Universitat Autònoma de Barcelona

STEREOSCOPIC USER INTERFACES
Creating a Pipeline for Stereo Application Development

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Stereoscopic User Interfaces: Creating a Pipeline for Stereo Application Development

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Ph.D. Thesis Dissertation

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- A Pía. Porque siempre quisiste que fuera doctor.

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And yet everything arrives to an end. Thanks.

Abstract

The present work is PhD research done in the field of stereoscopic graphical user interfaces. It evaluates the current state of 3D technology and the state of the art trends in the area and translates them to software applications. The main objective is to study how 3D depth can enhance a GUI application, by having an aesthetic and utilitarian function. Independent of medium, our main focus is to provide efficient tools and techniques that apply to the interface design process to add depth to it. In this vein we work with web, desktop, gestural technologies and perception User Experience (UX) studies with the intention of documenting both user reactions and innovative software implementations.

The present thesis documents our 4-year effort in the field of stereoscopic graphical user interface. We walk through the foundations of the stereo theory and the state of the technology. We then approach several phases of a GUI creating pipeline: from sketching prototypes to measuring the perceived depth effect. We built frameworks and plugins that go hand to hand with the current technology stack and allow other developers and enthusiasts to create both stereoscopic 3D GUIs and VR applications.

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Acronyms

3D	Third Dimension
AOI	Area of interest
API	Application Programming Interface
AR	Augmented Reality
C#	C Sharp
CGI	Computer Generated Images
CSS	Cascade Style Sheet
DOM	Document Object Model
GIF	[File type] Graphical Interchange Format
GUI	Graphical User Interface
HDR	High Dynamic Range
HFR	High Frame Rate
HTML	Hyper Text Markup Language
IDE	Integrated Development Environment
JPEG/JPG	[File type] Joint Photographic Experts Group
JS	JavaScript
KPI	Key Performance Indicator
MPO	[File type] Multi Picture Object
PNG	[File type] Portable Network Graphic
S3D	Stereoscopic 3D
SERP	Search Engine Result Page
SUM	Single Usability Metric
SUMI	Software Usability Measurement Inventory
SUPR-Q	Standardized User Experience Percentile Rank Questionnaire
SUS	System Usability Scale
SVG	Scalable Vector Graphics
UCD	User Centered Design
UHD	Ultra High Definition
VOD	Video On Demand
VR	Virtual Reality
WCF	Windows Communication Foundation
WPF	Windows Presentation Foundation
WWF	Windows Workflow Foundation
X3D	Extensible 3D
XAML	Extensible Application Mark-up Language

Section Zero

The reason behind this work

This initial section lays the foundation of the present work. Motivation, addressed problem, hypothesis, methodology and structure of the current work reside here. This chapter serves as an introduction and a guide to understand the present work.

1 Motivation

I am a visual person. Starting with the way I remember things and make associations, my memory and way of learning have always been visual. With this, as a computer engineer, I have always been very interested in exploring user interfaces and the small details that make them great –or not so great.

With the re-emergence of 3D in movies, I was exposed as a consumer to a new (new for me, at least) visual stimuli that was interesting enough to keep an eye on. I had never thought of the applications of this kind of language to things other than the ones one is exposed as a customer. Nevertheless, with a previous incursion into the field of stereoscopic images -to create subtitles for 3D movies in a past master degree- at the Autonomous University of Barcelona, I started looking into the idea of stereoscopic 3D (S3D) applications.

I learnt that while movies and games were areas that have had a big boost from different angles towards S3D, applications were being left behind. Almost trying to emulate the same mistake the industry was making with the current phase movies are right now, 2D techniques were being applied to this new medium and it was generating issues. These issues could have been avoided if they were tackled from the start for what they are: a new and different kind of problem.

Stereoscopic interfaces do exist. I am not saying the contrary, but their focus is shifted to artificial environments which again do not apply to the specific case of more "traditional" applications.

I add the fact that in this subject there is a mix of interaction, perception and other areas related to humanities. Leaving aside the technical part managing offsets, parallaxes, automation of pipelines and real-time rendering; we can say we are doing *digital stereoscopy applied to user interfaces*.

1.1 The Addressed Problem

The addressed issue resides in the lack of depth in current graphical user interfaces. While this is software related, we must point out that it is correlated to the current state of consumer hardware and use of applications. The average consumer does not own stereo capable devices nor content.

One can argue that there are no services that require stereo 3D depth. The rise of mobile platforms and smart environments, where multimedia takes a front and center approach in form of services and applications, makes the exploration of depth much more relevant. In summary, we address **stereoscopic depth in graphical user interfaces**.

