

**UNIVERSIDAD EAFIT**

Escuela de Ingenierías

Departamento de Ingeniería de Diseño de Producto



**Product conceptualization through a 3D natural  
interface considering in real-time spatial and  
ergonomic restrictions**

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Ingeniero Mecánico

TRABAJO DE GRADO PRESENTADO COMO REQUISITO PARCIAL PARA OPTAR AL TÍTULO DE  
MASTER OF SCIENCE IN ENGINEERING

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# Abstract

Currently, the conceptualization of products whose shape and configuration depends on the context is a highly time-consuming process since it has to be achieved asynchronously between the real environment of the product's usage and the design office. In general, the designer manually maps the context in order to create a 3D model of it and then to start the product design process. The literature presents some proposals to digitalize the context without the need of a manual mapping. However, these approaches are mainly computer-centric tools where the designer is desk-bound and (s)he does not have a clear spatial perception since the interactions with the 3D models are usually based on 2D interfaces. On this research we aimed to prove that conceptualization of context-dependent products directly over its real environment through gesture-based modeling tools, allows the designer to consider spatial and ergonomic restrictions that the context imposes to the product, through the real-time analysis of the interaction user-context. In order to prove that, we developed a tool called *Air-Modeling*; in which the designer is able to create virtual conceptual products quickly and efficiently, taking advantage of hand gestures meanwhile (s)he is interacting directly with the real scenario in an Augmented Reality (AR) environment. *Air-Modeling* also allows a continuous evaluation of the user postures involved in the product usage and assembly in order to analyze ergonomic risks, and perform the necessary changes in the product shape or configuration from early stages of the design process. A test was carried out to prove the effects of the use of the proposed tool in the design process in comparison with the traditional way through traditional CAD packages. We found that the real context can be used as an information input in real-time during product conceptualization. Beside this, we could notice that virtual parts creation is more efficient from a 3D input than a 2D interface such as a mouse or a keyboard. This was reflected in the experiment carried out in which 21 users conceptualized a bookcase for a given context using both *Air-Modeling* and a commercial

CAD tool. It was obtained a reduction in the modeling time using our tool on 76% of the cases with a final average reduction of 44%. Finally, we concluded that 3D modeling in AR environments using the hands as interface and the context as an information input in real-time, allows the designer to conceptualize potential solutions in quick and efficient manner, exploiting as much as possible, inspirational instants. On the other hand, modeling in a natural scale directly over the real scene prevents the designer to draw his/her attention on dimensional details but allows him/her to focus on the product itself and its relation with the environment. Besides, developing 3D models in natural scale allows analyzing the interaction between the user, the context and the virtual model for determining ergonomic issues related with the product usage or assembly process. We believe that this kind of technologies makes the development of customized products more efficient by adding spatial and ergonomic restrictions to the conceptualization process in real-time. This facilitates the convergence to the design solution, possibly avoiding some iteration in the design process.

**Keywords:** Augmented Reality, Modeling in Context, Solid Modeling, Conceptual Design, Hand Gestures, Natural Interfaces, Ergonomic Analysis

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# Chapter 1

## Introduction

The product development is a creative and iterative process (see Figure 1.1) in which from a need, a potential solution is generated at the end of the process. According to French (1998), in the scheme presented in Figure 1.1 the circles represent stages reached and rectangles represent activities. The process starts with the Analysis of Problem stage which consists on identifying, as clearly as possible, the need to be satisfied. This includes the analysis of the context in which the product will be used. The result of this stage is a set of technical requirements. With this information, the Conceptual Design stage begins generating some potential solutions to the proposed problem. This is the stage where engineering, practical knowledge, production methods and commercial aspects need to be brought together, and where the most important decisions are taken (French, 1998). At this point, the relation between the specifications and requirements must be performed and if there is any issue unconsidered a new iteration in the process must be carried out. After that, the Embodiment of Schemes takes place. During this stage the schemes are worked up in a greater detail, and if there is more than one, a final choice is made. Among other, ergonomics aspects of the schemes are evaluated during this stage in order to improve the quality of the product. This is why, a new review of the requirements is generally done at this point with the respective iterations, if needed. Finally, during the Detailing stage a very large number of specific aspects of the product and its production process has to be considered and solved.

In the last years, the human factor is gaining importance in design, engineering planning, manufacturing and maintenance of new products, in order to minimize workspace occupa-

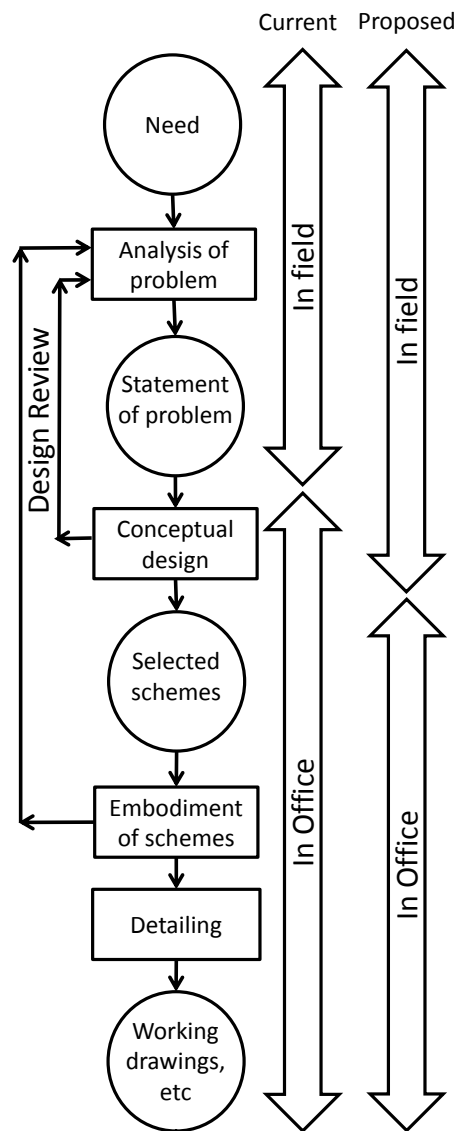


Figure 1.1: Design process (adapted from French (1998))

tional risks and increase the product's quality. Not only by the human health but also by the production performance. This is why there is a necessity to think about ergonomic issues even from product conception. Actually, the designers could encounter several problems in order to find an ergonomically appropriate design solution due to the lack of tools for decision making process in this subject in product conceptualization. Usually, the designers establish ergonomic requirements before starting the conceptual design, but the product is not ergonomically evaluated until the Embodiment of the Schemes are performed. In these

cases, if product remodeling is needed, the whole cycle is repeated until the resulting model of the product satisfies, among others, the ergonomic criteria. So, ergonomic analysis is neglected by the designers whom, without tools for decision making, left production engineers and ergonomists to analyze occupational risks in advanced stages of the product development process. Thus, the designers need to rely on their own knowledge and experience when making crucial decisions regarding ergonomic issues during product conceptualization (Kaljun and Dolšak, 2012). In that way, current product conceptualization and ergonomic analysis are asynchronous and independent phases within the product development process (see Figure 1.1). This because, at the initial stages of the product design, the knowledge about the design problem is limited, making difficult some analysis and decisions.

## 1.1 Problem statement

Particularly in the case of products whose shape, dimensions and configuration depend mainly on the spatial conditions of the environment (we call it a context-dependent product), such as furniture, structure frames and piping networks, generally a top-down strategy is implemented for its development. In this design strategy, the designer begins by indicating at the conceptual design phase the basic configuration of the entire assembly and in a detail design phase all the configuration of the subassemblies and individual parts with its respective dimensions and linkages. The design process of this kind of products usually begins in the real environment of the product (we call it 'in field') with the problem statement (see "Current" situation in Figure 1.1). During this stage, the designer analyzes and maps the space where the product will be installed to consider the restrictions and condition of the context, while discusses with the costumer the product's requirements. The context mapping process is commonly carried out manually using hand sketches and measurements instruments, with error-prone and time-consuming results. With this information, the designer generates some proposals generally as 2D sketches out of the design context. Once again in field, the proposals are discussed with the customer in order to choose the better one according to the requirements and restrictions. After that, in the design office, a 3D model of the chosen scheme is created with a Computer-Aided Desing (CAD) tool. Generally, also the 3D model of the context is required in order to consider possible issues related with interference,

installation and ergonomics. During this stage, the abstract concept is transformed into a definitive layout. At this point, a set of iterations begins to refine the concept. Each iteration is in general done asynchronously between the context of the product and the design office, so the designer has to go side to side for reviewing, performing model modifications, taking new measurements or discussing the modifications with the customer. The convergence of this process is accomplished when restrictions, requirements (functional, spatial and ergonomic ones) and customer are satisfied. As a result, the conceptualization stage and consequently, the whole design process for context-dependent products demands actually a lot of time and resources. Notice that in the current situation for designing context-dependent products, the real context itself plays a secondary roll left aside for the design office. In other words, there is many useful information that is not being considered during the product conceptualization.

Some proposals have been presented for taking into account, although in an indirect way, the context in the design process in order to interact with it. Arbeláez-Estrada and Osorio-Gómez (2013) explain different approaches related to this, such as context 3D modeling, camera mapping or projection, camera solving, context scanner or photogrammetry and photomontage. Though these approaches allow the designer to visualize the product over the context, they are mainly computer-centric tools where the designer is desk-bound (Shen et al., 2010) and he/she does not have a clear spatial perception since the interactions with the 3D models are usually based on 2D interfaces, such as a 2D mouse, and the visualization is commonly done in a 2D screen (Windows-Icon-Menu-Pointer (WIMP) interfaces). In this way, there is not a direct spatial mapping of virtual and physical spaces (Lapides et al., 2006), making the design and visualization tasks more difficult.

From 3D model of the context, two kinds of solutions are commonly implemented in order to evaluate the ergonomic aspects of context-dependent products. Stand-alone ergonomic tools (such as SAMMIE, APOLIN, TADAPS) which are WIMP-based tools in which the context, the product and the user are imported to a 3D virtual space to evaluate issues related with the user's postures against the product placed over the context. Notice that these tools are to be used once a virtual model of the product is already defined, so if any change in the product is needed the designer has to go back in the process and perform the modification

to start another iteration. The other kind of tools are modules compatibles with commercial CAD software (such as Jack, Delmia, SAFEWORK), that the user can use synchronously in the design stage by manipulating both a virtual human model against the product to check potential ergonomic problems. These two kind of tools can provide some assistance level during ergonomic design evaluation, but the designer still has to possess substantial experience and knowledge in the field of ergonomics (Kaljun and Dolšak, 2012) due to the difficulty on the selection of the parameters for the tests and the interpretation of its results. On the other hand, the simulations provided by these tools are based on virtual humans and consequently non-natural body movements and postures, implying non completely reliable results.

Mixed Reality (MR) is the set of technologies that merge virtual worlds with the real one. Milgram et al. (1994) describes MR as the continuum in wich in one side is the reality and in the other side is the virtuality as figure 1.2 depicts. This technologies are being used in CAD as an emergent alternative for human-computer interaction, allowing the user to perceive 3D models more clearly and to perform actions in a free and natural way, moving his/her hands in a 3D space (3D input).

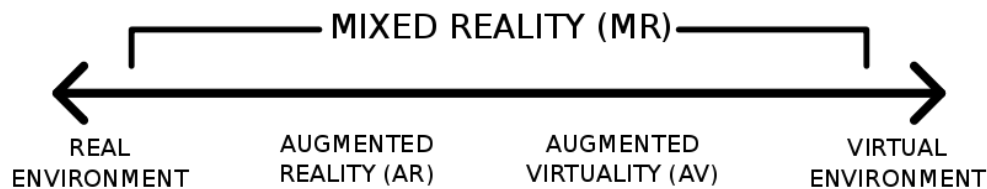


Figure 1.2: Reality-Virtuality continuum according to Milgram et al. (1994)

In the MR continuum (see Figure 1.2) is Virtual Reality (VR), in which the user is totally immersed in a completely synthetic world. For VR tools, the construction of the entire virtual workspace is required, which becomes complicated and time-consuming (Sun, 2007). In addition, VR does not allow the user to have a direct interaction with the real context.

On the other hand, Augmented Reality (AR) consists on merging a real scene with virtual information (Milgram et al., 1995). Although the subject of VR is being used from long time ago (from the mid 1960s (Lu et al., 1999)), AR technology is recently new (from the mids

1990s (Azuma et al., 1997)) and it is showing a great potential for many applications. In general, the use of MR in the sciences and the industry got become more common after 1990s due to easy access to the hardware (Adam, 1993).

One of the main advantages of the AR, is that this technology allows the user to have a direct interaction with a real environment, avoiding the need to compute and display a virtual one. This generates a more realistic experience while computational resources are saved.

## 1.2 Research justification

On this research we aimed to prove that conceptualization of 3D models of context-dependent products directly over its real environment through gesture-based modeling tools, allows to consider spatial and ergonomic restrictions that the context imposes to the product, through the real-time analysis of the interaction user-context.

In order to prove that, we developed a tool called Air-Modeling with a module for ergonomic assessment (called in this work as EAM) during product conceptualization. With this tool the designer is able to create virtual conceptual products in a quick and intuitive manner, taking advantage of hand gestures meanwhile he/she is interacting directly with the context. During the conceptualization process the designer can visualize the virtual model in a natural scale in its real position over the real scenario, so the user's postures related with the product can be simulated for inferring ergonomic risks during its operation assembly or maintenance, even from product's conception. This allows the designer, to consider in real-time in the design stage, the conditions that the context imposes on the product ergonomic, configuration, shape and dimensions. Thus, the designer is able to create, review and update the virtual concept according to the environment's requirements in a synchronous manner. In this way, we can map the virtual space with the real one and use the spatial restrictions as information inputs during the conceptualization without the need of a manual mapping of the context. The information obtained through the interaction between the user, the virtual product and the real context allows increasing the knowledge about the problem, and consequently making the convergence to the design solution more effective and even improving products quality. In other words, we add in real-time spatial and ergonomic constraints to a

highly unconstrained problem such as conceptual design.

Our case study is focused on furniture design, which are products whose configuration and dimensions are, in most cases, strongly influenced by the context.

## 1.3 Objectives

### 1.3.1 General objective

Conceptualize context-dependent products considering in real-time spatial and ergonomic restrictions that the context imposes to the product's shape, dimension and configuration; through the development of a gesture-based 3D modeling tool using AR technology.

### 1.3.2 Specific objectives

- To establish the research problem considering the design aspects imposed by the conceptualization stage in a product design process.
- To review the literature related to product conceptualization using natural interfaces and virtual reality tools.
- To develop a 3D modeling tool that allows the use of the context as information input in real-time.
- To design an experiment to prove the hypothesis.
- To collect and process the required data according to the designed experiment.
- To analyze the collected data.
- To elaborate conclusions and validate the hypothesis.

### 1.3.3 Publications

Part of this thesis is based on five publications at scientific forums:

- Ruiz, Oscar E., S. Arroyave, and J. F. Cardona. EGCL: an extended G-Code language with flow control, functions and mnemonic variables. *World Academy of Science, Engineering and Technology*. v67 (2012): 455-462.
- Ruiz, Oscar, Santiago Arroyave, and Diego Acosta. Fitting of Analytic Surfaces to Noisy Point Clouds. *American Journal of Computational Mathematics*. v3 (2013): 18-26.
- Santiago Arroyave, Gilberto Osorio-Gómez, Johana Hoyos. Assessment of ergonomic issues during conceptualization stage in augmented reality environments. *International Virtual Concept Workshop 2014*. Medellín-Colombia.
- Santiago Arroyave, Gilberto Osorio-Gómez. Real-time assessment of ergonomic issues during product conceptualization using gesture-based modeling tools. Submitted to: *International Journal of Interactive Design and Manufacturing (IJIDeM)*.
- Santiago Arroyave, Gilberto Osorio-Gómez, Juan F. Cardona. AIR-MODELING: A tool for gesture-based solid modeling in context during early design stages in AR environments. Submitted to: *Computers in Industry*. Submission date: dec 2013. Acceptance date: jul 2014. Actual state: accepted with minor changes.

## 1.4 Thesis organization

The rest of this document is organized as follow:

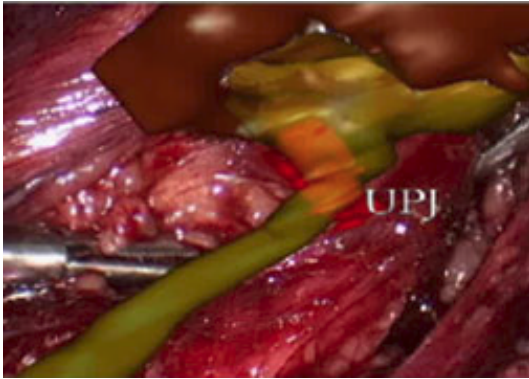
- In chapter 2 the state of the art about modeling in 3D spaces is presented, as well as the advances in the subject of ergonomic evaluation during conceptualization.
- In chapter 3 the details of the research methodology implemented for the development of this work are explained.
- Chapter 4 describes how Air-Modeling was created and tested.
- In chapter 5 the results of the tests carried out and the analysis of it are summarized.
- In chapter 6 the conclusion about the research, the hypothesis validation and the future work are presented.

## Chapter 2

# State of the art

After review the literature about product conceptualization process it was not possible to find any reference reporting available tools for developing context-dependent products such as furniture, piping or structural frames. Authors like Pahl et al. (2007) just mention tools for concept evaluation including AR technologies. However, we looked in the literature for the use of AR in CAD and its potential use for developing context-dependent products by considering in real-time spatial an ergonomic restrictions as it is summarized below.

