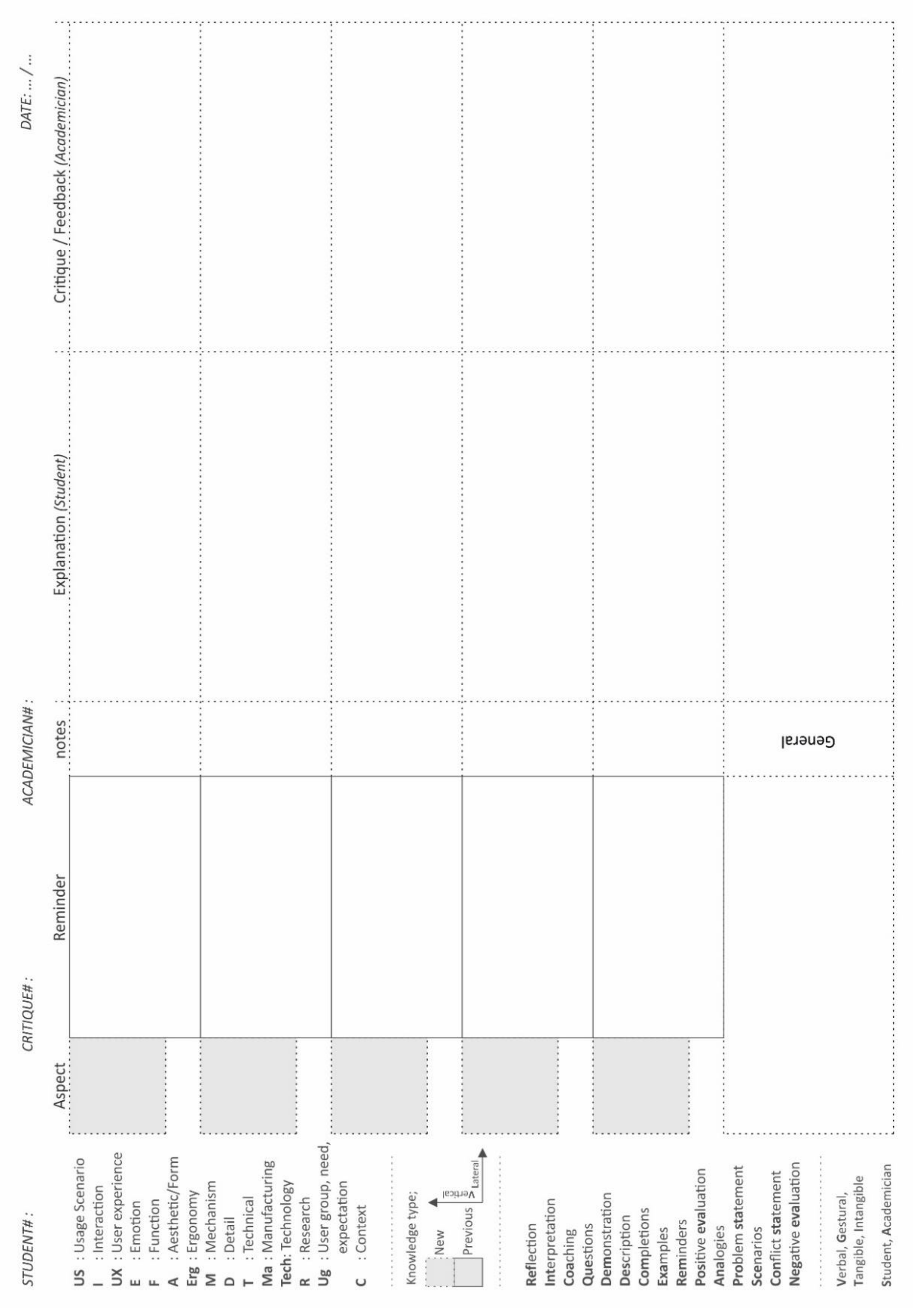
Supervisor;
Name Surname: Assist. Prof. Dr. Naz BÖREKÇİ
E-mail : nborekci@metu.edu.tr

Participant;
Name Surname:
Signature :
(not required)
Date :

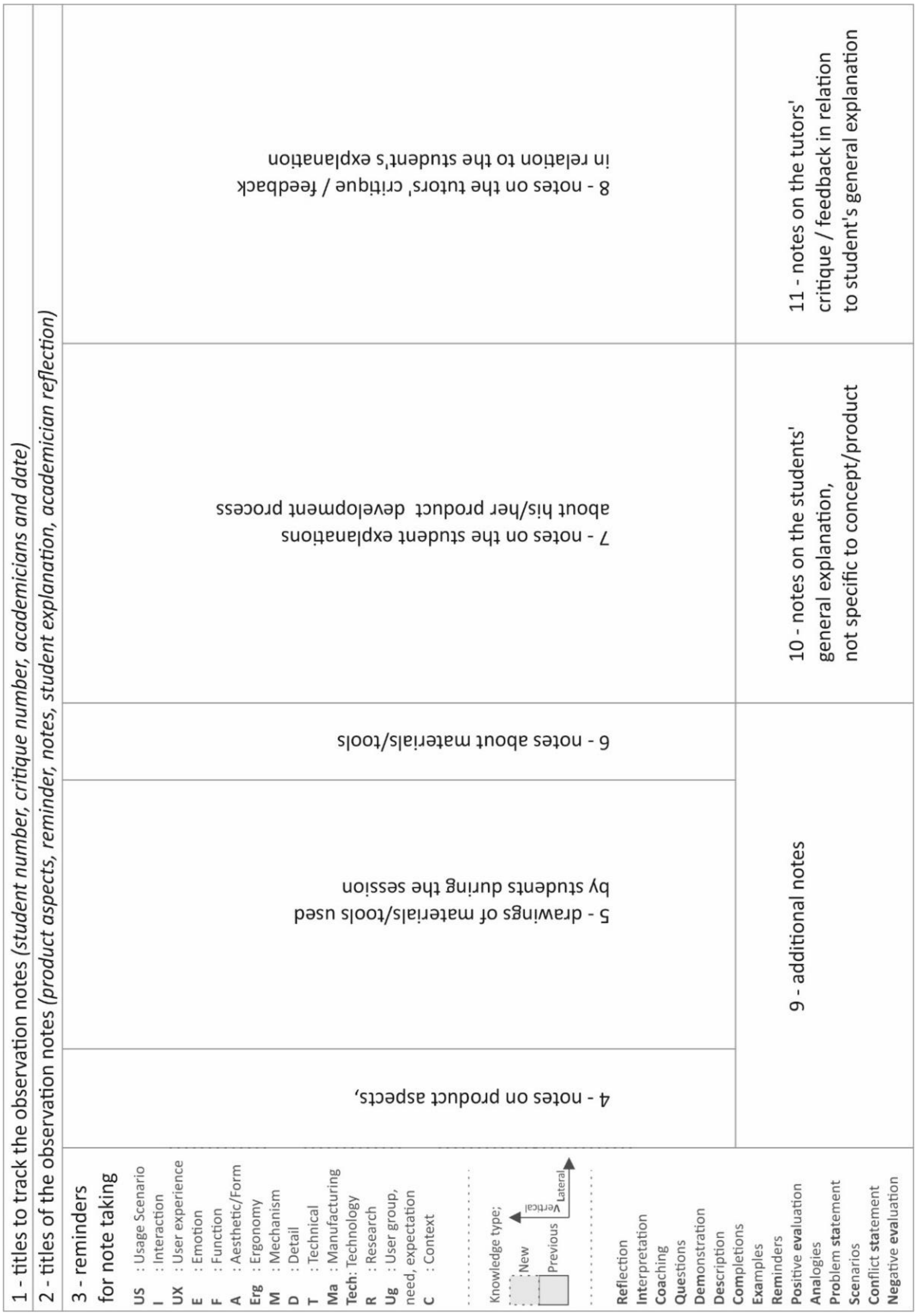
Contact information;
E-mail :
Phone :

B. OBSERVATION SHEET AND ITS EXPLANATION

B.1. Observation sheet used in the observation sessions



B.2. Explanation of the observation sheet used in the observation sessions



C. SURVEY GIVEN TO THE STUDENTS TO EVALUATE OBSERVATION SESSIONS

C.1. Survey given to the students (in Turkish)

Öğrenci #: Kritik #: Tarih: ... / ...