1.2 Hypothesis

For reference, the original hypothesis that we used to start our research was the following:

Stereoscopic 3D will enhance applications and bring a new paradigm to UI development.

It was broad. It was open. Nonetheless we were expecting 3D to take its course. The concept of "enhancing" had to be defined; and the fact that a new paradigm would appear due to 3D, morphed to completely different scenario when VR and AR became a trend. When we started this work the environment regarding stereoscopic 3D was very different. We were thinking that stereoscopic 3D could enhance (desktop-like) applications and could bring a new paradigm to user interface development. These changes would be studied to document semantic information given to objects placed in different parallaxes (z-depth) and their relation with navigation and selection processes in applications. The hierarchical relationship (created with depth differences) between objects would also be studied and its relation with the different uses of 2D images over depth maps and stereoscopic data. This would be done to prove that depth enabled user interfaces should not be bound only to virtual and augmented environments.

While this statement is still valid today, four years after conceiving it, the means for display and interaction have evolved significantly. Stereo has matured, and technology and consumers have had their say on 3Ds current position. We found ourselves more and more exploring different means of visualization other than traditional monitors, testing projection and virtual reality and interacting with gestures.

Therefore, our hypotheses are a specialization of our initial idea.

- ***A pipeline can be created with existing developer technologies to create 3D applications.***
- ***Stereoscopic 3D can aid tasks in applications.***
- ***Stereoscopic 3D can improve desirability in applications.***

These hypotheses derive from our initial idea, while defining what "enhance" means for us and allow us to create a pipeline for stereoscopic development. All concepts and ideas are exposed and clearly defined along the present work.

1.3 Objective

Upon starting the current work, the main objective of this work is the creation and evaluation of stereoscopic graphical user interface content by providing a set of tools and criteria using state-of-the-art software technologies.

The scenarios might range from media subtitling to user interfaces present in desktop applications and surfaces, but a consistent way of planning, creating and evaluating is presented.

Stereoscopic data, images and depth provide additional means of interaction that will be used to study the display of content (layout).

We will study depth cues and their effects in these selection and layout schemes that we find, in order to propose a framework and reference parallax values for working with 3D interfaces.

1.4 Methodology

The main methodology consists in prototyping and user testing. These prototypes and tests respond to the variables that will be studied to determinate the semantic relevance assigned to parallax values.

This work can be described in several stages that behave in an iterative cycle:

1. Initial knowledge body construction.
    a. Study of depth cues and hierarchical relationships and their mapping to parallax values.
    b. Evaluation of current UX patterns.
    c. Training CGI skills to create prototypes.
2. Construction of prototypes.
3. User and usability testing.

Three main experiments will be developed, each one built on experiences and knowledge extracted from the results obtained from its predecessor. These experiments are:

- Eye tracking perception of depth (2D vs. 3D web page).
- 3D memory test
- Measure of UX of 3D in a retailing GUI catalog.

1.5 Structure of the dissertation

The following chapters define the outline and backbone of the thesis.

Section One "*State of the 3D world*" denotes the current state of the art and state of the technology regarding all things 3D that affect the stereoscopic application world and related research being done in the area. This section sets the base from which we are starting, viewed from different angles.

- *The Third Dimension*: explores how we are able to perceive stereo 3D, how it is being applied to different areas and why is it important in those areas.
- *Creating the tools for S3D Development*: presents our first contributions to this state of the 3D world, in the form of tools tailored to create S3D applications, a fundamental part of the stereoscopic 3D pipeline we have envision.

Section Two "*In depth Software*" delves deeper into user interfaces and our approach into introducing 3D. We establish the important parameters related to user experience that we use to compare our applications. We also denote how we will utilise depth in our case studies.

- *UX Concepts for Measurement*: Denotes the UX concepts that present importance for our studies. We focus our efforts in usability and desirability of the software experiences we create. We specify the existing tools and techniques that will aid us in evaluating our applications. System Usability Scale, Product Reaction Cards and Eye tracking are explained here. A contribution on classification of the Product Reaction Cards is then presented.
- *Stereo Applications*: This chapter takes a look at the defined pipeline for stereo 3D development and specifies how we will use depth in our examples. It also defines the types of 3D that we use, and presents our case scenarios along with the experiments that support these implementations of depth.

Section Three "*Making sense of depth in software*" analyses the data from the experiments and presents conclusions. Also, main scientific contributions and the created pipeline are discussed and examined. Finally, a discussion on current and future trends on this same topic is presented, therefore closing the thesis on how our work has contributed in these directions.