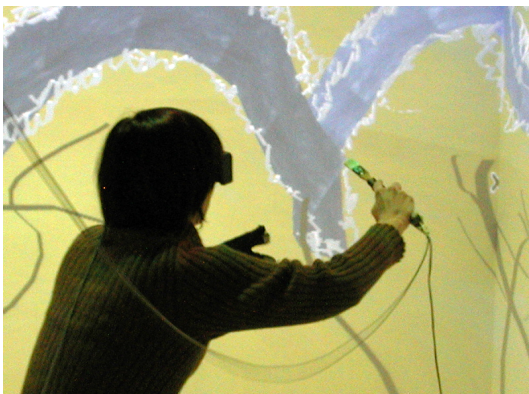
AR applications go from medical fields (Vemuri et al., 2012) (see Figure 2.1(a)) to entertainment (Piekarski and Thomas, 2002) (see Figure 2.1(b)), art design (Keefe, 2009) (see Figure 2.1(c)), manufacturing and repair (Nee et al., 2012; Zhang et al., 2010) (see Figure 2.1(d)) and design in engineering, our field of interest. Particularly in CAD, the main advantage of this technology is that the user may interact with a real environment during the design session. Additionally, when the limited 2D WIMP interface is substituted with a natural 3D one, the spatial manipulation and perception of 3D shapes result easier due to the direct mapping between the physical space and the modeling space (Wang et al., 2011). Although there are some researches in course in order to merge AR technology with CAD tools, there are still some aspects of the use of that kind of tools in the design process that remains unexplored.



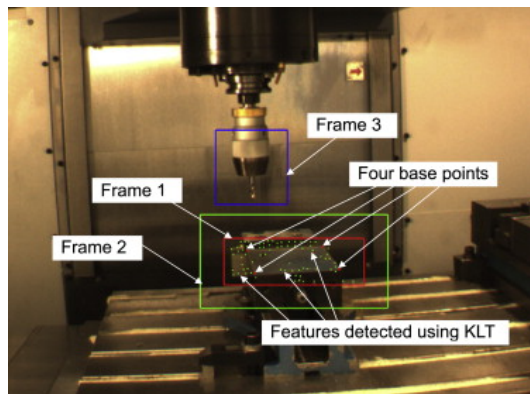
(a) Application of AR in the medical field (Vemuri et al. (2012))



(b) Application of AR in entertainment (Piekarski and Thomas, 2002)



(c) Application of AR in art (Keefe, 2009)



(d) Application of AR in manufacturing (Nee et al., 2012)

Figure 2.1: Application of AR in different fields

## 2.1 AR in CAD

Most works merging AR with CAD have centered its attention on the latest stages of the product development process, such as 3D models visualization (Huang et al., 2012; Shen et al., 2008; Hagbi et al., 2008), assembly modeling (Radkowski and Stritzke, 2012; Fiorentino et al., 2012; Wu and Wang, 2011; Valentini, 2009), staff training (Dünser et al., 2006; Peniche et al., 2012) and maintenance (Henderson and Feiner, 2011; De Crescenzo et al., 2011). On the other hand, early stages of product design using AR-based systems are just being explored. Some researches have been directed towards 3D sketching, others towards geometric modeling and other towards solid modeling.

### 2.1.1 AR in 3D Sketching

Haller et al. (2006) presented a tabletop AR environment for collaborative 2D drawing, Xin et al. (2008) presented a tool for creating 3D sketches on top of a physical napkin and Prieto et al. (2012) presented a system for creating 3D frames for structural design. These proposals only allow wireframes creation, which could be difficult to understand for complex geometries. Bergig et al. (2009) published the creation of a tool for converting 2D sketches into 3D models and display them in AR environments, thus allowing 3D modeling, but from limited and ambiguous 2D input.

### 2.1.2 AR in Geometric Modeling

Fiorentino et al. (2002) and Santos et al. (2003) reported the creation of tools for modeling of free-form curves and surfaces with tracked pens. Fuge et al. (2011) presented a similar system which allows interaction with the virtual model through a tracked glove. These tools are very useful to design products with organic shapes, such as car bodies, ski boots, motorbikes, packages, among others; but they could result complex and inefficient for aesthetic designing of simple-form products, such as furniture, structure frames and pipe networks.

### 2.1.3 AR in Solid Modeling

Tinmith-Metro, presented by Piekarski and Thomas (2001), is a wearable system for exterior building design that allows creating 3D models over a real scene but only through a limited and traditional 2D interface where the pointer is controlled by the user's hand, making the

manipulation of virtual objects complex. Similarly, Do and Lee (2008) presented 3DAR-Modeler, a tool for solid modeling that must be manipulated from a traditional 2D desktop interface but with visualization of AR scenes. Novotny et al. (2006) presented a prototype for visualizing and modifying 3D models that appear each one over independent physical markers; this implies that the modeling space is restricted only to the 2D space over the working desktop. Ong and Shen (2009) and Shen et al. (2010), created an application for creating and modifying 3D parts in collaborative AR environments. In this tool, the user can interact with the virtual model using a virtual stylus rendered on a marker, implying that the camera must always has in its range of vision both the marker related to the virtual part and the marker related to the stylus, restricting the modeling space only for small scale models. On the other hand, the tool presented in this work does not allow a natural bi-manual interaction with the 3D parts. Phan and Choo (2010) introduced interior design with AR technology with a system that lets the user include and position pre-designed 3D models over a real scene for decorating interior spaces, but it does not allow editing these models in real-time; if any modification is needed, a traditional over-desktop work is required. Ng et al. (2013) presented a AR-based system for solid modeling and part assembly using the hands; however, because to the proposed system architecture, the tools is limited only for table-top works and, consequently, it is restricted to small scale models lacking for real interaction with the environment, one of the main advantages of AR-based systems.

After the revision of the literature about CAD tools driven by natural interfaces, it was concluded that for our case study, furniture design, solid modeling is the best option for conceptualization in AR environments. Generally, furniture is composed mainly of primitives geometries, thus modeling of this kind of products as 3D sketches (wireframes) can result complicated and hard to understand. On the other hand, the modeling as free surfaces (geometric modeling) can become complex and inefficient. However, there still are some issues that remain unresolved in solid modeling with natural interfaces, which are studied in this work: (1) 3D model creation and modification with a bimanual interaction using the context in real-time as an information input and (2) new virtual parts creation without the need of adding new physical associated markers in the scene.

## 2.2 Ergonomic assessment during product conceptualization

Ergonomic evaluation of products under development is commonly carried out at final stages of the design process generally from two approaches: Digital Human Modeling (DHM) or MR.

### 2.2.1 DHM for ergonomic assessment

Many authors have resorted to DHM approach for ergonomic assessment of products in different stages of its development. Applications in products design go from tool-handle design (Harih and Dolšak, 2013; Kaljun and Dolšak, 2012), to vehicles interface testing (Gironimo and Patalano, 2008; Kuo and Wang), to barrow lifting (Cao et al., 2013), among others. Ergonomics in assembly processes also has been addressed from the DMH point of view (Mohamad et al., 2013; Battini et al., 2011; Pappas et al., 2007; Dukic et al., 2007; Mavrikios et al., 2007; Caputo et al., 2006).

On the other hand, some authors have proposed new tools for the creation of DHM for ergonomic analysis of products and its manufacturing process. Sun (2007) presented a tool for ergonomic evaluation of workspaces with a case study of a ship operation room. However, programming the human behavior is not an easy task which could result on non-natural postures and movements. Kaljun and Dolšak (2012) presented an intelligent decision support system for ergonomic design, which is limited for hand tools and its use must be asynchronous with the design stage. Khatib et al. (2013) exposed a tool for 2D conceptualization in which the designer and the ergonomist have a special interface for communication, however the ergonomic assessment is based on 2D manikins and required a dedicated ergonomic expert to develop a design. Jung et al. (2009) developed an interesting method for digital humans generation which is not in self a tool for ergonomic evaluation but a method for create virtual humans with different anthropometric according to some parameters such as nationality and age to be used in ergonomic analysis tools.

Despite the great utility of DHM in the industry, one of the main issues with this approach is that the movements are obtained through inverse kinematics, which gives the virtual human robot-like, unnatural behavior (Chaffin and Erig, 1991).

### 2.2.2 MR for ergonomic assessment

A new trend for products ergonomic evaluation is the simulation in VR and AR environments. In this approach real humans execute the movements and experiment the postures related with the usage (e.g. vehicles ergonomics evaluation (Qiu et al., 2011; Caruso, 2011; Kallmann et al., 2003)) or its manufacturing process. Although these simulations are still challenging (according to studies presented by Pontonnier et al. (2013) and Hu et al. (2011)), they allow a realistic experience avoiding the constructions of physical prototypes to perform ergonomic evaluations.

In manufacturing field, authors like Ma et al. (2010), Härtel et al. (2011) and Whitman et al. (2004) have presented analysis of weight lifting using VR tools. Dong et al. Dong et al. (2013) as well as Bennis et al. (2005) analyze assembly operations for maintenance purposes. Qiu et al. (2013) as well as Yang et al. (2007) presented an applied case study case of the use of MR technologies in ergonomic evaluation of engine assembly operations. and Markus Miezal et al. (2013) created a tool for assessing and giving feedback in real-time within an AR environment, the postures of a user executing assembly tasks. Tian and Duffy (2011) presented a tool that allows to achieve dynamic ergonomic assessment by job risk classification model. These tools result very useful for analysis of workspaces, however any detected problem imply to go back, redesign the manufacturing system or the product itself in a traditional WIMP-based CAD system and carry out again the ergonomic analysis; iterating until accomplish ergonomic criteria. Jayaram et al. (2006) integrated an interactive immersive simulation tool with a commercial ergonomic analysis tool. Afterwards, the same authors (Shaikh et al., 2004) presented their own ergonomic analysis tool and compare the results with the commercial one. These, being really interesting studies, are focused on products in advanced design stages, when the improvements start to imply more costs and efforts in relation with the conceptualization stage.

Finally, in the subject of ergonomic analysis during conceptualization stage, it was concluded that there are not tools that allow the evaluation of ergonomic issues relates with the designer postures against the product during its conceptualization with gesture-based modeling tools in AR environments. In general, there are not any tools for supporting decision

making process regarding ergonomic issues of a product during its conceptualization in a synchronous manner. The most of the existing tools are for ergonomic analysis in advances stages of the product development and do not allow immediately redesign of the product if any issue is detected. In this way, any modification to the design implies a new iteration in the design process (see Figure 1.1).



## Chapter 3

# Research methodology

This work was conducted as an applied research in order to determine if 3D modeling in context allows the designer take into account in real-time spatial and ergonomic restrictions that the environments impose to the product. The research design used to collect the data to answer the research question is described in this chapter.

### 3.1 Research approach

Research is a process of steps used to collect and analyze information to increase our understanding of a topic or issue. At a general level, research consists of three steps (Creswell, 2002):

1. Pose a question.
2. Collect data to answer the question.
3. Present an answer to the question.

This process can be conducted from a qualitative or a quantitative point of view. Qualitative approach to research is concerned with subjective assessment of attitudes, opinions and behavior. Research in such a situation is a function of researcher's insights and impressions. Such an approach to research generates results either in non-quantitative form or in the form which they are not subjected to rigorous quantitative analysis. Generally, the techniques of focus group interviews, projective techniques and depth interviews are used (Kothari, 2004). The other approach involves the generation of data in quantitative form which can

be subjected to rigorous quantitative analysis in a formal and rigid fashion (Kothari, 2004). This approach can be further sub-classified into inferential, experimental and simulation approaches to research. The purpose of inferential approach to research is to form a data base from which to infer characteristics or relationships of population. Experimental approach is characterized by much greater control over the research environment and in this case some variables are manipulated to observe its effect on other variables. Simulation approach involves the construction of an artificial environment within which relevant information and data can be generated.

From the afore mentioned classification, the research presented in this work is related with an experimental approach, in which the effects (dependent variables) of the use the context (independent variable) in real-time as an information input during product conceptualization are analyzed.

### **3.2 Research process**

A research process is a way to systematically solve the research problem. It may be understood as a science of studying how research is done scientifically (Kothari, 2004). In this work we followed an own implementation of the model presented by Creswell (2002). The implemented methodology is listed below and depicted in Figure 3.1:

1. Identifying the research problem
2. Establishing the hypothesis
3. Reviewing the literature
4. Developing the research instrument
5. Collecting data
6. Analyzing and interpreting the data
7. Reporting and evaluating research

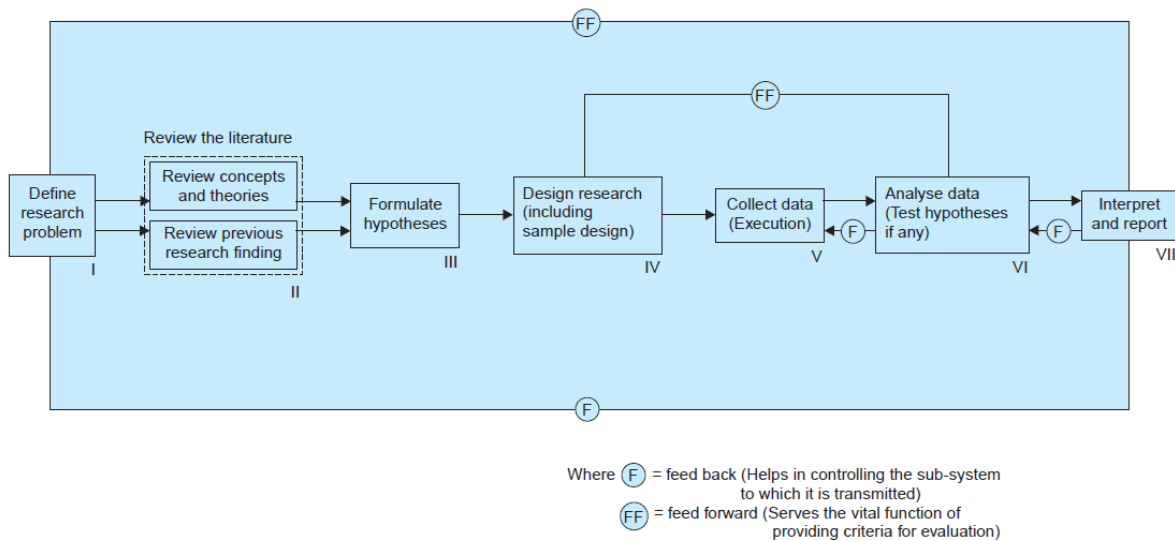


Figure 3.1: Research process in flow chart (reproduced from (Kothari, 2004))

### 3.2.1 Identifying the research problem

In this step is required to determine clearly enough an issue to study, developing a justification for studying it, and suggesting the importance of the study for people involved. By specifying a problem, the subject matter is limited and the attention is focused on a specific aspect of study (Creswell, 2002). Specifically, we analyzed that the conceptualization of products whose shape and configuration depends on the context is a highly time-consuming process due to it has to be achieved asynchronously between the real environment of the product and the design office. Normally, the designer has to map the context to after create a 3D model of it to start the product design. The research problem tackled by this work is better explained in Chapter 1.

### 3.2.2 Establishing the hypothesis

Establishing the hypothesis consists on generating an argument to be tested. The hypothesis is a focused statement which predicts an answer to the research question. The research hypothesis is often based on observations that evoke suspicion. This is one of the most important step in applied research due to the hypothesis is the guide along overall research process. It is important to identify clearly dependent and independent variables. Variables can take continuous values, integer values or boolean values. For the present work, the hypothesis was:

*Conceptualization of context-dependent products directly over its real environment through gesture-based modeling tools, allows to consider spatial and ergonomic restrictions that the context imposes to the product, through the real-time analysis of the interaction user-context.*

Details of the hypothesis are presented in Section 1.2.

### **3.2.3 Reviewing the literature**

To know and understand in detail all the previous developments around the subject of the research, is really important. This allows to get a broad perspective about the problem and the solution that other researches have presented to it. In that sense it is required to locate summaries, books, journals and indexed publications on the topic (Creswell, 2002). The review of the literature about product development process by natural interfaces in MR environments is presented in Chapter 2.

### **3.2.4 Developing the research instrument**

In this step is necessary to get all the required tools to carry out the experiment to collect the data and to prove the hypothesis. In some cases some required tools do not already exist, which implies that research must contemplated the development of the missing ones.

In the case of the present research, the tool for solid modeling in context was not developed. In fact, the creation of this tool is one of the main contributions of this research.

According to the proposed hypothesis, the required tool had to fulfill the following main characteristics:

- Visualization of the real context.
- Interaction with the real context.

The first requirement has been fulfilled with the use of AR technology for capturing the real scene and show it to the user with the superposition of the virtual model in the correct perspective. The second requirement was fulfilled with a natural interface based on the hand gestures of the user. Details about this development are given in Chapter 4.

### 3.2.5 Collecting data

Before to collect the data, it is required to have an experimental design to guide all the procedure and guarantee data reliability. The experimental design refers to the framework or structure of an experiment (Pahl et al., 2007). Research designs can be categorized as: (1) research design in case of exploratory research studies; (2) research design in case of descriptive and diagnostic research studies, and (3) research design in case of hypothesis-testing research studies (Kothari, 2004).

Exploratory research studies are also termed as formulative research studies. The main purpose of such studies is that of formulating a problem for more precise investigation or of developing the working hypotheses from an operational point of view.

Descriptive research studies are those studies which are concerned with describing the characteristics of a particular individual, or of a group, whereas diagnostic research studies determine the frequency with which something occurs or its association with something else.

Finally, the research design carried out in this work was Hypothesis-testing research studies (generally known as experimental studies). This kind of research designs are those where the researcher tests the hypotheses of causal relationships between variables. Such studies require procedures that will not only reduce bias and increase reliability, but will permit drawing inferences about causality.