Öğrenci değerlendirmesi;

Aşağıda sorulan sorularda kendi yapmış olduğunuz çalışmaların **hazırlık aşamaları (1)** ve **bugünkü aşama (2), (3)** için değerlendirme yapmanız beklenmektedir. Yanlış ya da doğru cevap olmamakla birlikte samimi verilecek cevaplar çalışma için önemlidir.

(1) Bu aşamaya konseptinizi/ürününüzü kullandığınız araçlarla ne kadar iyi **hazırladığınızı** düşünüyorsunuz? Aşağıda verilen araçların her biri için ayrı değerlendirme yapılması beklenmektedir.

	Uygun değil		**Çok iyi değil**						**Çok iyi**
El çizimi	UD		1	2	3	4	5	6	7
Ek bilgiler	UD		1	2	3	4	5	6	7
Mock-up	UD		1	2	3	4	5	6	7
Render	UD		1	2	3	4	5	6	7
3D-model	UD		1	2	3	4	5	6	7
Diğer: …………………. (Varsa, Lütfen belirtiniz)	UD		1	2	3	4	5	6	7

(2) Bu aşamada konseptinizi/ürününüzü kullandığınız araçlarla ne kadar iyi **anlattığınızı** veya konseptinizin/ürününüzün kullandığınız araçlarla ne kadar **anlaşılır olduğunu** düşünüyorsunuz? Aşağıda verilen araçların her biri için ayrı değerlendirme yapılması beklenmektedir.

	Uygun değil		**Çok iyi değil**						**Çok iyi**
El çizimi	UD		1	2	3	4	5	6	7
Ek bilgiler	UD		1	2	3	4	5	6	7
Mock-up	UD		1	2	3	4	5	6	7
Render	UD		1	2	3	4	5	6	7
3D-model	UD		1	2	3	4	5	6	7
Diğer: …………………. (Varsa, Lütfen belirtiniz)	UD		1	2	3	4	5	6	7

(3) Bu aşamada **hocaların** konseptinizi/ürününüzü kullandığınız araçlarla ne kadar iyi **anladığını** düşünüyorsunuz? Aşağıda verilen araçların her biri için ayrı değerlendirme yapılması beklenmektedir.

	Uygun değil		**Çok iyi değil**						**Çok iyi**
El çizimi	UD		1	2	3	4	5	6	7
Ek bilgiler	UD		1	2	3	4	5	6	7
Mock-up	UD		1	2	3	4	5	6	7
Render	UD		1	2	3	4	5	6	7
3D-model	UD		1	2	3	4	5	6	7
Diğer: …………………. (Varsa, Lütfen belirtiniz)	UD		1	2	3	4	5	6	7

C.2. Survey given to the students (in English)

Student #: Critique #: Date: ... / ...

Student evaluation;

For the questions given below, you are expected to evaluate your work for the **preparation stages (1)** and the **current stage (2), (3)**. There is no wrong or right answers for the questions, sincere answers are important for the study.

(1) What do you think how well you **prepared** your concept/product for this stage with the tools you used? You are expected to make an evaluation for each of the tools listed below.

	Not applicable		**Not very good**						**Very good**
Sketching	NA		1	2	3	4	5	6	7
Extra information	NA		1	2	3	4	5	6	7
Mock-up	NA		1	2	3	4	5	6	7
Render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
Other: …………………. (If any, please specify)	NA		1	2	3	4	5	6	7

(2) At this stage, what do you think how well you **explained** your concept/product with the tools you use or how **understandable** your concept/product was with the tools you used? You are expected to make an evaluation for each of the tools listed below.

	Not applicable		**Not very good**						**Very good**
Sketching	NA		1	2	3	4	5	6	7
Extra information	NA		1	2	3	4	5	6	7
Mock-up	NA		1	2	3	4	5	6	7
Render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
Other: …………………. (If any, please specify)	NA		1	2	3	4	5	6	7

(3) At this stage, what do you think how well **the tutors understood** your concept/ product with the tools you used? You are expected to make an evaluation for each of the tools listed below.

	Not applicable		**Not very good**						**Very good**
Sketching	NA		1	2	3	4	5	6	7
Extra information	NA		1	2	3	4	5	6	7
Mock-up	NA		1	2	3	4	5	6	7
Render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
Other: …………………. (If any, please specify)	NA		1	2	3	4	5	6	7

D. SURVEY GIVEN TO THE TUTORS TO EVALUATE OBSERVATION SESSIONS

D.1. Survey given to the tutors (in Turkish)

Öğrenci #: Kritik # Tarih : ... / ...

Akademisyen değerlendirmesi;

Aşağıda sorulan sorularda öğrencinin yapmış olduğu çalışmaları bu aşamada değerlendirme yapmanız beklenmektedir. Yanlış ya da doğru cevap olmamakla birlikte samimi verilecek cevaplar çalışma için önemlidir.

(1) Bu aşamada **öğrencinin** konseptini/ürününü kullandığı araçlarla ne kadar iyi **anlattığını** veya konseptinin/ürününün kullandığı araçlarla ne kadar **anlaşılır olduğunu** düşünüyorsunuz? Aşağıda verilen araçların her biri için ayrı değerlendirme yapılması beklenmektedir.

	Uygun değil		**Çok iyi değil**						**Çok iyi**
El çizimi	UD		1	2	3	4	5	6	7
Ek bilgiler	UD		1	2	3	4	5	6	7
Mock-up	UD		1	2	3	4	5	6	7
Render	UD		1	2	3	4	5	6	7
3D-model	UD		1	2	3	4	5	6	7
Diğer: ………………….. (Varsa, Lütfen belirtiniz)	UD		1	2	3	4	5	6	7

(2) Bu aşamada öğrencinin anlattığı konseptini/ürününü kullandığı araçlarla ne kadar iyi **anladığınızı** düşünüyorsunuz? Aşağıda verilen araçların her biri için ayrı değerlendirme yapılması beklenmektedir.

	Uygun değil		**Çok iyi değil**						**Çok iyi**
El çizimi	UD		1	2	3	4	5	6	7
Ek bilgiler	UD		1	2	3	4	5	6	7
Mock-up	UD		1	2	3	4	5	6	7
Render	UD		1	2	3	4	5	6	7
3D-model	UD		1	2	3	4	5	6	7
Diğer: …………………. (Varsa, Lütfen belirtiniz)	UD		1	2	3	4	5	6	7

D.2. Survey given to the tutors (in English)

Student #: Critique # Date: ... / ...

Tutor evaluation;

For the questions given below, you are expected to evaluate the student's work for this stage. There is no wrong or right answers for the questions, sincere answers are important for the study.

(1) At this stage, what do you think how well **the student explained** his/her concept/ product with the tools he/she used or how **understandable** the concept/product was with the tools he/she used? You are expected to make an evaluation for each of the tools listed below.

	Not applicable		**Not very good**						**Very good**
Sketching	NA		1	2	3	4	5	6	7
Extra information	NA		1	2	3	4	5	6	7
Mock-up	NA		1	2	3	4	5	6	7
Render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
Other: …………………. (If any, please specify)	NA		1	2	3	4	5	6	7

(2) At this stage, what do you think how well you **understood** the student's concept/ product with the tools he/she used? You are expected to make an evaluation for each of the tools listed below.

	Not applicable		**Not very good**						**Very good**
Sketching	NA		1	2	3	4	5	6	7
Extra information	NA		1	2	3	4	5	6	7
Mock-up	NA		1	2	3	4	5	6	7
Render	NA		1	2	3	4	5	6	7
3D-model	NA		1	2	3	4	5	6	7
Other: ………………… (If any, please specify)	NA		1	2	3	4	5	6	7

E. FOCUS GROUP MATERIALS

E.1. Evaluation of the tools used during the product development process

1A EVALUATION OF THE TOOLS USED DURING THE PRODUCT DEVELOPMENT PROCESS

	06-12 March Workshop (problem definition), Desk critiques	13-19 March Workshop (initial ideas), Desk critiques	20-26 March Initial idea jury	27March-2April COD, Desk critiques	03-09 April Workshop (Naz Hoca), Desk critiques	10-16 April Desk critiques	17-23 April Preliminary Jury	24-30 April Workshop (Mehtap Hoca), Desk critiques	01-07 May Desk critiques	08-14 May Design/ Models screening	15-21 May Board Screening	22-28 May Preparation for final
Sketching												
Photo												
Graphic												
Video												
Sketching												
Mock-up												
3D-model												
Render												

E.2. Evaluation of the product aspects developed during the product development process

1B EVALUATION OF THE PRODUCT ASPECTS DEVELOPED DURING THE PRODUCT DEVELOPMENT PROCESS

	06-12 March Workshop (problem definition), Desk critiques	13-19 March Workshop (initial ideas), Desk critiques	20-26 March Initial idea jury	27March-2April COD, Desk critiques	03-09 April Workshop (Naz Hoca), Desk critiques	10-16 April Desk critiques	17-23 April Preliminary Jury	24-30 April Workshop (Mehtap Hoca), Desk critiques	01-07 May Desk critiques	08-14 May Design/ Model screening	15-21 May Board screening	22-28 May Preparation for final
Design ideas												
Aesthetics / form												
Usage scenario												
Feature / Function												
Physical ergonomy												
User interaction												
User interface												
User experience												
Context / Environment												
Other:												

E.2. Continued

1B EVALUATION OF THE PRODUCT ASPECTS DEVELOPED DURING THE PRODUCT DEVELOPMENT PROCESS

	06-12 March Workshop (problem definition), Desk critiques	13-19 March Workshop (initial ideas), Desk critiques	20-26 March Initial idea jury	27March-2April COD, Desk critiques	03-09 April Workshop (Naz Hoca), Desk critiques	10-16 April Desk critiques	17-23 April Preliminary Jury	24-30 April Workshop (Mehtap Hoca), Desk critiques	01-07 May Desk critiques	08-14 May Design/ Models screening	15-21 May Board Screening	22-28 May Preparation for final
Size												
Details												
Technical standards												
Mechanism												
Inner parts												
Technology												
Material / color												
Manufacturing												
Maintenance												
Other:												

E.3. Evaluation of the product aspects with the tools used during product development process

1C **EVALUATION OF THE PRODUCT ASPECTS RELATED TO THE TOOLS USED DURING THE PRODUCT DEVELOPMENT PROCESS**

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?

	WRITING								PHOTO								GRAPHIC								VIDEO							
		Not very well						Very well		Not very well						Very well		Not very well						Very well		Not very well						Very well
	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7	NA	1	2	3	4	5	6	7
Design ideas	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o

E.3. Continued

1C EVALUATION OF THE PRODUCT ASPECTS RELATED TO THE TOOLS USED DURING THE PRODUCT DEVELOPMENT PROCESS

	SKETCHING							
		Not very well						Very well
	NA	1	2	3	4	5	6	7
Design ideas	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

	MOCK-UP							
		Not very well						Very well
	NA	1	2	3	4	5	6	7
Design ideas	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

	3D-MODEL							
		Not very well						Very well
	NA	1	2	3	4	5	6	7
Design ideas	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

	RENDER							
		Not very well						Very well
	NA	1	2	3	4	5	6	7
Design ideas	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

E.4. Evaluation of the product aspects of the final product

1D EVALUATION OF THE PRODUCT ASPECTS OF THE FINAL PRODUCT

Could you evaluate the product aspects of the final product of the product development process? It is expected to evaluate each aspect related to your product.

	Not applicable NA	Not very good 1	2	3	4	5	6	Very good 7
Design ideas	o	o	o	o	o	o	o	o
Aesthetics / Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Context / environment	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material / color	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

E.5. Evaluation of the desk crits on the product development process (Negative effects)

2A EVALUATION OF THE DESK CRITIQUES DURING THE PRODUCT DEVELOPMENT PROCESS (NEGATIVE EFFECTS)

- At which stages of the product development process did you encounter challenging moments during the desk critiques? Could you tell us briefly?
- How could you make the challenging moments easier?
- Do you think whether there is a difference between your explanation of the concept/product and tutors' comprehension during the desk critique? If so, what were the factors affecting this difference? Could you tell us briefly?

	06-12 March	13-19 March	20-26 March	27March-2April	03-09 April	10-16 April	17-23 April	24-30 April	01-07 May	08-14 May	15-21 May	22-28 May
	Workshop (problem definition), Desk critiques	Workshop (initial ideas), Desk critiques	Initial idea jury	COD, Desk critiques	Workshop (Naz Hoca), Desk critiques	Desk critiques	Preliminary Jury	Workshop (Mehtap Hoca), Desk critiques	Desk critiques	Design/ Models screening	Board Screening	Preparation for final
The number of the participant												
....												

E.6. Evaluation of the desk crits on the product development process (Positive effects)

2B EVALUATION OF THE DESK CRITIQUES DURING THE PRODUCT DEVELOPMENT PROCESS (POSITIVE EFFECTS)

- What were the positive moments that influence the explanation of your idea/concept/product during the desk critiques? Could you tell us briefly?
- What were the tools that affect the desk critiques positively (writing, picture, video, graphic, sketches, detail drawings, technical drawings, render, 3d-model, mock-up) and at which stages and in which ways did these tools provide positive effects?
- What kind of contributions can be provided in order to increase the comprehension of your idea/concept/product during the desk critiques?

	06-12 March	13-19 March	20-26 March	27March-2April	03-09 April	10-16 April	17-23 April	24-30 April	01-07 May	08-14 May	15-21 May	22-28 May
	Workshop (problem definition), Desk critiques	Workshop (initial ideas), Desk critiques	Initial idea jury	COD, Desk critiques	Workshop (Naz Hoca), Desk critiques	Desk critiques	Preliminary Jury	Workshop (Mehtap Hoca), Desk critiques	Desk critiques	Design/ Models screening	Board Screening	Preparation for final
The number of the participant												
....												

E.7. Evaluation of 3D modelling during the product development process

2C EVALUATION OF 3D MODELLING DURING THE PRODUCT DEVELOPMENT PROCESS

	In which stage of product development process should 3D modelling start?	Are there any restrictions in using 3D modelling?	Which of the product aspects (such as form, details, mechanism, etc.) do you explain more easily by using 3D models?
	When considered with the other tools, what are the effective points of using 3D models in explaining the concept/product?	What are the advantages and disadvantages of using 3D models during desk critique sessions?	Considering the product development process, in which stages should 3D models be used during the desk critiques to explain the concept/product?

E.8. Evaluation of the importance of product aspects for the development of AR technology

3B **EVALUATION OF THE IMPORTANCE OF THE PRODUCT ASPECTS IN DEVELOPING AR TECHNOLOGY**

Could you evaluate the importance of each product aspect given below in developing an augmented reality application for the product development process? Please evaluate the each product aspect.

	NA	Not very important 1	2	3	4	5	6	Very important 7
Design ideas	o	o	o	o	o	o	o	o
Form	o	o	o	o	o	o	o	o
Usage scenario	o	o	o	o	o	o	o	o
Feature / function	o	o	o	o	o	o	o	o
Physical ergonomy	o	o	o	o	o	o	o	o
User interaction	o	o	o	o	o	o	o	o
User interface	o	o	o	o	o	o	o	o
User experience	o	o	o	o	o	o	o	o
Size	o	o	o	o	o	o	o	o
Details	o	o	o	o	o	o	o	o
Technical standards	o	o	o	o	o	o	o	o
Mechanism	o	o	o	o	o	o	o	o
Inner parts	o	o	o	o	o	o	o	o
Technology	o	o	o	o	o	o	o	o
Material	o	o	o	o	o	o	o	o
Manufacturing	o	o	o	o	o	o	o	o
Maintenance	o	o	o	o	o	o	o	o

E.8. Continued

3B **EVALUATION OF THE IMPORTANCE OF THE PRODUCT ASPECTS IN DEVELOPING AR TECHNOLOGY**

Could you evaluate the importance of each product aspect given below in developing an augmented reality application for the product development process? Please evaluate the each product aspect.