At the same time, experimental designs can be classified into two broad categories (Kothari, 2004): informal experimental designs and formal experimental designs. Informal experimental designs are those designs that normally use a less sophisticated form of analysis based on differences in magnitudes, whereas formal experimental designs offer relatively more control and use precise statistical procedures for analysis. Important experiment designs are listed following (Kothari, 2004):

- a) Informal experimental designs:
  - i) Before-and-after without control design.

- ii) After-only with control design.
  - iii) Before-and-after with control design.
- b) Formal experimental designs:
- i) Completely randomized design.
  - ii) Randomized block design.
  - iii) Latin square design.
  - iv) Factorial designs.

After the review of the options to perform the experiment to prove the hypothesis, it was concluded that the needed experiment corresponds to an informal one of the type 'Before-and-after without control design'. In this kind of experiments a single test group or area is selected and the dependent variable is measured before the introduction of the treatment. The treatment is then introduced and the dependent variable is measured again after the treatment has been introduced (Kothari, 2004).

For our case, the modeling time was measure (independent variable) with the traditional way of modeling with WIMP-based interfaces and with a AR-based modeling tool. Other qualitative measurements were also carried out in order to analyze other effects in the use of the proposed tool. On Chapter 5 are given the details of the proposed experiment and its results.

### **3.2.6 Analyzing and interpreting the data**

After data collection, it is needed to organize the information to start understanding what it means. At this point, the hypothesis has to be validated supported on the results. In this step the principal and secondary findings are presented with the discussion about the whole research work and its implications. For the case of this research these step is summarized in the Section 5.

### **3.2.7 Reporting and evaluating research**

Finally, the results obtained from the conducted research methodology must be distributed to the interested community. In the case of this work, this step was achieved through the

published articles (see Section 1.3.3) and the present document.



## Chapter 4

# Air-Modeling Development

In order to answer the research question presented in Section 1.2, a tool for product conceptualization in 3D AR environments with a module for ergonomic assessment was developed. The details of the design and creation of the tools as well as the software implementation are presented in this chapter.

### 4.1 Requirements

Previous to start the tool development, its requirements had to be analyzed and clearly defined. Requirements on modeling tools for visualization and interaction with 3D models in a MR environment are in certain aspects different from tools for modeling through 2D interfaces based on computer screens. For example, the perspective projection of the model on MR-based tools must be updated continuously according to the user's head location and orientation, in order to display it stable at its place, just like a real object standing on a table (Wesche, 2004). The list of the identified requirements is presented below.

- Allow the user to visualize and interact with the real context.
- Track user's hand position and recognize some of his/her hand gestures.
- Display virtual parts in a natural scale over the context in the correct perspective according to the user point of view.
- Allow the user to import predesigned geometries and save created ones.

- Allow the creation of new virtual parts through a bimanual interaction in a 3D space.
- Allow the modeling of the parts in natural scale.
- Allow the user to delete and modify virtual parts by a bimanual interaction.
- Analyze in real-time user's postures from the ergonomic point of view.
- Advise the user about non-recommendable postures.

Figure 4.1 shows some images of the proposed operation for Air-Modeling before to start its development. In Figure 4.1(a) is represented how the user would interact with the real context of the product. In Figure 4.1(b) is represented the bimanual interaction for dimensioning and placing virtual parts over the 3D scene. In figure 4.1(c) is represented how we expected that the user could interact with virtual parts already created and placed over the context.

## 4.2 Overall system architecture

Air-Modeling is a tool for solid modeling during early stages of product design in which the user can create with his/her hands (see Figure 4.2) in an easy and intuitive way, conceptual virtual models inside the real scene using AR technology. It allows the designer to use the context as an information input and to visually verify the dimensions, proportions and positions of the 3D models at the modeling time and even take into account ergonomic issues of the product. This tool is more useful for aesthetic design of products whose shape depends mainly on the context, such as furniture, structure frames and pipe networks.

The system architecture of Air-Modeling tool is presented in Figure 4.3. The components of the system allow the user interacts in a natural manner with the virtual model as is reported in Section 4.3. Hardware is presented in the Section 4.4 while details of the software are given in the Section 4.5.

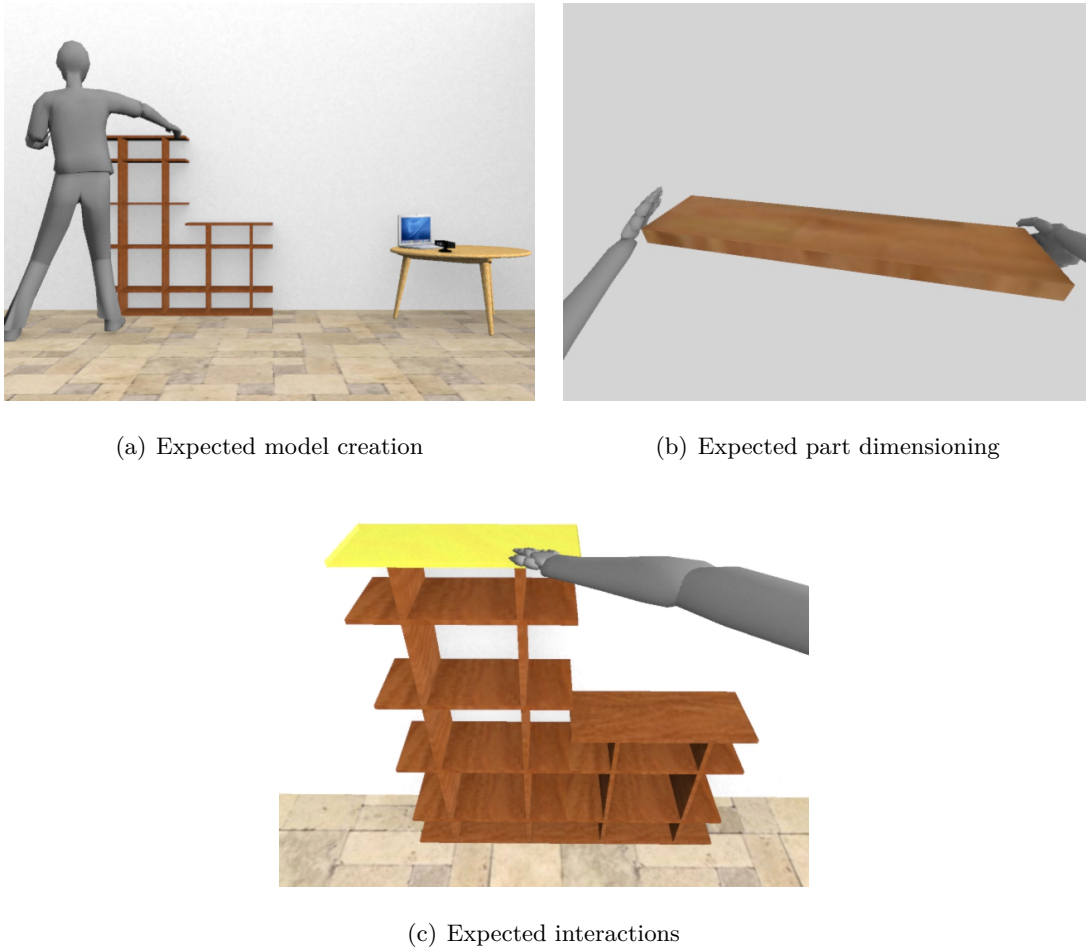


Figure 4.1: Expected operation of Air-Modeling

### 4.3 Interaction Techniques

With the aim of taking advantage of the gestures that, the designer does with his/her hands expressing potential solutions, after analyzing the problem, the interface of the presented system is based mainly on the user hands and their movement. In other words, the interface of the presented system is based on the natural language interaction paradigm. Thus, the user may quickly give the dimensions and place boxes over the scene using his/her hands as it is presented in Figure 4.2.

Because Air-Modeling was conceived as a tool for product conceptualization of context-dependent products, it was designed thinking on the top-down design approach. Taking this and the technical requirements into account the following interactions techniques were

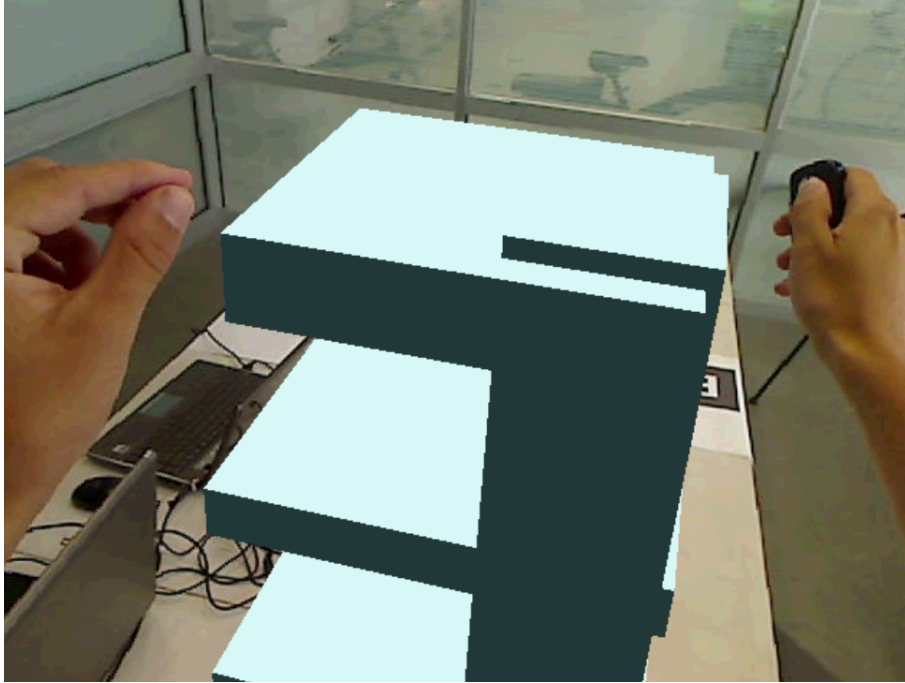


Figure 4.2: Box creation using Air-Modeling. User view

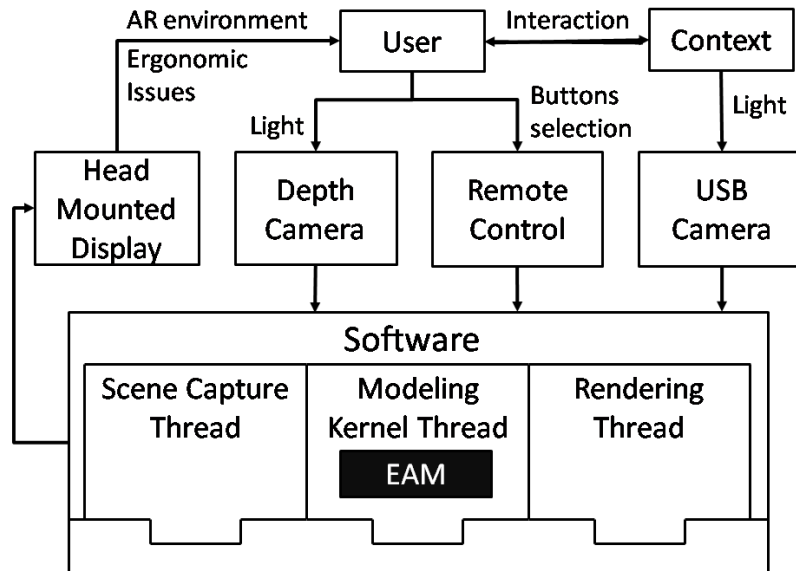


Figure 4.3: System Architecture

defined.

- Initially, the user has the possibility of loading pre-designed models by indicating the name of the file containing the geometry. Once the file has been found the user is able to place it in the desired position of the scene. In Appendix A it is shown an example of the format used for data interchanging in Air-Modeling.
- Afterwards, the designer can create new parts *in-situ*, by doing a gesture of push and pulling with his/her arm as it is showed in Figure 4.4, and locate and dimension them with the hands in the desired place confirming with the remote control. The gesture consists on holding the hand up, push it towards the sensor, and then immediately pulling it back.
- During the whole design process the user is able to analyze his/her postures against the product in order to determine ergonomic issues and take them into consideration for improve product-user interaction.
- The user is always able to modify or delete parts of the assembly. For selecting any part, the user must touch it with the 3D pointer, which is a small sphere as it is presented in Figure 4.5(a). Visual feedback is transmitted to the user highlighting the part with a wire frame as it is presented in Figure 4.5(b), when the user touches any part of the model with his/her hands.
- For displaying the menu (Figure 4.5(c)), the enabled key of the remote control must be pressed when the part is highlighted. The menu allows deleting, translating, rotating and stretching the selected part.
- After the user selects the translation option, the selected part is attached to his/her right hand and he/she just has to move the part according to his/her needs and releases it in the desired place.
- In order to rotate a part, the user must first select the desired rotation axis. Three orthogonal axis on the part are displayed as it is presented in Figure 4.5(d). After the axis selection the user can rotate the part around the selected direction. Finally, the part has to be released in the desired orientation with the key of the remote control.

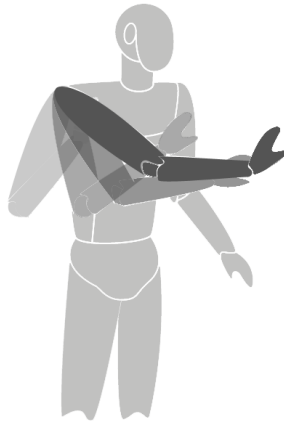


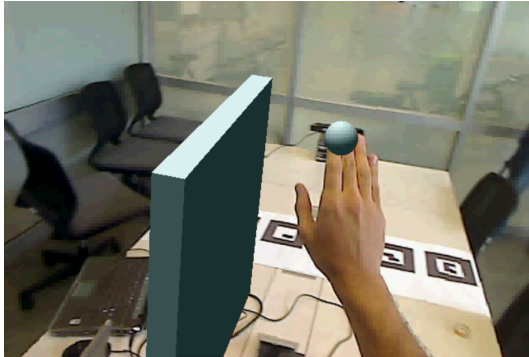
Figure 4.4: Dynamic gesture for new part creation

- For the stretching operation, the user should select the face to stretch. While the user's hand is near any face of the selected part a visual feedback is transmitted as Figure 4.5(e) shows. The user just has to select the desired face and release it according to the need.
- When the user finishes the design session, the 3D model created is saved in the same format used to import pre-designed models (see Appendix A).

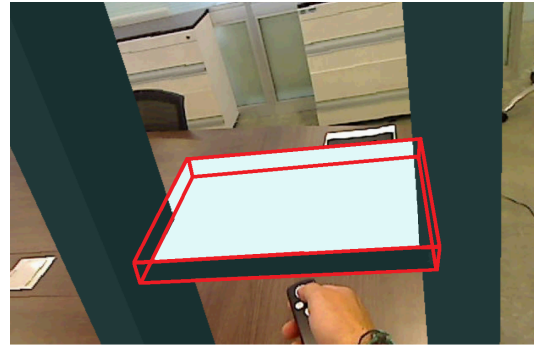
## 4.4 Hardware

Air-Modeling uses the Microsoft Kinect® depth camera to reconstruct the position vectors of the user's skeleton joints. The depth camera also detects a dynamic hand gesture (Figure 4.4) which was implemented as the command for creating new parts. The Kinect® has a video camera of 640x480 Pixel/30fps, a depth camera of 640x480 Pixel/30fps, a x/y resolution: 3mm @2m distance and a depth resolution 1cm @2m distance. Figure 4.6 shows the constructive details of the Kinect®.

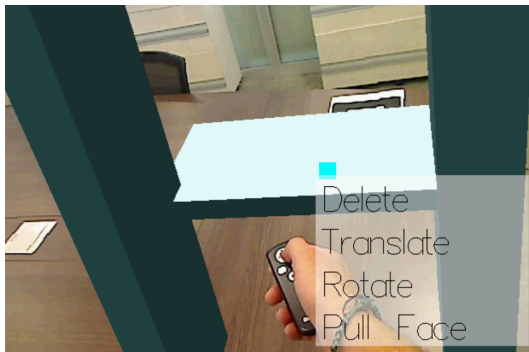
For event confirmation the user has to hold in his/her hand a single-command remote control. From this device just one key were putted in service. This key is required for parts releasing and menu navigation. The device used has a working distance of 10m with 2.4GHz Wireless Technology.