	NA	Not very important 1	2	3	4	5	6	Very important 7
Project statement	o	o	o	o	o	o	o	o
Keywords	o	o	o	o	o	o	o	o
Similar product	o	o	o	o	o	o	o	o
User group	o	o	o	o	o	o	o	o
User need	o	o	o	o	o	o	o	o
Current situation	o	o	o	o	o	o	o	o
Technology information	o	o	o	o	o	o	o	o
Different materials	o	o	o	o	o	o	o	o
Exploded drawing	o	o	o	o	o	o	o	o
Product alternatives	o	o	o	o	o	o	o	o
Product analysis	o	o	o	o	o	o	o	o
User evaluation	o	o	o	o	o	o	o	o
Context simulation	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o
Other:	o	o	o	o	o	o	o	o

F. EVALUATION OF THE PRODUCT ASPECTS RELATED TO THE TOOLS USED DURING THE PRODUCT DEVELOPMENT PROCESS

F.1. Evaluation of the product aspects with writing and photo

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?																				
	WRITING										PHOTO									
		Not very well						Very well				Not very well						Very well		
	NA	1	2	3	4	5	6	7		Avarage value	NA	1	2	3	4	5	6	7		Avarage value
usage scenario	0	0	0	1	3	6	6	2	*18*	5,28	4	1	0	0	1	5	4	2	*13*	5,23
user experience	4	0	0	3	4	5	2	0	*14*	4,43	10	0	0	0	3	1	2	0	*6*	4,83
user interaction	2	0	1	2	7	3	2	1	*16*	4,38	12	0	0	0	1	0	2	1	*4*	5,75
user interface	11	0	1	1	0	3	1	1	*7*	4,71	13	0	1	1	1	0	0	0	*3*	3,00
feature/func.	1	1	0	0	2	5	7	2	*17*	5,29	10	1	1	1	1	1	0	1	*6*	3,67
parts	12	0	1	1	2	2	0	0	*6*	3,83	13	0	0	0	1	1	1	0	*3*	5,00
physical erg.	10	2	4	1	1	0	0	0	*8*	2,13	11	0	1	0	3	0	0	1	*5*	4,20
form	12	4	1	0	1	0	0	0	*6*	1,67	9	1	0	1	3	0	2	0	*7*	4,00
size	8	0	0	1	2	3	1	3	*10*	5,30	11	0	0	0	0	1	3	1	*5*	6,00
material/color	6	0	0	1	3	4	2	2	*12*	5,08	10	1	0	1	1	3	1	0	*7*	4,14
context/env.	9	0	1	1	1	4	1	1	*9*	4,67	4	0	0	0	3	0	5	5	*13*	5,92
mechanism	12	1	1	1	1	2	0	0	*6*	3,33	11	0	0	0	0	2	3	0	*5*	5,60
details	3	0	0	2	6	7	0	0	*15*	4,33	13	1	0	0	1	0	0	1	*3*	4,00
technical stand.	4	0	0	3	4	5	2	0	*14*	4,43	10	0	1	0	1	2	2	0	*6*	4,67
inner parts	12	0	1	1	2	2	0	0	*6*	3,83	13	0	0	0	1	1	1	0	*3*	5,00
technology	9	0	0	1	2	3	0	3	*9*	5,22	9	0	0	0	1	1	3	2	*7*	5,86
maintenance	13	0	0	1	1	1	2	0	*5*	4,80	15	0	0	0	0	0	1	0	*1*	6,00
manufacturing	6	0	0	3	2	3	3	1	*12*	4,75	15	0	0	0	0	1	0	0	*1*	5,00

F.2. Evaluation of the product aspects with graphic and video

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?																				
	GRAPHIC										VİDEO									
		Not very well						Very well				Not very well						Very well		
	NA	1	2	3	4	5	6	7		Avarage value	NA	1	2	3	4	5	6	7		Avarage value
usage scenario	3	0	0	1	3	5	5	0	*14*	5,00	12	0	0	1	1	0	0	0	*2*	3,50
user experience	6	0	1	0	5	3	1	0	*10*	4,30	12	0	0	0	0	1	1	0	*2*	5,50
user interaction	5	0	1	0	5	4	1	0	*11*	4,36	12	0	0	0	1	0	1	0	*2*	5,00
user interface	6	1	0	1	2	0	6	1	*11*	5,00	14	0	0	0	0	0	0	0	*0*	
feature/func.	4	0	0	2	1	6	3	0	*12*	4,83	14	0	0	0	0	0	0	0	*0*	
parts	10	0	1	0	0	3	2	0	*6*	4,83	13	0	0	0	1	0	0	0	*1*	4,00
physical erg.	7	0	2	1	3	0	3	0	*9*	4,11	14	0	0	0	0	0	0	0	*0*	
form	7	0	2	1	2	3	1	0	*9*	4,00	14	0	0	0	0	0	0	0	*0*	
size	8	0	0	0	0	3	5	0	*8*	5,63	14	0	0	0	0	0	0	0	*0*	
material/color	11	0	0	1	1	1	1	1	*5*	5,00	13	0	0	0	0	0	1	0	*1*	6,00
context/env.	8	0	0	0	3	1	5	0	*9*	5,22	13	0	0	0	0	1	0	0	*1*	5,00
mechanism	8	0	0	0	0	5	2	1	*8*	5,50	13	0	0	0	0	1	0	0	*1*	5,00
details	6	0	1	1	2	4	1	1	*10*	4,60	13	0	0	1	0	0	0	0	*1*	3,00
technical stand.	7	0	0	1	0	5	3	0	*9*	5,11	11	0	1	0	0	2	0	0	*3*	4,00
inner parts	10	0	1	0	0	3	2	0	*6*	4,83	13	0	0	0	1	0	0	0	*1*	4,00
technology	12	0	0	1	2	1	0	0	*4*	4,00	11	0	0	0	0	1	1	1	*3*	6,00
maintenance	13	0	0	1	0	0	1	0	*2*	4,50	13	0	0	0	0	0	0	0	*0*	
manufacturing	13	0	1	1	0	0	0	1	*3*	4,00	14	0	0	0	0	0	0	0	*0*	

F.3. Evaluation of the product aspects with sketching and mock-up

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?

	SKETCHING										MOCK-UP										
		Not very well						Very well				Not very well						Very well		
	NA	1	2	3	4	5	6	7		Avarage value	NA	1	2	3	4	5	6	7		Avarage value
usage scenario	1	1	1	2	4	3	5	1	*17*	4,53	4	1	1	0	3	2	3	4	*14*	5,07
user experience	7	0	0	2	5	3	1	0	*11*	4,27	9	0	1	0	2	3	2	1	*9*	4,89
user interaction	4	1	3	0	4	4	2	0	*14*	3,93	5	2	0	1	0	3	6	1	*13*	4,85
user interface	8	0	0	0	2	4	4	0	*10*	5,20	13	1	0	0	2	0	1	1	*5*	4,40
feature/func.	2	0	1	0	6	5	3	1	*16*	4,75	3	2	1	1	1	3	6	1	*15*	4,60
parts	7	1	3	3	2	2	0	0	*11*	3,09	11	2	1	1	0	0	2	1	*7*	3,71
physical erg.	6	1	3	3	3	1	1	0	*12*	3,25	3	2	1	0	0	4	5	3	*15*	5,00
form	0	0	4	2	4	2	6	0	*18*	4,22	0	2	2	0	3	5	3	3	*18*	4,56
size	1	2	2	1	5	5	2	0	*17*	3,88	1	1	1	0	1	2	1	11	*17*	5,88
material/color	7	4	1	2	3	1	0	0	*11*	2,64	7	4	0	1	1	4	0	1	*11*	3,45
context/env.	5	1	4	2	2	1	3	0	*13*	3,54	10	1	2	0	2	1	2	0	*8*	3,75
mechanism	6	0	2	2	4	4	0	0	*12*	3,83	6	1	0	1	1	3	4	2	*12*	5,08
details	0	0	3	3	5	5	2	0	*18*	4,00	2	1	3	1	1	5	3	2	*16*	4,44
technical stand.	4	1	3	2	7	1	0	0	*14*	3,29	7	2	1	2	1	3	1	1	*11*	3,82
inner parts	7	1	3	3	2	2	0	0	*11*	3,09	11	2	1	1	0	0	2	1	*7*	3,71
technology	14	0	0	2	0	1	1	0	*4*	4,25	15	1	0	1	0	1	0	0	*3*	3,00
maintenance	13	0	0	2	1	1	1	0	*5*	4,20	15	0	0	1	0	0	1	1	*3*	5,33
manufacturing	9	2	2	1	3	1	0	0	*9*	2,89	10	1	1	2	2	0	1	1	*8*	3,75

F.4. Evaluation of the product aspects with 3D-model and render

Could you evaluate how well you explained the product aspects given below with the tools used during the design process?																				
	3D-MODEL										RENDER									
		Not very well					Very well					Not very well					Very well			
	NA	1	2	3	4	5	6	7		Avarage value	NA	1	2	3	4	5	6	7		Avarage value
usage scenario	6	0	0	1	4	4	3	0	*12*	4,75	2	0	0	2	2	7	2	3	*16*	5,13
user experience	9	0	1	0	3	3	2	0	*9*	4,56	6	0	0	1	5	3	2	1	*12*	4,75
user interaction	7	0	0	2	3	3	3	0	*11*	4,64	3	0	0	2	5	2	1	5	*15*	5,13
user interface	12	0	0	1	1	1	2	1	*6*	5,17	10	0	0	0	0	2	3	3	*8*	6,13
feature/func.	0	0	0	0	2	8	6	2	*18*	5,44	1	0	0	0	2	7	4	4	*17*	5,59
parts	5	0	0	1	3	5	2	2	*13*	5,08	5	0	2	0	4	2	3	2	*13*	4,77
physical erg.	3	1	1	3	2	4	3	1	*15*	4,33	5	0	3	0	3	4	2	1	*13*	4,38
form	0	0	0	0	1	4	10	3	*18*	5,83	0	1	0	0	0	4	7	6	*18*	5,83
size	0	0	1	0	2	1	8	6	*18*	5,83	1	0	0	0	1	3	9	4	*17*	5,94
material/color	7	3	3	1	1	0	2	1	*11*	3,18	2	0	0	1	1	3	3	8	*16*	6,00
context/env.	8	1	2	1	3	0	3	0	*10*	3,80	1	0	0	0	2	5	4	6	*17*	5,82
mechanism	5	0	0	3	1	5	2	2	*13*	4,92	6	0	3	2	3	0	2	2	*12*	4,17
details	1	0	0	1	1	4	8	3	*17*	5,65	1	0	1	0	0	6	6	4	*17*	5,65
technical stand.	1	0	2	2	1	3	6	3	*17*	5,06	1	0	3	2	3	2	6	1	*17*	4,53
inner parts	5	0	0	1	3	5	2	2	*13*	5,08	5	0	2	0	4	2	3	2	*13*	4,77
technology	10	0	0	2	3	2	1	0	*8*	4,25	10	1	2	0	1	2	1	1	*8*	4,00
maintenance	14	2	0	1	0	0	0	1	*4*	3,00	13	2	0	1	0	1	1	0	*5*	3,20
manufacturing	8	2	0	2	2	1	3	0	*10*	3,90	9	2	1	0	3	1	0	2	*9*	3,89

G. CONSENT FORM GIVEN FOR AUGMENTED REALITY STUDY

G.1. Consent form given to the students for AR study (in Turkish)

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
Mimarlık Fakültesi, Endüstri Ürünleri Tasarımı Bölümü
Dersin Adı: ID430 Dijital Modelleme ve Üretim

Kasım, 2019

Masa kritiği gözlemi için katılımcı izin formu:

Bu araştırma, Endüstri Ürünleri Tasarımı eğitiminde artırılmış gerçeklik (AG) teknolojisi kullanarak interaktif ve etkili ortamlar, *özellikle masa kritikleri*, oluşturmak üzerine doktora tezi için kurgulanmış bir araştırmayı içermektedir. AG teknolojisi kullanarak desteklenen masa kritiklerinin endüstriyel tasarım öğrencilerine süreçte nasıl destekleyici bir katkı sağlayabileceği yaklaşımını ortaya çıkarması hedeflenmektedir.

Bu çalışmanın amacı ise, Endüstri Ürünleri Tasarımı bölümü öğrencilerinin masa kritiklerinde diğer tasarım temsil araçlarına ek olarak kullanabilecekleri AG teknolojisinin kritiklerde nasıl katkı sağladığını gözlemlemektir. Kullandıkları çizim, görsel mock-up, dijital model, ve AG teknolojisini masa kritiğinde ne için ve nasıl kullandıklarını gözlemlemek ve masa kritiği sonrasında katılımcılara sorulacak sorularla desteklemektir. Masa kritiği gözlemleri ders saatleri süresinde yapılacak, katılımcının ekstra zamanını almayacaktır. Katılımcılardan ID430 Dijital Modelleme ve Üretim dersi kapsamında geliştirdiği ürün ile ilgili tasarım temsil araçlarıyla (*çizim, görsel mock-up, dijital model, gerçekçi görsel ve AR uygulaması)* kritik alması, ve kullandığı temsil araçlarını belgeleyerek dijital olarak odtuclass sistemine yüklemesi beklenmektedir. Gözlem sonrasında verilecek olan anket değerlendirmesinde yer alan sorulara cevap vermesi beklenmektedir. Gerekli görülen durumlarda gözlem sırasında fotoğraf çekilebilecektir.

Araştırma, katılımcılar açısından herhangi bir risk içermemektedir. Katılımcılar, bu araştırmada kendi çalışmaları ile ilgili doğru ya da yanlış gibi herhangi bir şekilde değerlendirilmeyeceklerdir. Araştırma süresince toplanacak olan verilerden elde edilecek bilgiler, yalnızca bilimsel amaçlarla, tez araştırmasında ve araştırma sonucunda ortaya çıkabilecek bilimsel yayın ve sunuşlarda kullanılacak olup, veriler hiçbir şekilde 3. kişilerle paylaşılmayacaktır. İstenildiği takdirde çalışma sonucunda ortaya çıkan bilgi katılımcılarla paylaşılacaktır. Çalışma katılımcılar için gönüllülük esasına bağlı olup, çalışmanın herhangi bir aşamasında çalışmadan çekilebilme özgürlüğüne sahiptirler. Araştırmaya katkıda bulunduğunuz için teşekkür ederiz.

Yapılacak araştırmayla ilgili yukarıda yazılmış olan açıklamayı anladım ve gönüllü olarak çalışmaya katılmayı kabul ediyorum.

Araştırmacının;
Adı Soyadı : Alper KARADOĞANER
İmza :

Tarih :

İletişim bilgileri;
E-mail : alperkaradoganer@gmail.com
Telefon : 0312 210 6241
Adres : Endüstri Ürünleri Tasarımı Bölümü, ODTÜ

Danışmanın;
Adı Soyadı : Doç. Dr. Naz BÖREKÇİ
E-mail : nborekci@metu.edu.tr

Katılımcının;
Adı Soyadı :
İmza :
(zorunlu değil)
Tarih :

G.2. Consent form given to the students for AR study (in English)

MIDDLE EAST TECHNICAL UNIVERSITY
Faculty of Architecture, Department of Industrial Design
Course Name: ID430 Digital Modelling and Fabrication

November, 2019

Participant consent form for desk crit observation:

This study is a part of the researcher's thesis and it aims to explore on creating interactive and effective environments, especially desk crits, by integrating augmented reality (AR) technology into the product development process in Industrial Design education. It aims to reveal an approach how desk crits supported with AR technology can support the product development process of industrial design students.

The aim of this study is to observe how AR technology, which can be used as a supportive design representation tool in addition to other tools by industrial design students, contributes to the desk crits. Sketchings, visual mock-ups, 3D-models, renders and AR technology tools will be observed in desk crits how and for what the participants will use. The participants will be asked questions to support observations to support desk crits. Desk crit observations will be made during course hours and will not take the participant's extra time. Participants are expected to get feedback from the tutors with the design representation tools (sketching, visual mock-ups, 3D-model, render and AR application) for the product developed within the scope of the ID430 Digital Modelling and Fabrication course. In addition, they are expected to digitally upload the design representation tools that they use to the odtuclass system. After desk crit observations, it is expected to answer the questions in the survey evaluation which will be given after the observation. Photographs can be taken during observation in necessary situations.

The research does not involve any risk for the participants. Participants will not be evaluated somehow as right or wrong regarding their own work and process in this study. The findings that will be drawn from the data collected during the study will only be used for scientific purposes, for the thesis research and for scientific publications and presentations. The data will not be shared with third parties in any way. The findings from the study will be shared with the participants, if requested. The study is voluntary for the participants and they have the freedom to withdraw from the study at any stage of the study. Thank you for contributing to the research.

I understand the explanation written above about the study and I agree to participate in the study voluntarily.

Researcher;	**Participant**;
Name Surname: Alper KARADOĞANER	Name Surname:
Signature :	Signature : *(not required)*
Date :	Date :
Contact information;	**Contact information;**
E-mail : alperkaradoganer@gmail.com	E-mail :
Phone : 0312 210 6241	Phone :
Address : Department of Industrial Design, METU	
Supervisor;	
Name Surname: Assist. Prof. Dr. Naz BÖREKÇİ	
E-mail : nborekci@metu.edu.tr	

H. SURVEY GIVEN TO THE STUDENTS TO EVALUATE AR SESSION

H.1. Survey given to the students (in Turkish)

ARTIRILMIŞ GERÇEKLİK (AG) TEKNOLOJİSİNİN
DİĞER TASARIM TEMSİL ARAÇLARIYLA BİRLİKTE
SUNUMDA KULLANIMININ DEĞERLENDİRİLMESİ

DEĞERLENDİRME FORMU

Bu anket 4 farklı bölümde toplamda 14 sorudan oluşmaktadır.