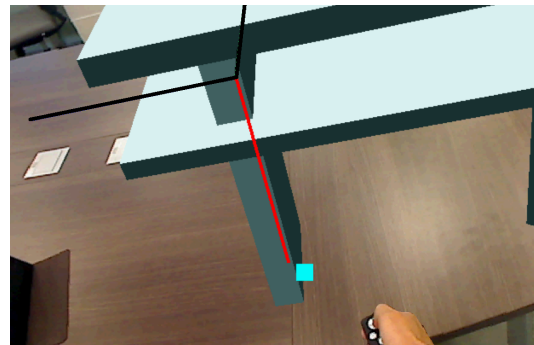
(a) 3D Pointer



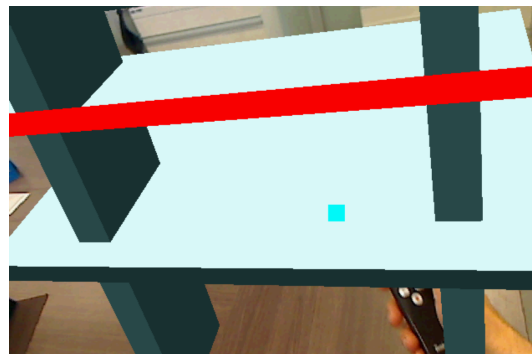
(b) Part selection feedback



(c) Menu for parts edition



(d) Part rotation



(e) Part stretching

Figure 4.5: Interaction with the 3D parts in Air-Modeling

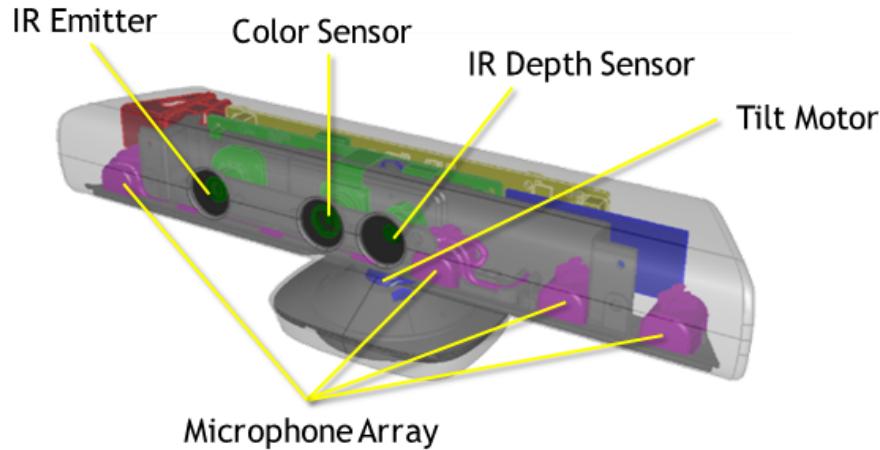


Figure 4.6: Microsoft Kinect® architecture

With a lightweight USB video camera the scene is captured. The camera with a resolution of 2MP/30fps and auto-focus, was attached to the Head Mounted Display (HMD) for achieving the user's perspective of the environment as it is depicted in Figure 4.7. Additionally, a marker was installed in the scene in order to get the correct perspective projection of the virtual model over the real scene. The marker used was composed by multiple individual patterns with aim of increase the tracking chance and reduce the occlusion problem that the user may incur with his/her hands while he/she be using the tool.

As it is depicted in Figure 4.7, Air-Modeling is composed by a processing unit that links the software and the hardware. It was used a laptop with the following specifications:

- Intel Core i7 1.6 GHz processor
- 4.00 GB RAM
- 1 GB NVIDIA Quatro FX 2800M GPU
- Microsoft Windows™ version 7 with 32 bits operative system.

The AR scene created with the real context video stream and the projection of the virtual model according to the marker perspective is shown back to the user in real-time through a HMD with two 640x480 LCD displays with 24-bit true color (16 million colors). Thus, the

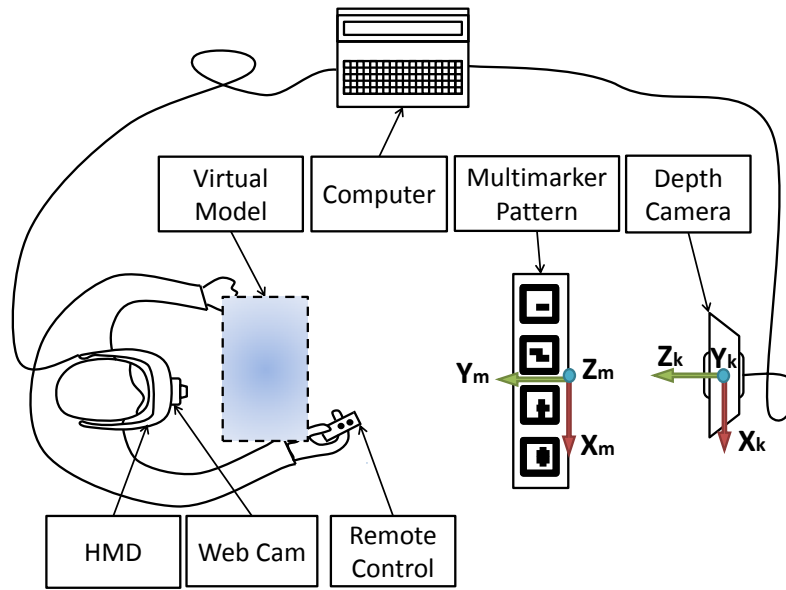


Figure 4.7: Air-Modeling's Scene Setup

user is able to visualize the context and the virtual model from any point of view. Limitations are associated with wire length and angle between camera gaze and the marker. However, the field of visualization is wide enough to give the user a stable and realistic AR experience.

## 4.5 Software

The software of Air-Modeling was developed in C programming language using Visual Studio 2010® for compilation tasks. The software is composed by multiple threads as Figure 4.8 shows. In Appendix B.1 the main function of Air-Modeling's software is shown in which the threads are launched and finished. The first thread of the software is called scene capture thread and it is in charge of capturing the scene, including both the user and the context (details are given in Section 4.5.1). The second thread is called modeling engine thread and in it a B-rep (Boundary representation) of the virtual models is created, stored and updated according to the user's commands, see Section 4.5.2 for details. The AR scene, merging the stream of the real environment captured from the HMD with both the user perspective and the virtual model, is provided by the third thread: the rendering engine thread (details of its implementation is given in Section 4.5.3). The whole Air-Modeling's code is composed

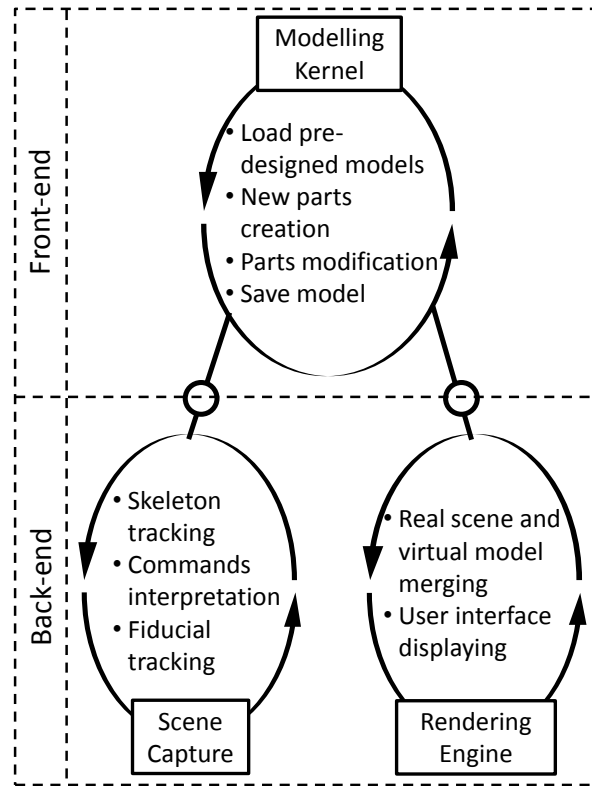


Figure 4.8: Air-Modeling's Software Architecture

by 82 functions with a total of 2672 Physical Executable Lines of Code (SLOC-P). Table 4.1 presents more details of the metrics of code.

#### 4.5.1 Scene capturing

As aforementioned, the interface of the developed tool is based mainly on the user hands. In that way, user's hand position must be tracked and his/her hand gestures must be recognized. The body tracking is achieved by the NITE<sup>TM</sup> library. These algorithms use depth and color streams from Kinect<sup>®</sup> for calculating the spatial position of users' skeleton giving the position vectors of 15 joints (see figure 4.9). In Appendix B.2 the implementation of this thread based on the NITE<sup>TM</sup> algorithms is shown.

Lines of Code (LOC)	3485
Blank Lines of Code (BLOC)	699
Physical Executable Lines of Code (SLOC-P)	2672
Logical Executable Lines of Code (SLOC-L)	2025
McCabe VG Complexity (MVG)	304
Code and Comment Lines of Code (C&SLOC)	61
Comment Only Lines of Code (CLOC)	114
Commentary Words (CWORD)	732
Header Comment Lines of Code (HCLOC)	0
Header Commentary Words (HCWORD)	2

Table 4.1: Air-Modeling code's metrics

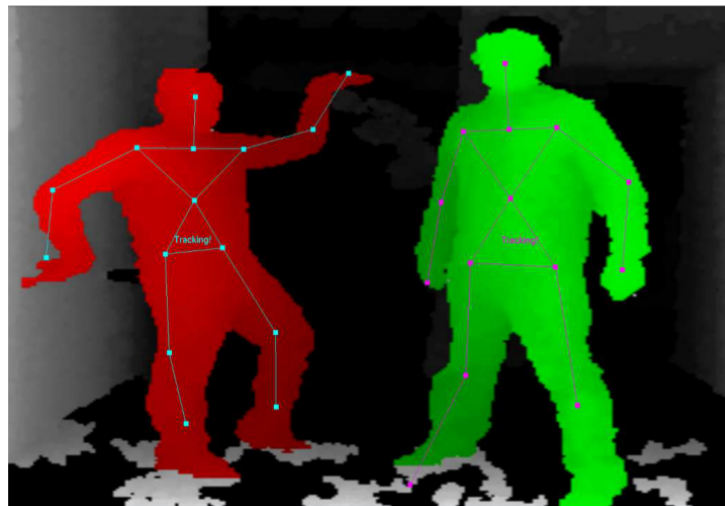


Figure 4.9: Skeleton tracking using NITE™. Reproduced from Pri (2010)

### 4.5.2 Modeling Engine

The management of the 3D models that the user imports, creates, manipulates, modifies and saves is achieved by the modeling engine thread. The general algorithm of this thread is represented in the flowchart in Figure 4.10. In Appendix B.3 the implementation of this thread is shown.

A plain text file with an own format was used to import 3D predesigned models or ex-

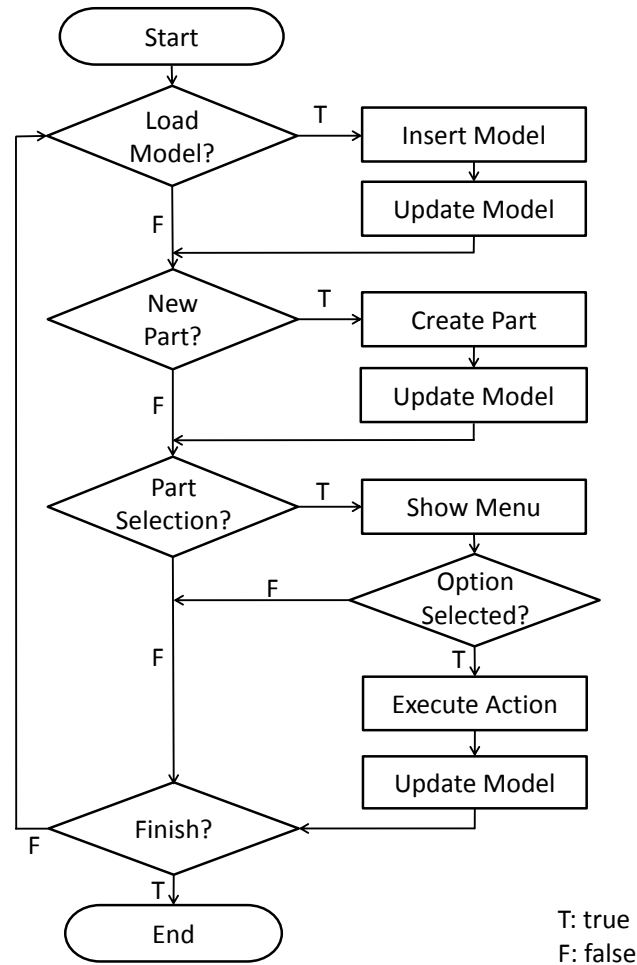


Figure 4.10: Flowchart of the modeling procedure in Air-Modeling

port created ones. Basically, the file contains the geometry of the parts (the 8 vertex of the cuboids) as is shown in the sample file in Appendix A. The topology is already known by the fact that it is assumed the parts are cuboids. However, in a future release of Air-Modeling in which the possibility of creating different shapes be able, the topology of the bodies has to be specified in the file.

During the modeling session it is required to create new parts and delete existing ones. This implies that the number of parts that the 3D model will have at the end of the design session is unknown at the moment of the software starting. This means that the RAM memory, while the program is running, has to be treated dynamically. According to this, a linked list data structure was implemented in Air-Modeling software. A linked list is a group of

nodes representing a sequence. Each node is composed of a data and a reference (in other words, a link) to the next node in the sequence (see Figure 4.11). This structure allows for efficient insertion or removal of elements from any position in the sequence.

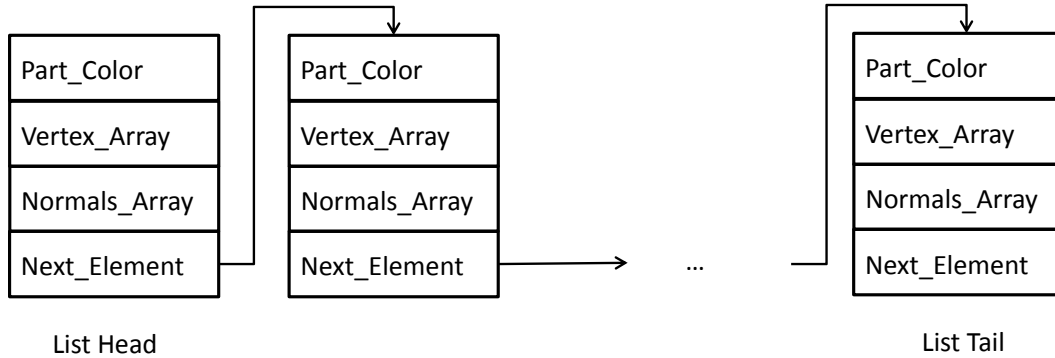


Figure 4.11: Linked list for memory management

For the parts editing operations: translating, rotating and stretching a set of geometric transformations was implemented in the algorithm in order to transform the parts according to the user requirements. Following the details of the implementation of the geometric transformations are given.

Let  $B$  be the body in homogenous coordinates:

$$B = \begin{bmatrix} Vt1_x & \cdots & Vt8_x \\ Vt1_y & \cdots & Vt8_y \\ Vt1_z & \cdots & Vt8_z \\ 1 & 1 & 1 \end{bmatrix}$$

The associated right handed basis  $x_i, x_{i+1}, x_{i+2}$  is attached to the body's centroid and oriented according the direction of the length, width and height of the cuboid. Let  $V_c$  be the 'current' position indicating any position of the user's hand.

For the rotation, the reference point  $V_r$  is created when the user selects the desired rotation axis  $x_i$ . Let  $V_{pr}$  and  $V_{pc}$  be the orthogonal projections of the points  $V_r$  and  $V_c$  over the axis  $x_i$ . See Figure 4.12(a) for graphic details. The angle between the vectors  $\overrightarrow{V_r V_{pr}} = V_r - V_{pr}$  and  $\overrightarrow{V_c V_{pc}} = V_c - V_{pc}$  is the desired rotation angle. In order to perform the rotation, first the body  $B$  has to be placed in the absolute coordinate system  $B_{abs}$  and after that the matrix product can be carried out to obtain  $B_{r\_abs}$ .

$$B_{r\_abs} = R_i * B_{abs}$$

Where  $R_i$  is the rotation matrix in homogenous coordinates according to the selected axis  $x_i$ :

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \alpha & -\sin \alpha & 0 \\ 0 & \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad R_2(\alpha) = \begin{bmatrix} \cos \alpha & 0 & \sin \alpha & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \alpha & 0 & \cos \alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad R_3(\alpha) = \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 & 0 \\ \sin \alpha & \cos \alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Finally,  $B_{r\_abs}$ , that is the rotated body but still placed in the absolute coordinate system, has to be placed again in the original coordinate system to obtain the rotated part with angle  $\alpha$  along  $x_i$ .

For the case of translation,  $V_r$  is defined as the reference position of the user's hands when he/she selects the translation option. At the same moment, the position of the selected part  $B$  is stored as the reference position  $B_r$ . The vector  $\vec{T} = V_c - V_r$  is added to each vertex  $Vti$  of  $B_r$  (see Figure 4.12(b) for details):

$$Vti = Vti_r + \vec{T}$$

with  $i=1:8$ .

For the case of stretching any face of  $P_i$ ,  $V_r$  is defined as the reference position of the user's hands when he/she selects the stretching option. After that, the user has to select the desired

part's face to stretch. At this moment, the 4 vertices  $Vt_i, Vt(i+1), Vt(i+2), Vt(i+3)$ , are stored as the reference. The new face's vertices are defined by:

$$Vt_i = Vt_{i_r} + \vec{x}_i * d$$

with  $i=1:4$ .

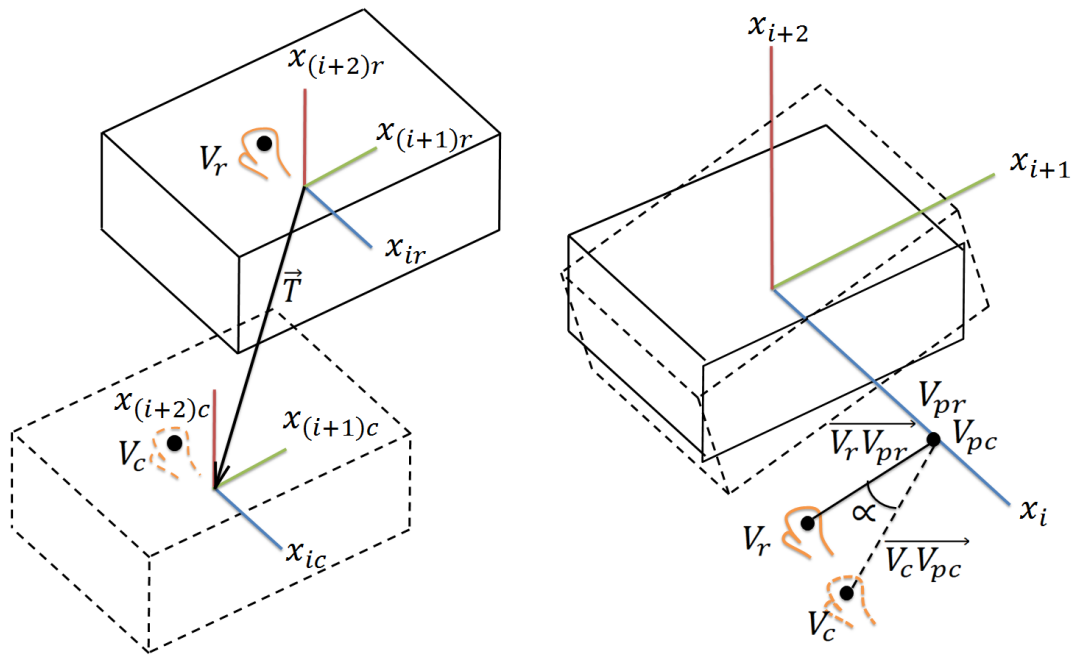
Where  $d$  is the magnitude of the distance between the points  $V_{pr}$  and  $V_{pc}$ , which are the orthogonal projections of the points  $V_r$  and  $V_c$  over the axis perpendicular to the selected face  $x_i$  (see Figure 4.12(c)).

### 4.5.3 Rendering Engine

In order to generate the AR scene merging the real world video stream with the 3D virtual model we used ARToolkit library. This is an open C and C++ language software library for developing AR applications. The ARToolkit algorithms use computer vision techniques to calculate the real camera position and orientation relative to marked cards (Kato et al. (1999)) in order to achieve the correct perspective projection of the virtual model. The algorithm is based on the next five steps (see figure 4.13 for details):

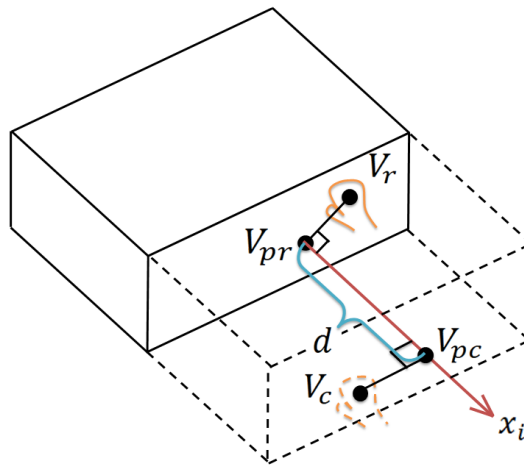
1. Search for markers
2. Find marker 3D position and orientation
3. Identify markers
4. Position and orient objects
5. Render 3D objects

Finally, the 2D graphics of the AR scene generated by ARToolkit algorithms are rendered on the HMD using OpenGL library. In Appendix B.4 the implementation of this thread is shown.



(a) Model for parts rotation

(b) Model for parts translation



(c) Model for parts stretching

Figure 4.12: Models for parts transformation

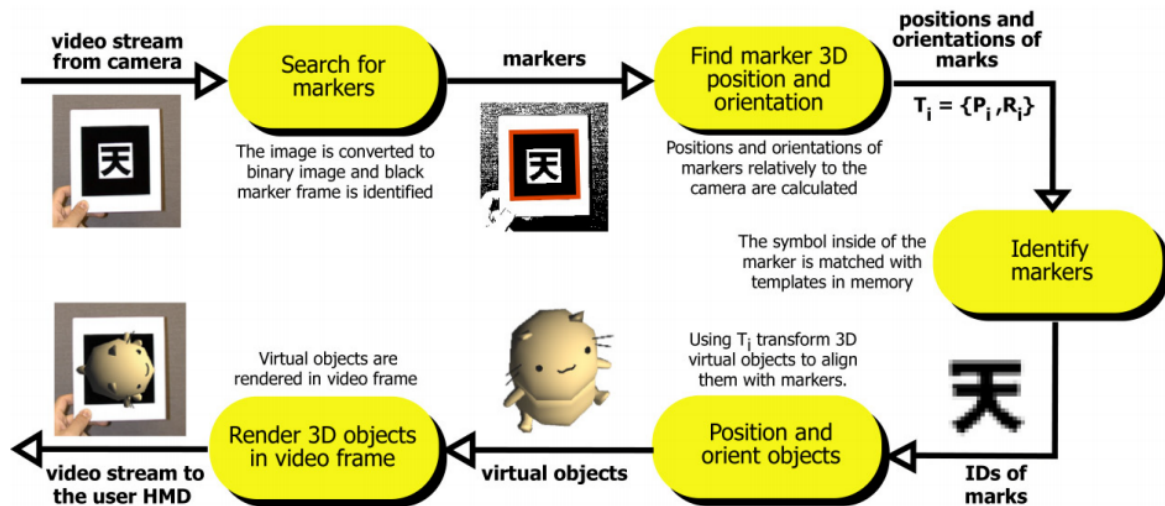


Figure 4.13: Internal process in ARToolkit (Kato et al. (1999))

#### 4.5.4 Threads Communication

For data interchange between the scene capturing thread, the modeling kernel thread and the rendering thread, a communication model was implemented not only to pass information to each other but to do it making sure that two or more processes do not get in each other's way and to concern proper sequencing between threads' requests. In that way, a limited buffer producer-consumer model was implemented twice (see reference Tanenbaum (2007) for details). In the first case the producer is the scene capture thread and the consumer is the modeling engine one. The scene capture thread must provide the modeling kernel thread with the user's hands position vectors and the recognized gestures. In the second case the modeling engine thread is the producer and the rendering engine is the consumer. The modeling kernel thread yields the geometry of the virtual models to the rendering engine. In both cases a limited buffer, as a critical region of memory, was created for the couple producer-consumer share information. However, a mutex (mutual exclusion) lock has also been implemented in order to guarantee the synchronization in data interchanging, avoiding the consumer and producer access to the critical region of memory at the same time. In figure 4.14 is shown the algorithm proposed by Tanenbaum Tanenbaum (2007) for solving the producer-consumer problem with mutex locks.

```

#include <pthread.h>
#define MAX 1000000000 /* how many numbers to produce */
pthread_mutex_t the_mutex;
pthread_cond_t condc, condp;
int buffer = 0; /* buffer used between producer and consumer */

void *producer(void *ptr) /* produce data */
{
    int i;
    for (i= 1; i <= MAX; i++) {
        pthread_mutex_lock(&the_mutex); /* get exclusive access to buffer */
        while (buffer != 0) pthread_cond_wait(&condp, &the_mutex);
        buffer = i; /* put item in buffer */
        pthread_cond_signal(&condc); /* wake up consumer */
        pthread_mutex_unlock(&the_mutex); /* release access to buffer */
    }
    pthread_exit(0);
}

void *consumer(void *ptr) /* consume data */
{
    int i;
    for (i = 1; i <= MAX; i++) {
        pthread_mutex_lock(&the_mutex); /* get exclusive access to buffer */
        while (buffer == 0) pthread_cond_wait(&condc, &the_mutex);
        buffer = 0; /* take item out of buffer */
        pthread_cond_signal(&condp); /* wake up producer */
        pthread_mutex_unlock(&the_mutex); /* release access to buffer */
    }
    pthread_exit(0);
}

int main(int argc, char **argv)
{
    pthread_t pro, con;
    pthread_mutex_init(&the_mutex, 0);
    pthread_cond_init(&condc, 0);
    pthread_cond_init(&condp, 0);
    pthread_create(&con, 0, consumer, 0);
    pthread_create(&pro, 0, producer, 0);
    pthread_join(pro, 0);
    pthread_join(con, 0);
    pthread_cond_destroy(&condc);
    pthread_cond_destroy(&condp);
    pthread_mutex_destroy(&the_mutex);
}

```

Figure 4.14: Producer-consumer problem solved with mutex. Reproduced from Tanenbaum (2007)

## 4.6 Ergonomic Assessment Module implementation

The Ergonomic Assessment Module (EAM) is an additional part of the Air-Modeling software in which the analysis of the user postures during the design session is carried out in order to analyze and detect ergonomics issues of the product even from its conceptualization.

The inputs of the EAM, to assess the postures, are the angles between body parts and the forces exerted by the user. The reconstruction of the user skeleton is employed for calculating the angles between each pair of continuous body parts (e.g.  $\beta_R$ ,  $\beta_L$  in Figure 4.15). On the other hand, the weight of the virtual parts that the user manipulates are calculated according to the parts' geometry and the density of the pre-selected material.

In the modeling kernel thread of the software (see section 4.5.2) the EAM was implemented. This module launches warns to the user in real-time, regarding non-recommendable postures. This information results very useful to detect ergonomic issues of the product during products conceptualization.

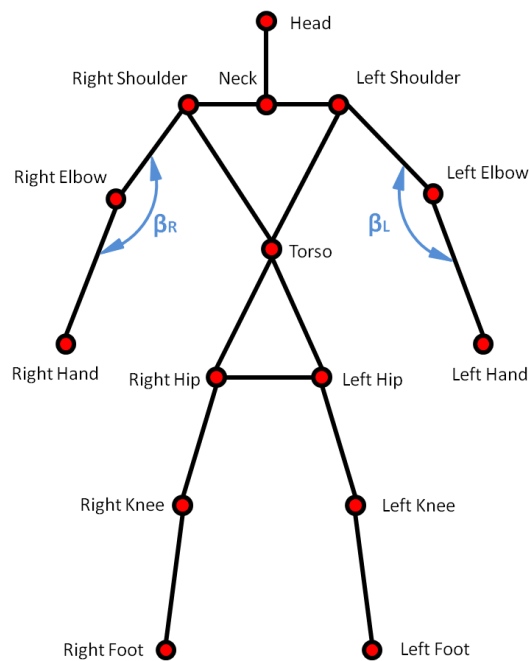


Figure 4.15: Skeleton reconstruction using Microsoft Kinect<sup>®</sup> and NITE<sup>™</sup>

The user's postures are evaluated by the EAM with the RULA tool (McAtamney and Corlett, 1993). This tool was developed to investigate the exposure of workers to risk factors associated with work-related upper limb disorders. Positions, forces, and frequencies concerns with focus on the upper limbs, neck, and trunk are analyzed. RULA associates body postures to numerical values evaluating exposure to risk factors and uses three scoring tables to compute a final score for each body side. Figure 4.16 shows the worksheet for manual evaluation of ergonomic issues of upper limbs using RULA tool. For example, if the upper arm is in the range of  $-20$  to  $20^\circ$ , in relation with the trunk orientation, a value of 1 is given, if is less than  $-20^\circ$  a value of 2, if is in the range of  $45-90^\circ$  a value of 3 and if is more than  $90^\circ$  a value of 4 is associated. With this score and others from other limbs, a final score is calculated using three scoring tables provided by the tool (see reference McAtamney and Corlett (1993) for details). The level of intervention required to reduce the risks of injury due to physical loading on the operator is indicated. Postures are classified in acceptable, postures that may be studied, postures that may be changed soon and postures that may be changed immediately. Finally, a coded version of the RULA tool was implemented in the modeling kernel thread of the Air-Modeling's software.

## 4.7 EAM Validation

In order to validate the results of the EAM, i.e. our RULA implementation, we compared the scores of some postures obtained in Air-Modeling through the EAM against the scores obtained with similar postures in the module Delmia<sup>TM</sup> of the Catia<sup>TM</sup> commercial software. The angles of the test postures where obtained from the Air-Modeling tool and with this information the posture where replicated in Delmia<sup>TM</sup> (see figure 4.17). Table 4.2 presents the information of the posture shown in Figure 4.17. As it can notice, we obtained the same RULA scores in both tools, which allow us to be sure that the results obtained by the EAM are reliable.

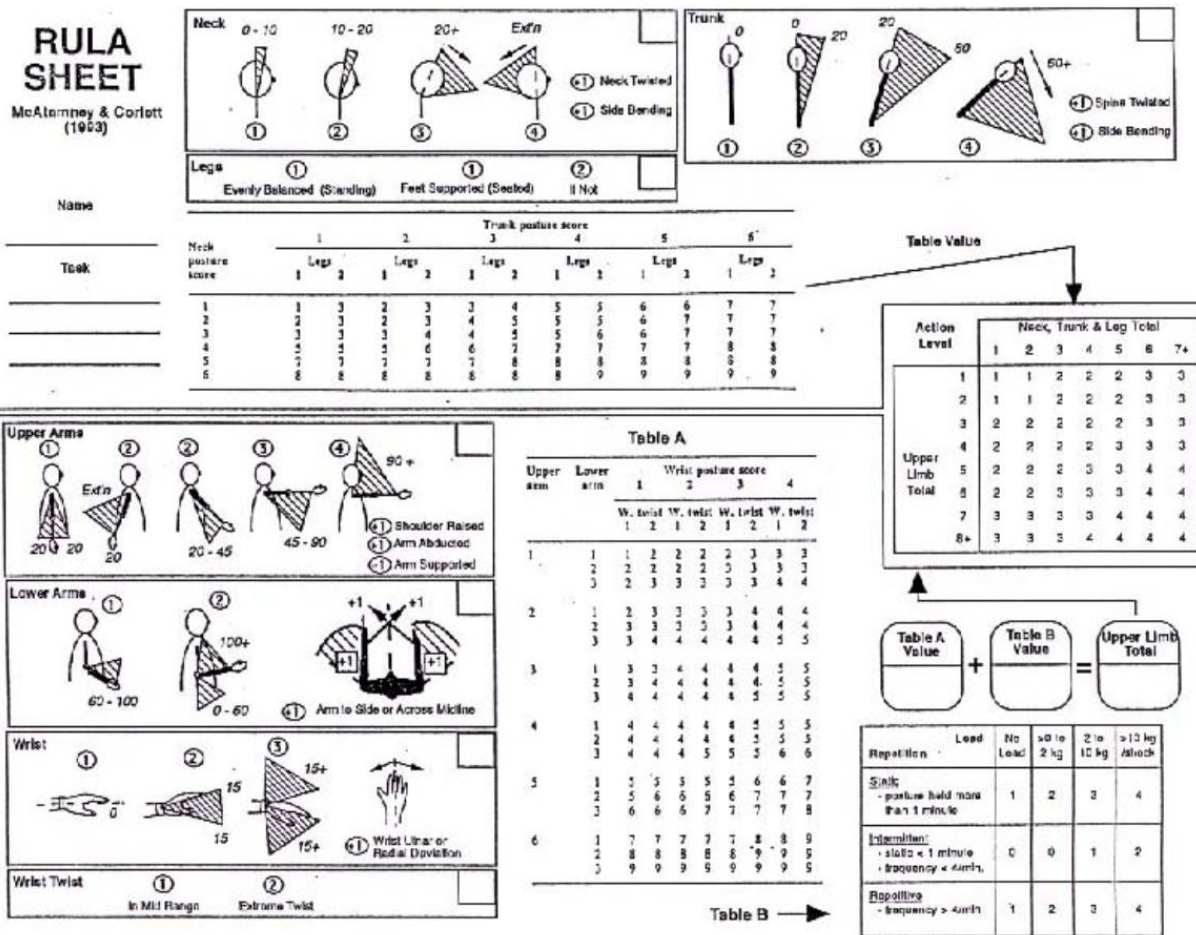


Figure 4.16: RULA worksheet for manual ergonomic evaluation (McAtamney and Corlett (1993))

		AM	Delmia
	Angles	RULA	RULA
		Score	Score
Right Lower arm angle	22,90°		
Right Upper arm angle	51,17°	3	3
Left Lower arm angle	36,82°		
Left Upper arm angle	94,37°	4	4
Neck side angle	-6,54°	4	4
Trunk front angle	10,81°		
Trunk side angle	-9,54°	2	2
Righth Total Score	N/A	4	4
Left total Score	N/A	5	5

Table 4.2: RULA results comparison from Air-Modeling (AM) and Delmia™



Figure 4.17: Results validation against Delmia™

## Chapter 5

# Experiment and Results

With the development of Air-Modeling we aimed to prove that it is possible to extract useful information from the interaction user-context in 3D conceptualization in AR environments with gesture-based modeling tools. In addition some of the consequent effects of the use of this kind of tools in the design process are also analyzed in this chapter.

### 5.1 Testing Air-Modeling in the design process

As mentioned in Section 3.2.5, we selected a before-after experiment to collect the data. With this kind of experiment we aimed to analyze the effect on the design process when the interface of the modeling tool was altered. In that way, we carried out a test in which 21 users were invited to do some task in two tools: in Air-Modeling (CAD tool based on a natural interface) and in SolidWorks® (CAD tool based on a WIMP interface).

The test comprised two sessions (see Figure 5.1): one analyzing the usability of the different modeling commands and the other one for comparing the designer's performance during a real conceptualization case. Both sessions were carried out with the two afore mentioned tools.