A- AG uygulaması kullanarak gerçekleştirilen masa kritiğinin değerlendirilmesi

1- Diğer tasarım temsil araçları ile birlikte AG teknolojisi kullanarak sunum yapmak sana neler düşündürttü? Nasıl bir deneyim olduğunu düşünüyorsun? (Lütfen kısaca belirtiniz.)

2- Sunumda AG teknolojisi kullanarak ürünü anlatıyor olmanın olumlu yanları neler olmuştur? (Lütfen kısaca belirtiniz.)

3- Sunumda AG teknolojisi kullanarak ürünü anlatırken, varsa yaşadığınız olumsuz noktalar nelerdir? (teknik zorluklar, kullanım zorluğu, vs.) (Lütfen kısaca belirtiniz.)

4- AG teknolojisinin diğer temsil araçlarına göre (çizim, mock-up, dijital model, vb.) avantajlı olduğu ve kullanılabilecek özellikleri nelerdir? (Lütfen kısaca belirtiniz.)

5- Eğer varsa, AG teknolojisi ile ilgili eklemek istedikleriniz nelerdir? (Lütfen kısaca belirtiniz.)

1, 2, 3, 4 ve 5. sorulara tanımlanmış alanlar yetmezse bu sayfadaki kalan boş alanı soru numarasını belirterek kullanabilirsiniz.

B- AG uygulaması kullanarak gerçekleştirilen masa kritikleri için aşağıda verilen ifadeleri değerlendirmenizi rica ederiz.	Kesinlikle katılmıyorum	Katılmıyorum	Ne katılıyorum Ne katılmıyorum	Katılıyorum	Kesinlikle katılıyorum
Sunum ile ilgili;					
AG teknolojisi kullanarak gerçekleştirilen sunum motivasyonumu artırmıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG teknolojisi kullanarak gerçekleştirilen sunum ürünle ilgili anlaşılabilirliği artırmıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG teknolojisi kullanarak gerçekleştirilen sunum hoca ile olan etkileşimi artırmıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG teknolojisi kullanarak gerçekleştirilen sunum daha iyi geri bildirim almamı sağlamıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG teknolojisi kullanarak gerçekleştirilen sunum daha verimli geçmiştir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG teknolojisi kullanarak gerçekleştirilen sunum daha eğlenceli olmuştur.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					

B. Sorunun devamı	Kesinlikle katılmıyorum	Katılmıyorum	Ne katılıyorum Ne katılmıyorum	Katılıyorum	Kesinlikle katılıyorum
AG uygulaması ile ilgili;					
AG uygulaması kolay anlaşılabilir bir uygulamadır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG uygulaması kullanması kolay bir uygulamadır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG uygulaması ürünün 3 boyutlu olarak gerçekçiliğini hissettirebilmeyi sağlamıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG uygulaması önemli noktalara doğrudan dikkat çekebilmeyi sağlamıştır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG uygulaması kolay erişilebilen bir uygulamadır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
AG uygulaması etkileşimi kolay bir uygulamadır.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					

B. Sorunun devamı	Kesinlikle katılmıyorum	Katılmıyorum	Ne katılıyorum Ne katılmıyorum	Katılıyorum	Kesinlikle katılıyorum
Stüdyo projelerinde kullanımı ile ilgili;					
AG teknolojisi masa kritiklerinde kullanılabilecek destekleyici bir tasarım temsil aracı olabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanmak tasarım sürecinde motivasyonumu artırabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanmak tasarım sürecinde performansımı artırabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanarak hocalarla gerçekleştirilen masa kritiklerinde ürünümün daha anlaşılabilir olmasını sağlayabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanarak hocalarla gerçekleştirilen masa kritiklerinin daha verimli geçmesini sağlayabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					

B. Sorunun devamı	Kesinlikle katılmıyorum	Katılmıyorum	Ne katılıyorum Ne katılmıyorum	Katılıyorum	Kesinlikle katılıyorum
Stüdyo projelerinde AG teknolojisi kullanarak hocalarla gerçekleştirilen masa kritiklerinin daha etkileşimli geçmesini sağlayabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanarak gerçekleştirilen masa kritiği hocalardan daha iyi geri bildirim almamı sağlayabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					
Stüdyo projelerinde AG teknolojisi kullanarak gerçekleştirilen masa kritikleri ürünle ilgili hafızada daha kalıcı etki yatabilir.	○	○	○	○	○
Neden? (Lütfen kısaca belirtiniz.)					

C- AG teknolojisinin ürün geliştirme sürecinde kullanım potansiyellerinin değerlendirilmesi

AG teknolojisindeki sorunların en aza indirilmiş ve hazırlama sürecinin daha kolay olduğunu düşünerek, ürün geliştirme sürecinin hangi aşamalarında nasıl kullanım potansiyellerinin olabileceğini aşamalarına göre kısaca açıklayıcı şekilde belirtiniz.

proje tanımı	ilk fikirler jurisi	..... masa kritikleri	ön juri	..... masa kritikleri	final screening (tasarım/model) (paftalar)	final jurisi
		** ilk fikirler ve ön juri aşaması arasında 3B modellemeye başladığınızı düşünerek* *** örnek olarak Seçtiğim konseptleri hızlıca modelleyip masa kritiklerinde gösterebilirim.**				

C- AG teknolojisinin ürün geliştirme sürecinde kullanım potansiyellerinin değerlendirilmesi (ön sayfa yetmezse, ek olarak devam ediniz) AG teknolojisindeki sorunların en aza indirilmiş ve hazırlama sürecinin daha kolay olduğunu düşünerek, ürün geliştirme sürecinin hangi aşamalarında nasıl kullanım potansiyellerinin olabileceğini aşamalarına göre kısaca açıklayıcı şekilde belirtiniz.

proje tanımı	ilk fikirler jurisi	..... masa kritikleri	ön juri	..... masa kritikleri	final screening (tasarım/model) (paftalar)	final jurisi
		** ilk fikirler ve ön juri aşaması arasında 3B modellemeye başladığınızı düşünerek* *** örnek olarak Seçtiğim konseptleri hızlıca modelleyip masa kritiklerinde gösterebilirim.**				

D- AG teknolojisi kullanarak anlatılabilecek ürün özelliklerinin değerlendirilmesi

Aşağıda verilen ürünle ilgili bilgilerin AG teknolojisi kullanarak anlatımının ne kadar önemli olduğunu düşünüyorsunuz? Geçerli olan her bilgi için ayrı değerlendirme yapmanız beklenmektedir.	*Uygun değil*	Çok önemli değil				Çok önemli
Konsept alternatifleri	○	○	○	○	○	○
Ürün kullanım senaryosu	○	○	○	○	○	○
Kullanıcı deneyimi	○	○	○	○	○	○
Ürün-kullanıcı etkileşimi	○	○	○	○	○	○
Kullanıcı arayüzü	○	○	○	○	○	○
Ürün özellikleri	○	○	○	○	○	○
Ürün parçaları	○	○	○	○	○	○
Ürün ergonomisi	○	○	○	○	○	○
Ürün formu	○	○	○	○	○	○
Ürün boyutları	○	○	○	○	○	○
Ürün malzemesi/rengi	○	○	○	○	○	○
Kullanılacağı ortam	○	○	○	○	○	○
Ürün mekanizması	○	○	○	○	○	○
Ürün detayları	○	○	○	○	○	○
Ürün teknik standartları	○	○	○	○	○	○
Ürün iç aksamları	○	○	○	○	○	○
Ürünün birleşimi	○	○	○	○	○	○
Ürün teknolojisi	○	○	○	○	○	○
Ürünün üretimi	○	○	○	○	○	○
Ürünün bakımı	○	○	○	○	○	○
Kullanıcı değerlendirmesi	○	○	○	○	○	○
Diğer (Lütfen belirtiniz)…………………………		○	○	○	○	○
Diğer (Lütfen belirtiniz)…………………………		○	○	○	○	○

AG teknolojisi ile ilgili eklemek istedikleriniz varsa, lütfen kısaca belirtiniz.

H.2. Survey given to the students (in English)

EVALUATION OF THE USE OF
AUGMENTED REALITY (AR) TECHNOLOGY WITH OTHER
DESIGN REPRESENTATION TOOLS IN PRESENTATION

EVALUATION FORM

This survey consists of 14 questions in 4 different parts.

A- Evaluation of desk crit which was supported with AR application

1- What do you think about presenting your design concept by using AR technology together with other design representation tools? What are your experiences? (Please briefly mention.)