The evaluation included quantitative as well as qualitative methods, such as questionnaires, user observation and interviews. The aspects evaluated during and after both sessions of the test were:

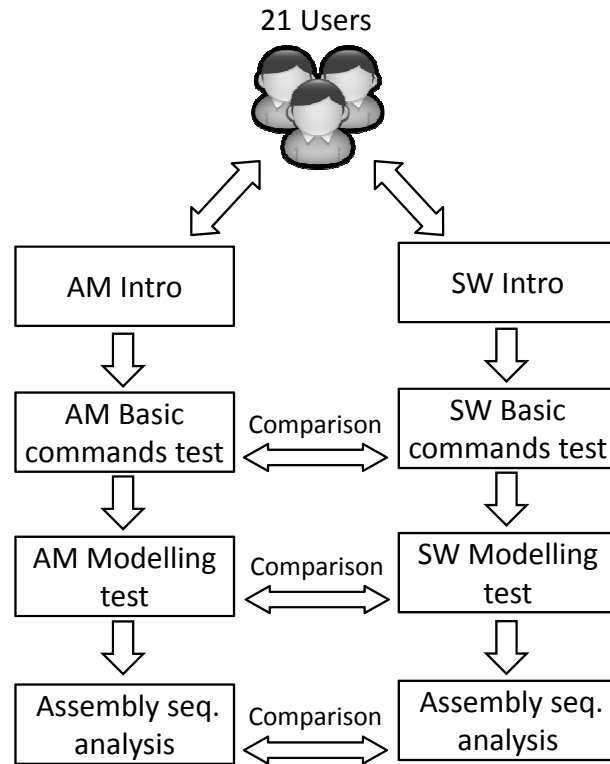


Figure 5.1: Methodology for Air-Modeling testing

- In the first session: time to complete individual tasks for creating and manipulating geometries (create a box, rotate a box, translate a box, stretch a box).
- In the second session: time to complete a conceptual design of a proposed case study.
- In the second session: number of times in which each user used measurement tools during the conceptualization.
- During both sessions: expressions of satisfaction, confusion, frustration or tiredness of the users using both tools.
- After both sessions: tiredness on feet, arms and eyes after finishing the test.
- After both sessions: preferred tool to create and modify boxes.

- After both sessions: tool that allowed better perception of the modeling space.

### 5.1.1 Sample

The users, who were mostly students of the Product Design Engineering program at the Universidad EAFIT, were selected with different characteristics and knowledge: 71% (of the total users) without any AR experience, 81% (of the total users) with CAD experience from which only 53% with specific experience with SolidWorks® (SW). Table 5.1 presents the sample details.

Total Users	21
Male Users	15
Female Users	6
Experience with CAD	19
Experience with SW	9
Experience with AR	6

Table 5.1: Sample Description

### 5.1.2 Test session 1: usability test

Before to start the test, a brief introduction to each tool was first made explaining and showing to each user how to carry out the different actions. After that, in the first session, the users were asked to perform in both tools, elementary tasks for creating and manipulating (translating, rotating, stretching) boxes in a 3D space. During this part of the test, the time that each user employed for complete each action was measured in order to determine which operations could result more effective or more time-consuming in each tool.

Figure 5.2 shows the result of the session 1 of the test comparing the mean time to perform individual task (such as creation, translation, rotation and stretching boxes) using both tools. It can be noted that there is a significant difference in the time to create new geometries. The mean time for creating new box in Air-Modeling was 66% lower than the mean time for the same action in SolidWorks®. However, in translation, rotation and stretching we obtained

similar performance between the proposed tool and the standard WIMP-based CADtool.

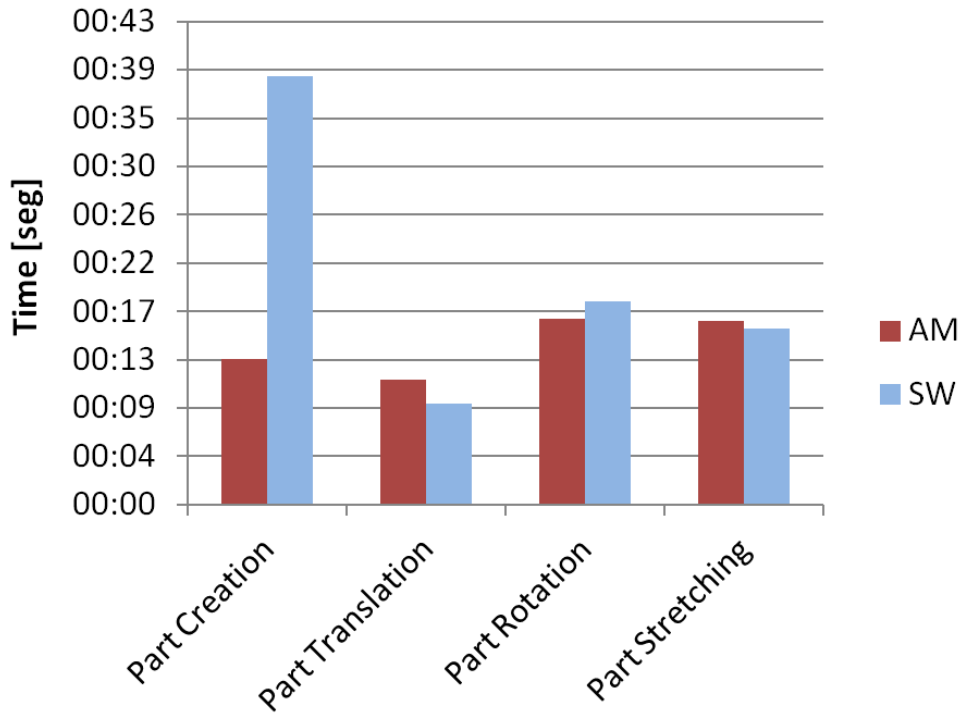


Figure 5.2: Usability test results using SolidWorks® (SW) and Air-Modeling (AM)

### 5.1.3 Test session 2: conceptualization case

In the second session of the test, a case study was presented to each user in which they should propose a conceptual 3D model of a bookcase for certain context. The users should design a three-level bookcase over an existent desk and they were free to choose their own design, but exactly the same concept was to be modeled in both tools. The order of use of the tools for the case study was altered for preventing that the usage of one of the tools conditioned the conceptualization, and consequently, the usage of the other tool. The whole session was registered to ensure that all actions of the user were recorded for analysis.

Table 5.2 shows the results of the second sessions of the test. The analysis was not made between the different users but it was made comparing the performance of each user using both tools. It could be noted that in the most of the cases, exactly 76% of them, there was a

time reduction using Air-Modeling in comparison to the traditional way of creating 3D models for product concepts. This could be, to a certain extent, due to the time associated to the use of measurement tools during the design process. No users employed measurement tools during the design sessions with Air-Modeling, in contrast 67% of the users used measurement tools modeling with SolidWorks® once or twice (see Figure 5.3). In Figure 5.4 the histogram of the reduction percentages in the cases with positive results is shown. The histogram has a peak at 40-50%, where the average reduction of 44%, with a standard deviation of 20%, is located. Some examples of the created concepts for the proposed case study using both tools are shown in Figure 5.5. It can be noted that the models created in the traditional CAD package are more accurate, however, the core in conceptual design is to conceive a physical configuration to meet the demand of the customer (Kroll and Jansson., 2001) and in a later stage the details of the model are refined.

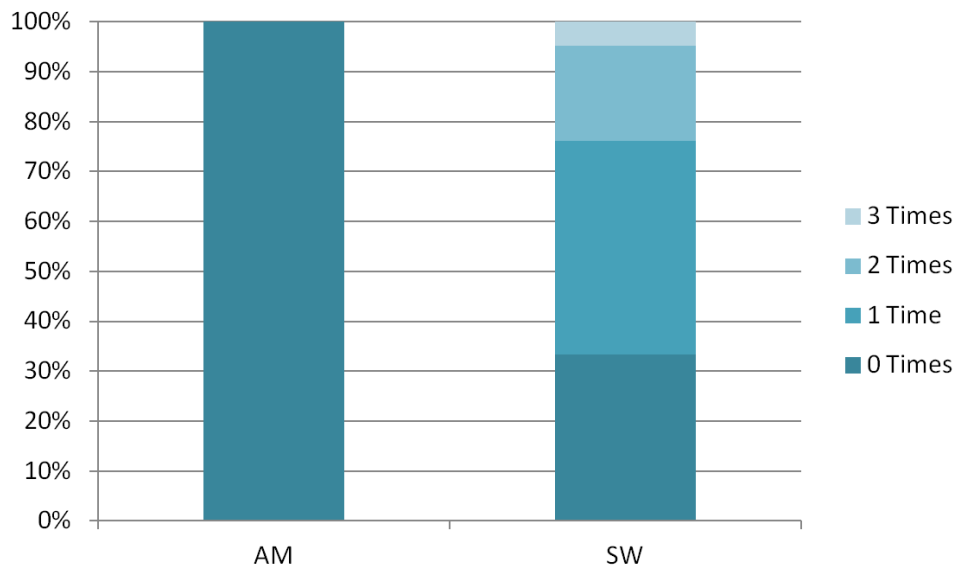


Figure 5.3: Use of Measurement tools during the tests using SolidWorks® (SW) and Air-Modeling (AM)

After finalizing the test, all users were interviewed in order to evaluate their feelings and usage experience. Summarized results of the questionnaire are shown in table 5.3. We found that almost half of the users showed tiredness gestures during the sessions with Air-Modeling, which could be due to the weight of the HMD. Although only 33% of the users manifested

User	Modeling Time		Lower in AM	Reduction
	AM [mm:ss]	SW [mm:ss]		
N°1	06:21	07:44	Yes	18%
N°2	12:24	23:19	Yes	47%
N°3	06:03	09:55	Yes	39%
N°4	12:04	31:17	Yes	61%
N°5	06:58	14:17	Yes	51%
N°6	03:58	05:11	Yes	23%
N°7	03:07	11:13	Yes	72%
N°8	02:35	05:05	Yes	49%
N°9	04:15	08:26	Yes	50%
N°10	09:01	08:50	No	2%
N°11	05:15	08:02	Yes	35%
N°12	11:29	08:40	No	25%
N°13	05:10	06:46	Yes	24%
N°14	01:42	03:05	Yes	45%
N°15	07:57	07:45	No	3%
N°16	04:48	13:26	Yes	64%
N°17	02:37	04:51	Yes	46%
N°18	09:25	15:51	Yes	41%
N°19	07:57	07:45	No	3%
N°20	03:50	05:49	Yes	34%
N°21	09:36	07:48	No	19%

Table 5.2: Results of the modeling session in AM and in SW

tiredness in their arms or legs after using our tool, it is clear that prolonged use will generate ergonomics issues. Despite this, the majority of the users (76%) expressed to have a better perception of the modeling space using Air-Modeling. Results show a preference of the users for boxes creation and translation using our tool but it seems that rotation and stretching do not generate a better experience than the traditional way using a WIMP-based interface (see table 5.3).

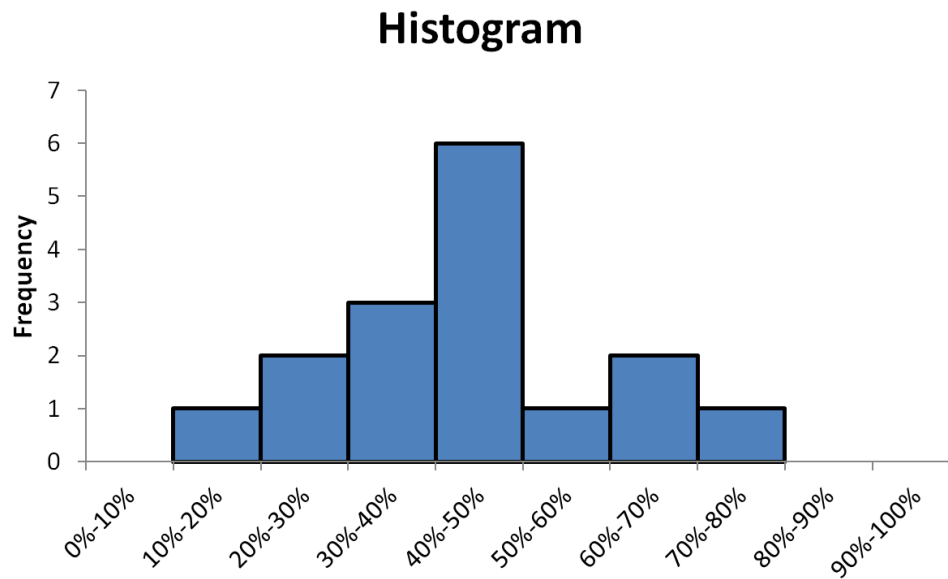


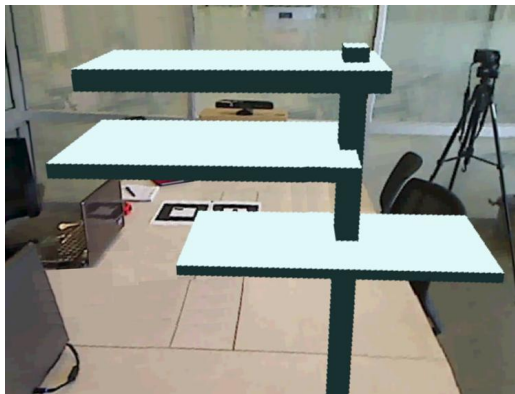
Figure 5.4: Histogram of the modeling test results

Tiredness Gestures	48%
Despair Gestures	19%
Satisfaction Gestures	38%
Confusion Gestures	10%
Tiredness on Legs	10%
Tiredness on Arms	33%
Tiredness on Eyes	33%
Preference for AM for boxes creation	81%
Preference for AM for boxes rotation	48%
Preference for AM for boxes translation	71%
Preference for AM for boxes stretching	52%
Better space perception in AM	76%

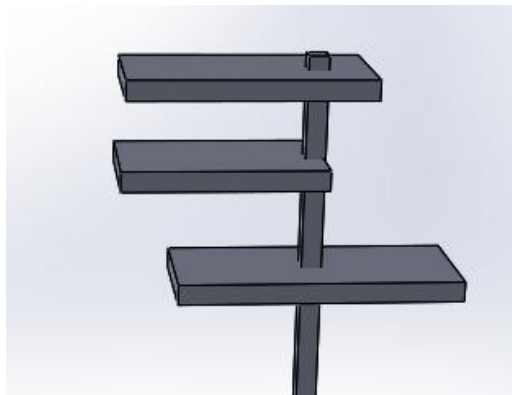
Table 5.3: Qualitative results of the Air-Modeling (AM) usage test

## 5.2 Assembly sequence analysis after Air-Modeling sessions

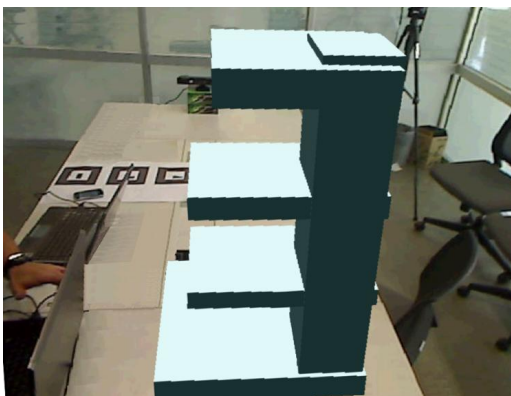
After the second session of the test, we also analyzed the assembly sequences carried out, for each user, for the developed models in both tools for determining if the fact of modeling in



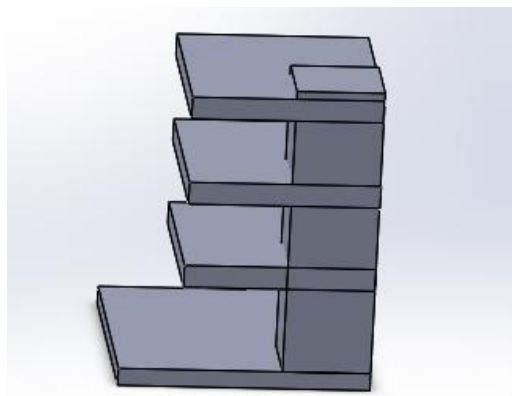
(a)



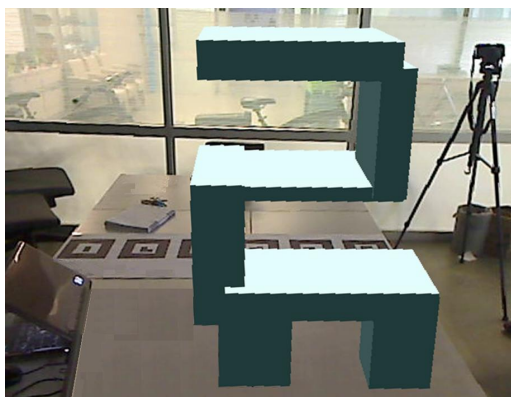
(b)



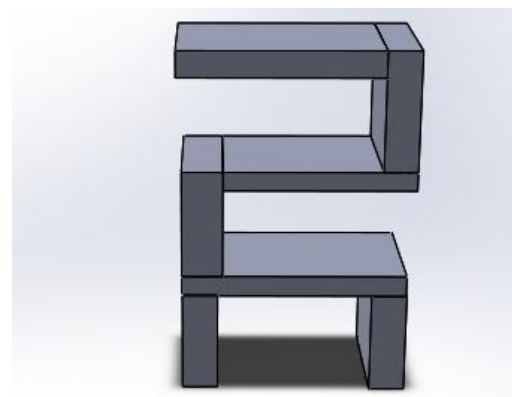
(a)



(b)



(a)



(b)

Figure 5.5: Products developed in (a) Air-Modeling and (b) SolidWorks®

natural scale directly over the context and with this kind of modeling influences or not the order of the parts creations. The feasibility of the sequence was determined from the correctness of the assembly precedence relations. In other words, a feasible assembly sequence is one in which the physical laws are considered and consequently all the parts have to be well supported between them during the whole assembly process and where there are not interferences problems.

As it is presented in Figure 5.6, there was a greater number of valid assembly sequences using our AR-based modeling tool (AM) in comparison with the usage of a traditional CAD-software (SW). Specifically, 74% of the users considered a valid assembly sequence, whereas using SolidWorks® there were 58% of valid sequences.

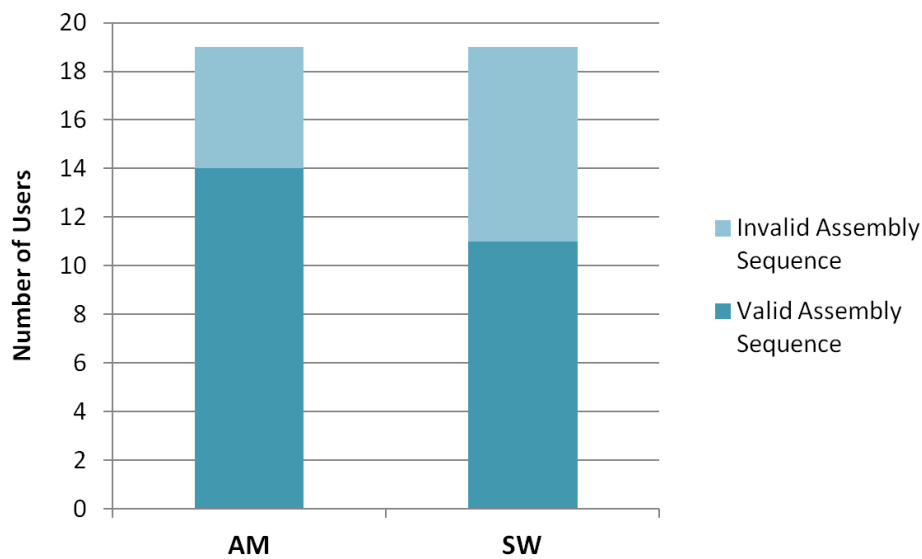


Figure 5.6: Results of the assembly sequences comparison in AM and SW

From the obtained results it could be inferred that modeling in context through a natural interface in AR environments tends to increase the physical feasibility of the assembly sequence in comparison with the traditional way of modeling in commercial CAD software through a WIMP (Windows-Icon-Menu-Pointer) interface. Figure 5.7 presents one of the cases in which the user modeled the product with a valid sequence in Air-Modeling but with an invalid one with SolidWorks®. On the other hand, Figure 5.8 presents a case in which

the user carried out a valid assembly sequence using both tools.

### 5.3 Case Study for the EAM

With the information given by the EAM in Air-Modeling, the designer is able to know continuously in real-time the evaluation of his/her postures. The user can simulate the usage and assembly of the product to assess the risk that the final user could have. In addition, because Air-Modeling works with a top-down design strategy, the design process can be associated with the real assembly process and consequently ergonomic risk of the assembly operators can be analyzed. This information is useful during the product concept development, in order to consider the aspects of the product that could imply ergonomic risks in further phases of the product lifecycle.

While the user is developing a product in Air-Modeling, he/she is given feedback with the evaluation of his posture in real-time. In the HMD the user skeleton reconstruction highlighting the body parts in risk is shown. Figure 5.9 presents two different postures evaluated by the EAM. This information appears in a corner of the screen in the HMD as Figures 5.10 and 5.11 present. This warns the user about ergonomic risks related with the product. The colors of the skeleton and the flag given with the final RULA score, warn about the risk level of the posture: green color means no risks, while red imply the highest risk.

An additional test was carried out to prove the EAM and its usefulness in the design process. The same case study in which one user was asked for conceptualizing a bookcase over a certain context was carried out, but now analyzing during the modeling activity the ergonomics issues related with the product usage and its assembly process. Figure 5.11 presents a situation in which the user is releasing a virtual board. The EAM is warning the postures of the right arm and the trunk, considering the weight of the virtual part that is being manipulated. According to the results given by the EAM, the posture needs to be analyzed, but still it does not represent any considerable risk. That means that possibly the assembly operator has to realize a similar posture during the product installation in that context. On the other hand, figure 5.10 presents a screen capture in the moment in which the user was simulating the usage of the bookcase; specifically she was trying to reach something

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in its upper level. Notice that in the ergonomic evaluation, the neck is highlighted as a body part in notable risk. This means that possibly the final user of the product could have the same ergonomic implication while using the bookcase. This is why the designer should analyze these postures taking into account, among others, the spatial restrictions that the context imposes to the product configuration, usage and assembly. That means that the user, even from the product conception, would be able to detect possible problems in the product usage or assembly.

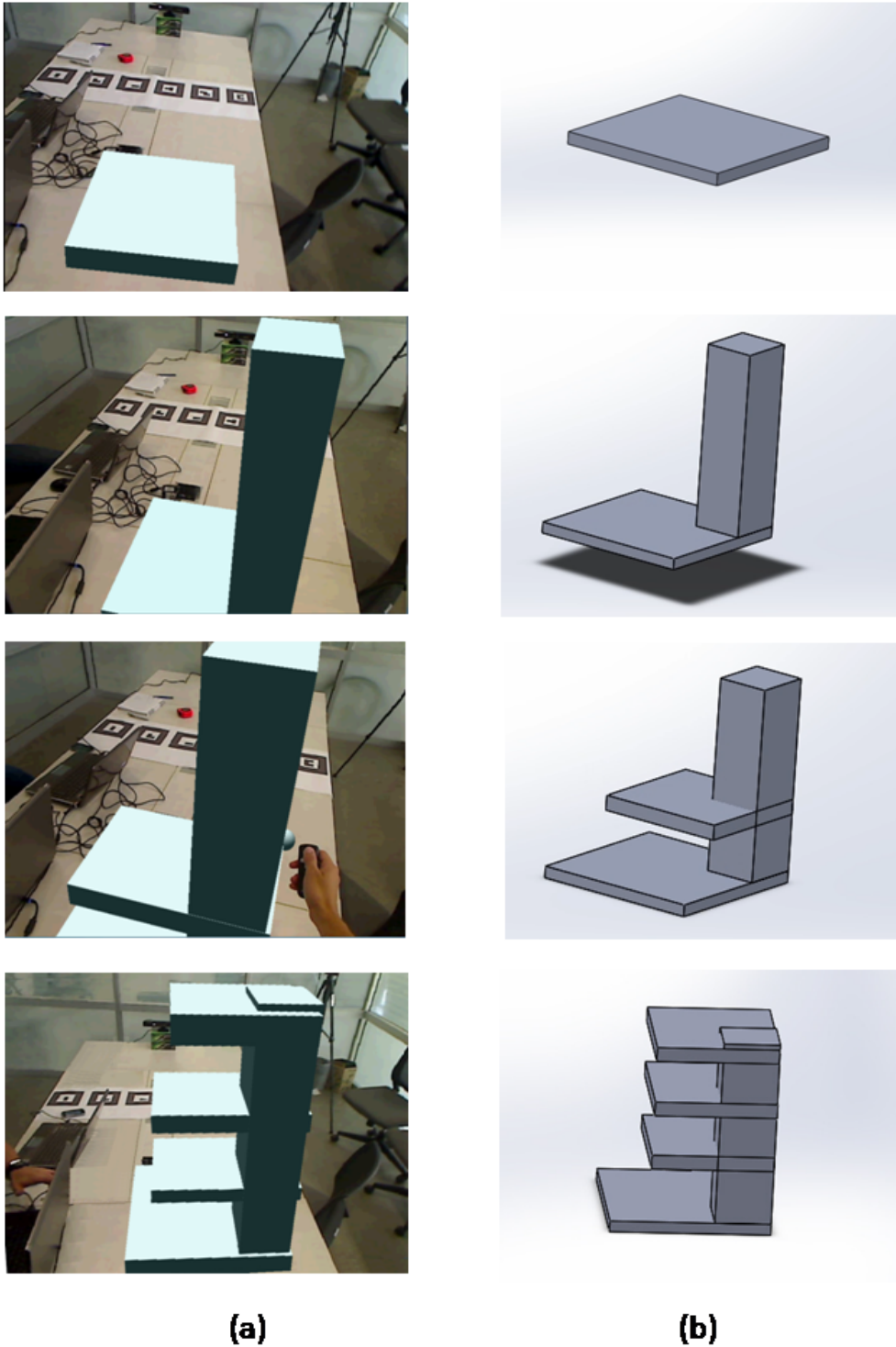


Figure 5.7: Valid assembly sequence using Air-Modeling (a) but invalid using SolidWorks® (b)

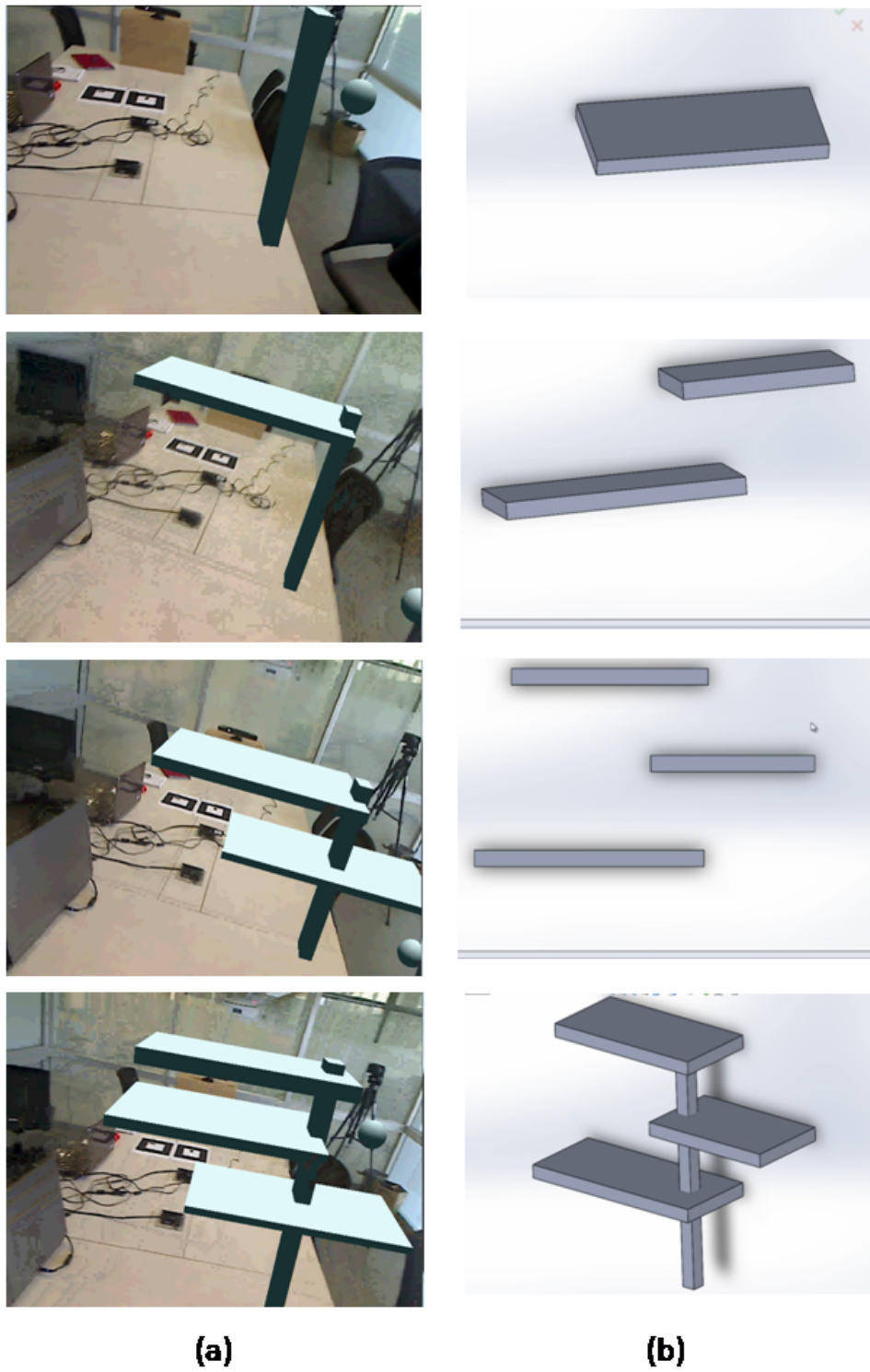


Figure 5.8: Valid assembly sequence using Air-Modeling (a) but invalid using SolidWorks® (b)

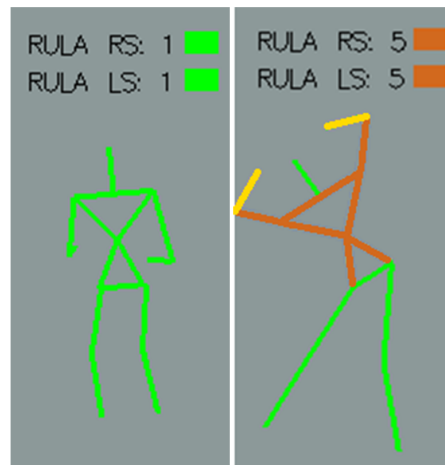


Figure 5.9: Posture evaluation shown to the user in Air-Modeling



Figure 5.10: Posture warned as non-recommendable while the product usage was being simulated

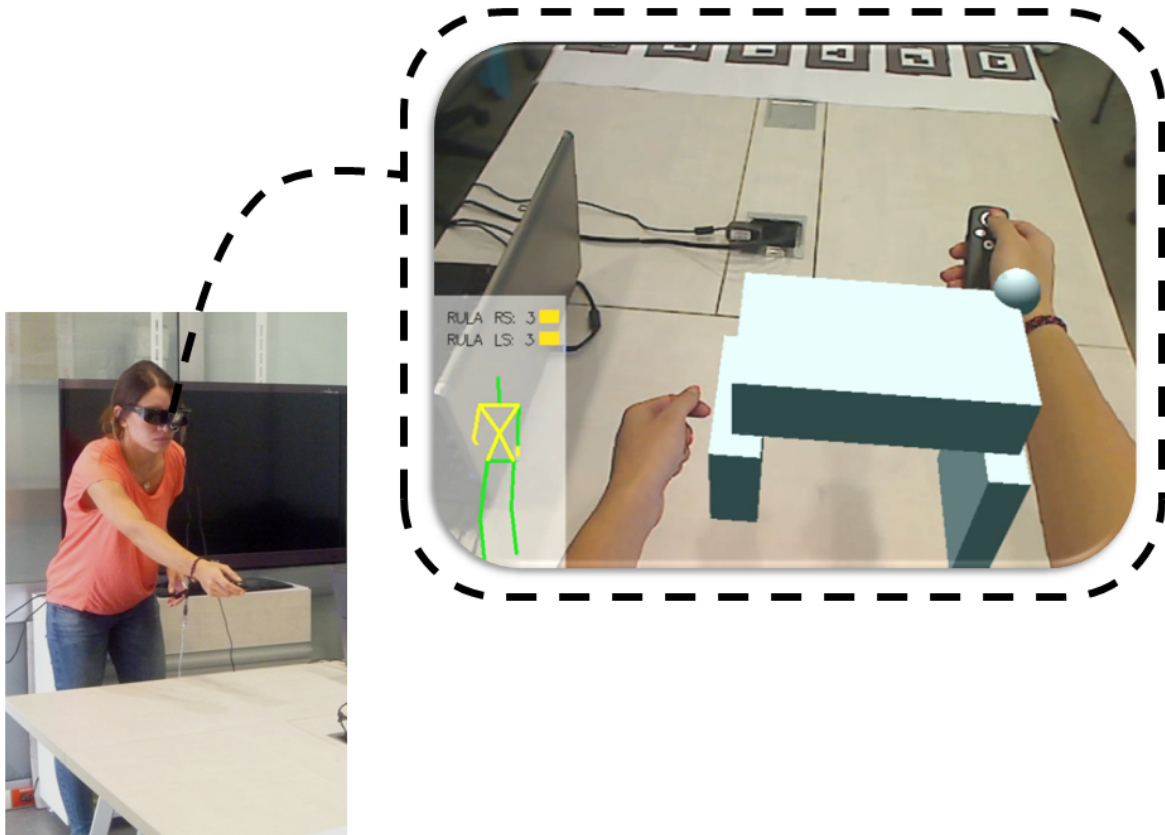


Figure 5.11: Posture warned as non-recommendable during the model creation



## Chapter 6

# Conclusions and Future Work

### 6.1 Conclusions

This research was conducted with the purpose of explore the effects of the use of natural interfaces on context-dependent products conceptualization. Advances in this area can imply a more effective convergence to an appropriate design solution in the product development process. The literature about this field and specifically in the subject of AR-based modeling tools presents voids in the user-context interaction discourse. In this sense, this study sought to validate the following statement:

*It is possible to consider, during the conceptualization of context-dependent products in AR environments with gesture-based modeling tools, spatial and ergonomic restrictions that the environment imposes to the product through the analysis in real-time of the interaction user-context?*

In order to validate the proposed hypothesis we developed and proved Air-Modeling, a tool for solid modeling during early stages of product design in which the user can create with his/her hands in an easy and intuitive way, conceptual virtual models over the real scene using AR technology. Air-Modeling allows the designer to use the context as an information input for taking into account in real-time spatial restrictions that the scene imposes to the product's shape, configuration, usage and assembly process, instead to have to map the context to create a 3D model of the scene to proceed with the conceptualization. In addition,

the created tool allows to visually verify the dimensions, proportions and positions of the 3D models at the modeling time and even take into account ergonomic issues of the product during its design. By the fact that in the created tool the modeling is in a natural scale, ergonomic aspects related with the product during its conceptualization can be analyzed in real-time and in the real context. Thus, the designer can simulate the postures involved in the product usage and assembly in order to analyze ergonomic risks to which the user or the assembly operators could be exposed. In this way, improvements in terms of ergonomics can be performed at early stages of the product design. It is not more than limit the spectrum of the potential solutions of the design problem, adding ergonomic constrains during the conceptualization stage when the information about the problem is vague enough. In this way, the convergence to the near-optimal solution may be more effective possibly avoiding some iterations in the design process. However, it is clear that not for all kind of products the modeling with the kind of tools as the presented one is helpful, as in the case of too large-scale products such as airplanes, ships or buildings or too small-scale product such as watches or cell phones. So, this technology becomes more relevant for products whose shape, configuration and dimensions depend mainly on the environment such furniture, piping networks and structural frames.