2- What are the advantages of using AR technology in desk crit to explain the product aspects? (Please briefly mention.)

3- What are the negative sides that you experienced when using AR technology in desk crit? (Technical difficulties, difficulty of use, etc.) (Please briefly mention.)

4- What are the advantages of AR technology when compared to other design representation tools (sketching, mock-up, digital model, etc.) and which features can be used in desk crits? (Please briefly mention.)

5- If any, what would you like to add about AR technology? (Please briefly mention.)

If the fields defined for questions 1, 2, 3, 4 and 5 are not enough, you can use the remaining blank space on this page by specifying the question number.

B- We kindly ask you to evaluate the statements given below for desk crit supported with AR application.	Strongly disagree	Disagree	Neither disagree Nor agree	Agree	Strongly agree
About presentation in desk crit;					
Presenting design concept with AR technology during desk crit increased my motivation.	○	○	○	○	○
Why? (Please explain briefly.)					
Presenting design concept with AR during desk crit increased intelligibility of the concept.	○	○	○	○	○
Why? (Please explain briefly.)					
Presenting design concept with AR during desk crit increased the interaction with the tutor.	○	○	○	○	○
Why? (Please explain briefly.)					
Presenting design concept with AR during desk crit enabled me to get better feedback.	○	○	○	○	○
Why? (Please explain briefly.)					
Presenting design concept with AR technology during desk crit was more efficient.	○	○	○	○	○
Why? (Please explain briefly.)					
Presenting design concept with AR technology during desk crit was more fun.	○	○	○	○	○
Why? (Please explain briefly.)					

B. Continuation of the question	Strongly disagree	Disagree	Neither disagree Nor agree	Agree	Strongly agree
About AR application;					
AR application is easy to understand.	○	○	○	○	○
Why? (Please explain briefly.)					
AR application is easy to use.	○	○	○	○	○
Why? (Please explain briefly.)					
AR application enabled to feel the concept 3D realistically.	○	○	○	○	○
Why? (Please explain briefly.)					
AR application enabled to direct the attention to important points.	○	○	○	○	○
Why? (Please explain briefly.)					
AR application is an easily accessible application.	○	○	○	○	○
Why? (Please explain briefly.)					
AG application is easy to interact.	○	○	○	○	○
Why? (Please explain briefly.)					

B. Continuation of the question	Strongly disagree	Disagree	Neither disagree Nor agree	Agree	Strongly agree
About the use of AR in studio projects;					
AR technology can be a supportive design representation tool that can be used in desk critics.	○	○	○	○	○
Why? (Please explain briefly.)					
Using AR in studio projects can increase my motivation during the design process.	○	○	○	○	○
Why? (Please explain briefly.)					
Using AR in studio projects can improve my performance during the design process.	○	○	○	○	○
Why? (Please explain briefly.)					
Using AR in studio projects can make design concept more understandable in the desk crits with tutors.	○	○	○	○	○
Why? (Please explain briefly.)					
Using AR in studio projects can make the desk crits with tutors more efficient.	○	○	○	○	○
Why? (Please explain briefly.)					

B. Continuation of the question	Strongly disagree	Disagree	Neither disagree Nor agree	Agree	Strongly agree
Using AR in studio projects can make the desk crits with tutors more interactive.	○	○	○	○	○
Why? (Please explain briefly.)					
Desk crits supported with AR in studio projects can enable better feedback from tutors.	○	○	○	○	○
Why? (Please explain briefly.)					
Desk crits supported with AR in studio projects may have positive effect on long-term memory.	○	○	○	○	○
Why? (Please explain briefly.)					

C- Evaluation of the potential use of AR technology in product development process

Considering that the problems in AR technology are minimized and the preparation process is easier, please explain how AR technology can be used in which stages of the product development process.

project definition	initial idea jury	..... desk crits	preliminary jury	..... desk crits	final screening (design/3D-model) (boards)	final jury

** thinking that you are starting 3D modeling between the initial ideas and the pre-jury stage*

*** for example**
I can quickly model the concepts that I choose and show them in table critics.

C- Evaluation of the potential use of AR technology in product development process (If the front page is not enough, continue to this page) Considering that the problems in AR technology are minimized and the preparation process is easier, please explain how AR technology can be used in which stages of the product development process.

project definition	initial idea jury	..... desk crits	preliminary jury	..... desk crits	final screening (design/3D-model) (boards)	final jury
	** thinking that you are starting 3D modeling between the initial ideas and the pre-jury stage* *** for example** **I can quickly model the concepts that I choose and show them in table critics.**					

D- Evaluation of product aspects that can be explained with AR technology

What do you think how important it is to explain the product aspects given below with AR technology? You are expected to make an evaluation for each product aspect.	*Not applicable*	Not very important				Very important
Design concepts	○	○	○	○	○	○
Usage scenario	○	○	○	○	○	○
User experience	○	○	○	○	○	○
User interaction	○	○	○	○	○	○
User interface	○	○	○	○	○	○
Feature/function	○	○	○	○	○	○
Parts	○	○	○	○	○	○
Physical ergonomics	○	○	○	○	○	○
Aesthetics/form	○	○	○	○	○	○
Size	○	○	○	○	○	○
Material/color	○	○	○	○	○	○
Context/environment	○	○	○	○	○	○
Mechanism	○	○	○	○	○	○
Details	○	○	○	○	○	○
Technical standards	○	○	○	○	○	○
Inner parts	○	○	○	○	○	○
Assembly/set-up	○	○	○	○	○	○
Technology	○	○	○	○	○	○
Manufacturing	○	○	○	○	○	○
Maintenance	○	○	○	○	○	○
User evaluation	○	○	○	○	○	○
Other (If any, please specify) …………………………		○	○	○	○	○
Other (If any, please specify) …………………………		○	○	○	○	○

If you would like to add anything about AR technology, please briefly explain.

I. SURVEY GIVEN TO THE GUEST TUTOR TO EVALUATE AR SESSION

I.1. Survey given to the guest tutor (in Turkish)

ARTIRILMIŞ GERÇEKLİK (AG) TEKNOLOJİSİNİN
DİĞER TASARIM TEMSİL ARAÇLARIYLA BİRLİKTE
SUNUMDA KULLANIMININ DEĞERLENDİRİLMESİ

DEĞERLENDİRME FORMU

Bu anket 3 farklı bölümde toplamda 14 sorudan oluşmaktadır.

A- AG uygulaması kullanarak gerçekleştirilen masa kritiğinin değerlendirilmesi

1- Diğer tasarım temsil araçları ile birlikte AG teknolojisi kullanarak öğrencilerin sunum yapması size neler düşündürttü? Nasıl bir deneyim olduğunu düşünüyorsunuz? (Lütfen kısaca belirtiniz.)

2- Öğrencilerin sunumda AG teknolojisi kullanarak ürünü anlatıyor olmasının olumlu yanlarının neler olduğunu düşünüyorsunuz? (Lütfen kısaca belirtiniz.)

3- Öğrencilerin sunumda AG teknolojisi kullanarak ürünü anlatıyor olmasının olumsuz yanlarının neler olduğunu düşünüyorsunuz? (Lütfen kısaca belirtiniz.)

4- AG teknolojisinin diğer temsil araçlarına göre (çizim, mock-up, dijital model, vb.) avantajlı olduğu ve kullanılabilecek özelliklerinin neler olduğunu düşünüyorsunuz? (Lütfen kısaca belirtiniz.)

5- Eğer varsa, AG teknolojisi ile ilgili eklemek istedikleriniz nelerdir? (Lütfen kısaca belirtiniz.)

1, 2, 3, 4 ve 5. sorulara tanımlanmış alanlar yetmezse bu sayfadaki kalan boş alanı soru numarasını belirterek kullanabilirsiniz.

B- AG uygulaması kullanarak gerçekleştirilen masa kritikleri için aşağıda verilen soruları değerlendirmenizi rica ederiz.
Sunum ile ilgili;
1- AG teknolojisi kullanarak gerçekleştirilen sunum motivasyonunuzu nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)
2- AG teknolojisi kullanarak gerçekleştirilen sunum ürünle ilgili bilgilerin anlaşılabilirliğini nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)
3- AG teknolojisi kullanarak gerçekleştirilen sunum öğrenci ile olan iletişimi nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)
4- AG teknolojisi kullanarak gerçekleştirilen sunum geri bildiriminizi nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)
5- AG teknolojisi kullanarak gerçekleştirilen sunumun verimini nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)
6- AG teknolojisi kullanarak gerçekleştirilen sunumun etkinliğini nasıl etkilemiştir? (Lütfen kısaca belirtiniz.)