According to this, we validate the hypothesis. Besides we also discovered other implications of the use of gesture-based modeling tool in product conceptualization as are mention below.

- One of the main advantages of the AR technology, in comparison with VR, is that the scene does not have to be modeled. Instead, a real scenario is used as input of visual and tactile information. This allows to save computational resources at the same time that allows a more realistic experience.
- Modeling in AR environments using the hands as interface, allows the designer to conceptualize quickly and efficiently, potential solutions, exploiting as much as possible, his/her inspirational instants. In that way, the designer is more in contact with the problem itself and the potential solution without the need to be focus on the interface of the modeling tool.

- Dimensioning and placing parts is more efficient with a 3D input in comparison with the 2D interface of traditional CAD packages. We think that it could be related with the fact that in the traditional CAD package, because of the limitations with the interface, the user must perform many steps to create a simple geometry body: activate the feature, select the plane, draw a sketch and select the extrusion direction and its dimension. These results can imply a more effective product conceptualization if the effectiveness is measured in terms of time. This conclusion can be supported with the results of the design session comparing the user performance with Air-Modeling with SolidWorks®.
- Modeling in a natural scale directly over the real scene prevents the designer from drawing his/her attention to dimensional details, but allows him/her to focus on the product itself and its relation with the environment.
- Conceptualizing in AR-based modeling tools increases the possibility to define a valid assembly sequence even in early stages of product development, which means that even from the conceptualization stage useful information of the assembly sequence for latest stages of the product design can be obtained. This could be related with the mapping that the user makes between the real world and the modeling space, even associating the physical laws of the real world to the modeling space due to the realistic feel generated by the sense of presence in the virtual world during the modeling process, that AR yields to the user.

## 6.2 Future work

We detected that marker-based AR software is very sensitive to scene luminosity, affecting the pattern recognition during the image processing and consequently producing some jitter in the virtual model visualization under certain conditions. Therefore, further research is required to improve the AR module of our proposed tool, in order to make the virtual models rendering more robust. On the other hand, it would be interesting to allow the modeling with more primitive geometries and features and prove the applicability of the tool in other products that depend highly on the context, such as piping networks and structure frames. Data interchange in standard CAD formats is required to use pre-designed models from com-

mercial CAD packages and to post-process models generated in Air-Modeling. In addition, it is clear that the scale of the products modeled in the presented tool is limited by the volume that the user can reach with his/her hands. In that way, future work is required for allowing to zoom in and zoom out the virtual model, in order to adjust it to the active modeling volume. This will allow a better performance developing both large-scale and small-scale products.

Our implementation of the EAM is based only on the anthropometrics and the postures of the designer to compute the ergonomics risks. Thus, it is possible that the final user or the assembly operator belongs to a different percentile, so it is possible that his/her posture against the product usage or assembly be different. As future work it would be interesting to infer and analyze the postures of users belonging to percentiles different to the one of the designer. Additionally, the shape and configuration of a product can change between its conceptualization and the detail design stage. So, traditional ergonomic analysis in advances stages of the product development is still required. In this way, our proposal is not to translate the ergonomic analysis phase (commonly carried out in the embodiment of schemes stages, see figure 1.1) to the conceptual design stage, but to start analyzing and improving ergonomic issues related to the general shape of the product from the conceptualization design stage, when the changes in the design still does not imply representative costs.

It is required to add the possibility of adding mating relationships in Air-Modeling for allowing the creation of more accurate designs and decrease the workload in the detail design stage. On the other hand, future work is required to develop a Computer-Aided Assembly Planning (CAAP) module integrated with Air-Modeling in order to check the validity of the assembly sequence, even from the conceptualization of the product, and warn the user for carrying out the respective changes in the product design.

It would be interesting to analyze the effects of adding realistic physical interaction between parts, with a dynamic engine, which would be closer the way in which the design develop its model with the real assembly process of the product. In addition, forces feedback related with parts lifting possibly influences the designer's postures and movements while

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he/she is developing a 3D model using Air-Modeling. In this way, dynamic ergonomic analysis could be carried out in order to analyze in detail the manual assembly work of the product and even its usage.

Finally, we believe that this kind of technologies would encourage both designers and customers, making the conceptualization of customized products more efficient by adding the real physical and ergonomics restrictions to the conceptualization process in real-time. This facilitates the convergence to the design solution, possibly avoiding some iterations in the design process. In addition, it is possible to increase the customer satisfaction since he/she can visualize a virtual model of the product in natural scale over the real scene and take decisions before the product materialization. We also consider that modeling in context in AR environments increases the realism of the conceptualization experience, opening the possibility of extracting useful information, as assembly sequence, for latest stages of product development, such as manufacturing and product installation.



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# Appendices



## Appendix A

# Implemented format for data interchange in Air-Modeling

Following is presented our own format implemented to load and save 3D model to Air-Modeling. In the file there are as many blocks of coordinates as there are cuboids in the model. Each block is composed by 8 coordinates in  $R^3$  referring to the 8 vertex of a cuboid. Notice that before each block there is the symbol % as spacer.

```
%  
-291.178040 -461.647583 501.203430  
-291.178040 -149.503174 501.203430  
-291.178040 -149.503174 -98.680786  
-291.178040 -461.647583 -98.680786  
659.919250 -149.503174 -98.680786  
659.919250 -149.503174 501.203430  
659.919250 -461.647583 501.203430  
659.919250 -461.647583 -98.680786  
%  
206.532562 -703.611206 407.843414  
206.532562 -541.027832 407.843414  
206.532562 -541.027832 261.426147  
206.532562 -703.611206 261.426147
```

471.229767 -541.027832 261.426147

471.229767 -541.027832 407.843414

471.229767 -703.611206 407.843414

471.229767 -703.611206 261.426147

%

-23.564886 -541.832031 678.552124

-23.564886 -538.859863 678.552124

-23.564886 -538.859863 483.307373

-23.564886 -541.832031 483.307373

271.142548 -538.859863 483.307373

271.142548 -538.859863 678.552124

271.142548 -541.832031 678.552124

271.142548 -541.832031 483.307373

%

30.685980 -713.964050 708.229614

30.685980 47.738770 708.229614

30.685980 47.738770 -109.019440

30.685980 -713.964050 -109.019440

743.257874 47.738770 -109.019440

743.257874 47.738770 708.229614

743.257874 -713.964050 708.229614

743.257874 -713.964050 -109.019440

## Appendix B

# Fragment of the Air-Modeling code

### B.1 Main function code

---

```
int main(int argc, char** argv){

    AllocConsole();

    // Charging predesigned models
    printf("Do you want to charge a predesign model? <Y/N>...\n");
    char str [8];
    scanf ("%s", &str);
    bool chargemodel;
    if ( (str[0] == 'Y') || (str[0] == 'y'))
        chargemodel = true;
    else
        chargemodel = false;

    // Asking for the material density for ergonomic analysis
    printf("Please enter the density of the product material...\n");
    float materialDens;
    scanf ("%f", &materialDens);
    while (materialDens<=0){
```

```
    printf(" Please enter a valid density...\n");
    scanf ("%f", &materialDens);
}

// Launching the threads
thread t1(trackSkeleton , argc , argv);
thread t2(Modelingkernel ,chargemodel ,materialDens);
thread t3(drawScene , argc , argv);

// Finishing the threads
t1.join();
count_mtx.lock();
count_threads++;
count_mtx.unlock();
t2.join();
count_mtx.lock();
count_threads++;
count_mtx.unlock();
t3.join();

return 0;
}
```

---

---

## B.2 Scene capture thread code

---

```
int trackSkeleton(int argc, char** argv)
{
    nite::UserTracker userTracker;
    nite::Status niteRc1, niteRc2;
    nite::HandTracker handTracker;

    nite::NiTE::initialize();

    niteRc1 = userTracker.create();
    if (niteRc1 != nite::STATUS_OK)
    {
        printf("Couldn't create user tracker\n");
        return 3;
    }
    printf("\nStart moving around to get detected...\n(PSI pose may
        be required for skeleton calibration, depending on the
        configuration)\n");

    niteRc1 = handTracker.create();
    if (niteRc1 != nite::STATUS_OK)
    {
        printf("Couldn't create user tracker\n");
        return 3;
    }

    handTracker.startGestureDetection(nite::GESTURE_CLICK);

    nite::UserTrackerFrameRef userTrackerFrame;
```

```
nite::HandTrackerFrameRef handTrackerFrame;
termSkelThread_mtx.lock();
while (termSkelThread==false){
    termSkelThread_mtx.unlock();
    niteRc2 = userTracker.readFrame(&userTrackerFrame);
    niteRc1 = handTracker.readFrame(&handTrackerFrame);
    if (niteRc1 != nite::STATUS_OK) {
        printf("Get next frame failed \n");
        continue;}
    const nite::Array<nite::GestureData>& gestures =
        handTrackerFrame.getGestures();
    for (int i = 0; i < gestures.getSize(); ++i)
    {
        if (gestures[i].isComplete())
        {
            printf("Clic \n");
            clicGest_mutex.lock();
            clicGest = true;
            clicGest_mutex.unlock();
        }
    }
}

const nite::Array<nite::UserData>& users =
    userTrackerFrame.getUsers();
for (int i = 0; i < users.getSize(); ++i)
{
    const nite::UserData& user = users[i];
    updateUserState(user, userTrackerFrame.getTimestamp());
    if (user.isNew())
    {
        userTracker.startSkeletonTracking(user.getId());
    }
}
```

```
}
else if (user.getSkeleton().getState() ==
        nite::SKELETON_TRACKED)
{
    skeleton_mutex.lock();
    getJointCoordinates(user, nite::JOINT_HEAD,
        &userSkeleton.headPos);
    getJointCoordinates(user, nite::JOINT_NECK,
        &userSkeleton.neckPos);
    getJointCoordinates(user, nite::JOINT_LEFT_SHOULDER,
        &userSkeleton.leftShoulderPos);
    getJointCoordinates(user, nite::JOINT_RIGHT_SHOULDER,
        &userSkeleton.rigthShoulderPos);
    getJointCoordinates(user, nite::JOINT_LEFT_ELBOW,
        &userSkeleton.leftElbowPos);
    getJointCoordinates(user, nite::JOINT_RIGHT_ELBOW,
        &userSkeleton.rigthElbowPos);
    getJointCoordinates(user, nite::JOINT_TORSO,
        &userSkeleton.torsoPos);
    getJointCoordinates(user, nite::JOINT_LEFT_HIP,
        &userSkeleton.leftHipPos);
    getJointCoordinates(user, nite::JOINT_RIGHT_HIP,
        &userSkeleton.rigthHipPos);
    getJointCoordinates(user, nite::JOINT_LEFT_KNEE,
        &userSkeleton.leftKneePos);
    getJointCoordinates(user, nite::JOINT_RIGHT_KNEE,
        &userSkeleton.rigthKneePos);
    getJointCoordinates(user, nite::JOINT_LEFT_FOOT,
        &userSkeleton.leftFootPos);
    getJointCoordinates(user, nite::JOINT_RIGHT_FOOT,
        &userSkeleton.rigthFootPos);
}
```

```
    getJointCoordinates(user, nite::JOINT_LEFT_HAND,
        &userSkeleton.leftHandPos);
    getJointCoordinates(user, nite::JOINT_RIGHT_HAND,
        &userSkeleton.righthandPos);
    skeleton_mutex.unlock();
}
}
termSkelThread_mtx.lock();
}
termSkelThread_mtx.unlock();

nite::NiTE::shutdown();
return 0;
}
```

---

## B.3 Modeling kernel thread code

---

```
void Modelingkernel(bool chargemodel, float materialDens){
    vector3 *v1_tail, *v2_tail;
    asm_tree* board;

    vector3 v1, v2;
    fillVector(&v1,0,0,0);
    fillVector(&v2,0,0,0);

    v1_tail = &v1;
    v2_tail = &v2;

    list_mutex.lock();
    treeHead = initializeLinkedList(v1_tail, v2_tail);
    treeTail = treeHead;

    treeHead->dens = materialDens;
    list_mutex.unlock();

    termModThread_mtx.lock();
    while (termModThread==false){
        termModThread_mtx.unlock();
        if (chargemodel){
            free(treeHead);
            treeHead = NULL;
            chargeModelFromFile("PredesignModel.txt");
            chargemodel = false;
            list_mutex.lock();
            saveModelInFile(treeHead, "Saved_File.txt");
        }
    }
}
```

```
list_mutex.unlock();
chargemodel = false;
}

skeleton_mutex.lock();
rulaAssessment(userSkeleton, treeTail, treeHead->dens);
skeleton_mutex.unlock();

board = selectedBoard();

if (board != NULL){

    updatePartMenuInfo(false, 50, RH_inScreen_x, RH_inScreen_y);

    RH_inScreen_mutex.lock();
    menu_mutex.lock();
    if ((RH_inScreen_y - partMenuInfo.boxH) < 0) // por si el
        menu aparece mas abajo de la ventana reubicarlo para que
        se vea todo
        RH_inScreen_y = partMenuInfo.boxH;
    if ((RH_inScreen_x + partMenuInfo.boxW) > WIDTH) // por si el
        menu aparece mas abajo de la ventana reubicarlo para que
        se vea todo
        RH_inScreen_x = WIDTH - partMenuInfo.boxW;
    if (RH_inScreen_y > HEIGHT) // por si el menu aparece mas
        arriba de la ventana reubicarlo para que se vea todo
        RH_inScreen_y = HEIGHT;
    if (RH_inScreen_x < 0) // por si el menu aparece mas arriba
        de la ventana reubicarlo para que se vea todo
        RH_inScreen_x = 0;
```

```
menu_mutex.unlock();
updatePartMenuInfo(true, 50, RH_inScreen_x, RH_inScreen_y);
RH_inScreen_mutex.unlock();

int opt = menuOptionSelected();

menu_mutex.lock();
partMenuInfo.drawPartMenu = false;
menu_mutex.unlock();

if (opt != 0)
    executeMenuAction(board, opt);
}

if (newBoard()){

    bKeyFlag_mutex.lock();

    while (bKeyFlag != false){
        bKeyFlag_mutex.unlock();

        list_mutex.lock();
        skeleton_mutex.lock();

        fillVector(&treeTail->v1_g, userSkeleton.righthandPos.x,
            userSkeleton.righthandPos.y,
            userSkeleton.righthandPos.z);
        fillVector(&treeTail->v5_g, userSkeleton.lefthandPos.x,
            userSkeleton.lefthandPos.y,
            userSkeleton.lefthandPos.z);
```

```
fillVector(&treeTail->v2_g, userSkeleton.rigthHandPos.x,
          userSkeleton.leftHandPos.y,
          userSkeleton.rigthHandPos.z);
fillVector(&treeTail->v3_g, userSkeleton.rigthHandPos.x,
          userSkeleton.leftHandPos.y,
          userSkeleton.leftHandPos.z);
fillVector(&treeTail->v4_g, userSkeleton.rigthHandPos.x,
          userSkeleton.rigthHandPos.y,
          userSkeleton.leftHandPos.z);
fillVector(&treeTail->v6_g, userSkeleton.leftHandPos.x,
          userSkeleton.leftHandPos.y,
          userSkeleton.rigthHandPos.z);
fillVector(&treeTail->v7_g, userSkeleton.leftHandPos.x,
          userSkeleton.rigthHandPos.y,
          userSkeleton.rigthHandPos.z);
fillVector(&treeTail->v8_g, userSkeleton.leftHandPos.x,
          userSkeleton.rigthHandPos.y,
          userSkeleton.leftHandPos.z);

skeleton_mutex.unlock();
list_mutex.unlock();

skeleton_mutex.lock();
rulaAssessment(userSkeleton, treeTail, treeHead->dens);
skeleton_mutex.unlock();

bKeyFlag_mutex.lock();
}

bKeyFlag = false;
bKeyFlag_mutex.unlock();
```

```
    checkBoxOrientation( treeTail );

    skeleton_mutex.lock();
    if ( (userRulaScore.leftFinalScore > 2) ||
        (userRulaScore.rightFinalScore > 2) ){
        screenshot_mutex.lock();
        screenshotFlag = true;
        screenshot_mutex.unlock();
    }
    skeleton_mutex.unlock();

    list_mutex.lock();
    v1_tail = (vector3*)malloc(sizeof(vector3));
    v2_tail = (vector3*)malloc(sizeof(vector3));
    fillVector(v1_tail,0,0,0);
    fillVector(v2_tail,0,0,0);
    treeTail = addAsmElement(v1_tail,v2_tail,treeTail);
    list_mutex.unlock();

    clicGest_mutex.lock();
    clicGest = false;
    clicGest_mutex.unlock();

}
termModThread_mtx.lock();
}
termModThread_mtx.unlock();

list_mutex.lock();
saveModelInFile(treeHead, "producedModel.txt");
```

```
list_mutex.unlock();  
//ExitThread(0);  
return;  
  
}
```

---

## **B.4 Rendering engine thread code**

---

```
void drawScene(int argc, char** argv){
    glutInit(&argc, argv);
    glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH);
    init();
    arVideoCapStart();
    argMainLoop(NULL, keyEvent, mainLoop);
}
```

---