C- AG uygulaması ve stüdyo süreçlerinde kullanımı ile ilgili aşağıda verilen soruları değerlendirmenizi rica ederiz.
AG uygulaması ve stüdyo süreçlerinde kullanımı ile ilgili;
1- Gördüğünüz ve deneyimlediğiniz kadarıyla, AG uygulaması hakkında neler düşünüyorsunuz? (Lütfen kısaca belirtiniz.)
2- Ürün geliştirme sürecinin farklı aşamaları düşünüldüğünde, tasarım eğitiminde stüdyo süreçlerinde AG uygulaması nasıl kullanılabilir? (Lütfen kısaca belirtiniz.)
3- Stüdyo projelerinde öğrencilerin masa kritiklerinde AG teknolojisi/uygulaması kullanması masa kritiklerine nasıl etkileyebilir? (Lütfen kısaca belirtiniz.)

AG teknolojisi ile ilgili eklemek istedikleriniz varsa, lütfen kısaca belirtiniz.

I.2. Survey given to the guest tutor (in English)

EVALUATION OF THE USE OF
AUGMENTED REALITY (AR) TECHNOLOGY WITH OTHER
DESIGN REPRESENTATION TOOLS IN PRESENTATION

EVALUATION FORM

This survey consists of 14 questions in 3 different parts.

A- Evaluation of desk crit which was supported with AR application

1- What do you think about presentation of the students' design concept by using AR technology together with other design representation tools? What are you experiences? (Please briefly mention.)

2- What are the advantages of students explaining the product by using AR technology in desk crit? (Please briefly mention.)

3- What are the negative sides that you experienced when the students were using AR technology to explain the product in desk crit? (Please briefly mention.)

4- What are the advantages of AR technology when compared to other design representation tools (sketching, mock-up, digital model, etc.) and which features can be used in desk crits? (Please briefly mention.)

5- If any, what would you like to add about AR technology? (Please briefly mention.)

If the fields defined for questions 1, 2, 3, 4 and 5 are not enough, you can use the remaining blank space on this page by specifying the question number.

B- For the desk crit which supported with AR application, we kindly ask you to answer the questions given below.
About presentation in desk crit;
1- How did the presentation in desk crit supported with AR technology influence your motivation? (Please briefly mention.)
2- How did the presentation in desk crit supported with AR technology influence the understandability of the design concept/product? (Please briefly mention.)
3- How did the presentation in desk crit supported with AR technology influence the interaction with the student? (Please briefly mention.)
4- How did the presentation in desk crit supported with AR technology influence your feedback? (Please briefly mention.)
5- How did AR technology influence the efficiency of the students' presentation in desk crit? (Please briefly mention.)
6- How did AR technology influence the effectiveness of the students' presentation? (Please briefly mention.)

C- We kindly ask you to evaluate the following questions about AR application and its use in studio projects.
About AR application and the use of AR in studio projects;
1- From what you have experienced during desk crits, what do you think about the AR application? (Please briefly mention.)
2- Considering the different stages of the product development process, how can AR application be used in studio projects in design education? (Please briefly mention.)
3- How can the students' use of AR technology/application affect their desk crits in studio projects? (Please briefly mention.)

If you would like to add anything about AR technology, please briefly explain.

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name:	Karadoğaner, Alper
Nationality:	Turkish (TC)
Date and Place of Birth:	1985, Ankara
Marital Status:	Single
Phone:	+90 312 210 6241 / 2214
Fax:	+90 312 210 7963
email:	akaradog@metu.edu.tr, alperkaradoganer@gmail.com

EDUCATION

Degree	Institution
Master of Science 2008-2010	**Design for Interaction**, Industrial Design Engineering *Delft University of Technology (Delft, Netherlands)*
International Joint M.S. Programme	**Design for Interaction**, Department of Industrial Design, Graduate School of Natural and Applied Science *Middle East Technical University (Ankara, Turkey)* Thesis title: The effect of emotional facial expressions of a virtual character on people’s performance for interactive digital tasks (September, 2010)
Bachelor 2003-2008	**Industrial Design**, Faculty of Architecture *Middle East Technical University (Ankara, Turkey)* 3rd rank in the department
High school 2000-2003	Mathematics *Ankara Atatürk Highschool (Ankara, Turkey)*

WORK EXPERIENCE

Year	Institution/Organization	Enrollment
2013 February - Ongoing	Middle East Technical University, *Ankara, Turkey*	Instructor *Department of Industrial Design*
2012 September - 2012 November	Atılım University *Ankara, Turkey*	Research Assistant *Department of Industrial Design*
2011 December - 2012 March	Havelsan (METU - Technopolis) *Ankara, Turkey*	Industrial Designer *Peace Eagle Project*
2010 May - 2011 April	Futerodesign *Ankara, Turkey*	Industrial Designer *Product Development*
2008 January - 2009 January	Designnobis *Ankara, Turkey*	Industrial Designer *Product Development*
2006 September - 2008 June	Middle East Technical University, *Ankara, Turkey*	Student Assistant *Department of Industrial Design*

PROJECTS

Design Researcher, 2018
BILTIR-UTEST Product Usability Unit
Project title: Identifying use cases and product evaluation dimensions for Voice User Interface (VUI) at Home

Design Researcher, 2017
BILTIR-UTEST Product Usability Unit
Project title: Procedure and methodology advisory for the integration of user insight generation process into R&D processes

Industrial Designer, 2014
Ankara, İvedik Organized Industrial Zone
Project title: Ankara İvedik OSB Bio Engineering, Medical Devices and Sanitary Ware Manufacturers Sector Project to Increase International Competitiveness

Design Researcher, 2013
BILTIR-UTEST Product Usability Unit
Project title: Information System Design: Guidelines for graphical user interface, hardware and feedback

DESIGN AWARDS

Institution / Competition	Degree of Award	Year	Participation
TIM – Packaging Design Competition	1st place, Metal Packaging Category (Professional)	2014	Group
Design Turkey 2008	Concept Award	2008	Group
Green Dot Awards	Honorable Mention, Concept Category	2008	Group
Green Dot Awards	2nd place ‘Green Product Design’	2008	Group
International Design Awards	1st place Sustainable Living/Environmental Preservation, Rural Sustainable Design	2008	Group

COURSES GIVEN

Undergraduate Courses
ID430 - Digital Modelling and Fabrication, METU
ID290 - Elementary Workshop Practice & Computer Literacy in Design, METU

PUBLICATIONS

Karadoğaner, A. (2020). Form Stratejileri ile Birlikte Kâğıttan Form Geliştirme Yöntemi Üzerine Değerlendirme. In S. Turhan, M. Öztürk Şengül, D. Özgen Koçyıldırım (Eds.), *UTAK2020 Bildiri Kitabı: Tasarım ve Öngörü* (in press). Ankara, Turkey: Middle East Technical University.

Karadoğaner, A. & Börekçi, N.A.G.Z. (2018). Endüstriyel Tasarım Eğitiminde Temsil Araçlarının Kullanımı ve Proje Geliştirme Süreci Üzerine Değerlendirme. In G. Töre Yargın, A. Karadoğaner, & D. Oğur (Eds.), *UTAK2018 Bildiri Kitabı: Tasarım ve Umut* (pp. 511-529). Ankara, Turkey: Middle East Technical University.

Erbug, C., Kuru, A., Töre-Yargın, G., **Karadoğaner, A.**, & Dikmen, F. (2014). Kullanıcı Arayüzü Rehber Bilgi Sistemi. *SAVTEK2014, Savunma Teknolojileri Kongresi*, 25-27 Haziran, Ankara.

Karadoğaner, A. (2010). *The effect of emotional facial expressions of a virtual character on people's performance for interactive digital tasks* (Unpublished Master thesis). Middle East Technical University, Ankara, Turkey.

WORKSHOPS

Karadoğaner, A. & Oğur, D. (2019). Form Generation Through 3D Paper Folding. In *DRS Learn X Design 2019: Insider Knowledge*. 11 July 2019. Ankara, Turkey: Middle East Technical University. Retrieved from http://drslxd19.id.metu.edu.tr/workshops/.

Karadoğaner, A. & Oğur, D. (2018). Modelleme Kartları ve Taslak Model Kullanarak Form Geliştirme. In G. Töre Yargın, A. Karadoğaner, & D. Oğur. (Eds.), *UTAK2018 Bildiri Kitabı: Tasarım ve Umut* (pp. 659). Ankara, Turkey: Middle East Technical University.