Section One

State of the 3D world

In order to work on the area of stereoscopic 3D, we must first define and comprehend what 3D is. We offer an explanation of the theory and physiology behind our perception of depth. Additionally, we also need to know what exists in the consumer world and which are the technology trends that gravitate around stereoscopic 3D. For this, we look into the different kinds of 3D content available in the market, hardware required to visualize stereo content, and software components like file formats, applications, and most importantly for us, the implementation alternatives that we have for 3D.

2 The Third Dimension

There are many ways to represent and think of the third dimension. The acronym '3D' is associated with many different areas that nowadays range from physical '3D' printing to virtual '3D' worlds. As examples, using additive manufacturing ('3D' printing) has found widespread use among biomedical engineering to bioengineer tissue. Research in this area is broad, varying in composition from teeth and bones to vascular and organ scaffolding. In this area, where bioresorption (ability of the body to absorbed the used material) and biocompatibility (whether or not the body will reject the used material) are of great concern, '3D' printing allows for individualized treatment since it is possible to customize a 3D printed scaffold for tissue regeneration (Gross, Erkal, Lockwood, Chen, & Spence, 2014). Likewise, rapid prototyping for surgical planning and prosthetics (Rengier, et al., 2010), along with new material development give a clear path for research opportunities.

THE ACRONYM '3D' IS ASSOCIATED WITH MANY DIFFERENT AREAS THAT NOWADAYS RANGE FROM PHYSICAL '3D' PRINTING TO VIRTUAL '3D' WORLDS.

Similarly, in the virtual '3D' world space, research related to environmental effects (like sound) (Mehra, Rungta, Golas, Lin, & Manocha, 2015), rendering, space estimation (Bruder, Lubas, & Steinicke, 2015), ergonomics (Bach & Scapin, 2003) and social 'virtual' interaction (Wang, Lin, Ng, & Low, 2001), (Robb A. , et al., 2015) and (Chen, Ladeveze, Clavel, Mestre, & Bourdot, 2015), again, show the broad range of research in this type of 3D technology.

These examples are to show the different areas of knowledge that come into play when referring to '3D' technology. But we are interested in the field of software applications. When we bring up '3D' in software applications, we can immediately relate to the concept of Medical Imaging, Video Games and other Big Data Visualizations.

2.1 Understanding Projections

From these mentioned areas, we will use examples from video games to scope the definition of 3D that we are interested in. To set a basic example, let us look at the game play for each different case. Game play, as defined in (Salen & Zimmerman, 2004) is the formalized interaction that occurs when players follow the rules of a game and experience its system though play. We can picture the differences between game play in a game like 1985's Super Mario Bros. for the Nintendo Entertainment System (see Figure 1a) and 2007's Super Mario Galaxy for the Nintendo Wii (see Figure 1b). The former is considered a scroller, since it scrolls the playing field in a continuous area and the player can move in the X-axis (forward and backwards) and jump (Up and down), maintaining always a 2D control scheme. The latter allows "free movement" in any direction. Even though the concept of movement in all three axes exists, and that the graphics have a 3D *look and feel*, notice there is no real perception of depth, it remains a 2D frame.

Figure 1: (a): Scroller Super Mario Bros. **(b): 2.5D Super Mario Galaxy.**

The graphics on Super Mario Galaxy appear 3D due to the *projection* type that is employed. A projection is the process or technique of reproducing a spatial object upon a plane or curved surface or a line by projecting its points (Merriam-Webster, 2015). There are several types of projections, but to illustrate our explanation we will focus on two of them of the basic plane.

Depending on the application, Perspective or Parallel Projections are used. As an example, axonometry, a type of parallel projection, provides an important graphic technique for artists, architects and engineers that allows the depiction of 3D space on a 2D picture plane (Krikke, 2000). This is used heavily in certain video games and in pixel art representations. Other terms for this projections are 2.5D or the ¾ perspective (for isometric projections). For comparison reasons, Figure 2a and 2b show the same cube from a top/front view from a perspective and parallel projections.

The images in Figure 2 give a sense of 3D, but by definition are not 3D. According to the Merriam-Webster dictionary, "3-D" is a "three-dimensional form" (Merriam-Webster, 2015). These three dimensions are width, height and depth. This might immediately imply the notion of volume. And while that assumption is correct, we will define here the main difference in the notion of the type of 3D we are working with. As the title of the present work states, we are interested in stereoscopic 3D. This kind of 3D is the one that is composed by a pair of similar images that together create an illusion of depth.

To further comprehend the difference between the concepts, let's think about the notion of '3D cinema'. The term 3D in cinema refers to two concepts: computer-generated images (CGI or CG), which relies on 3D virtual models of objects and projections; and stereoscopic (S3D) movies, in which images seem to reach in and out of the screen.

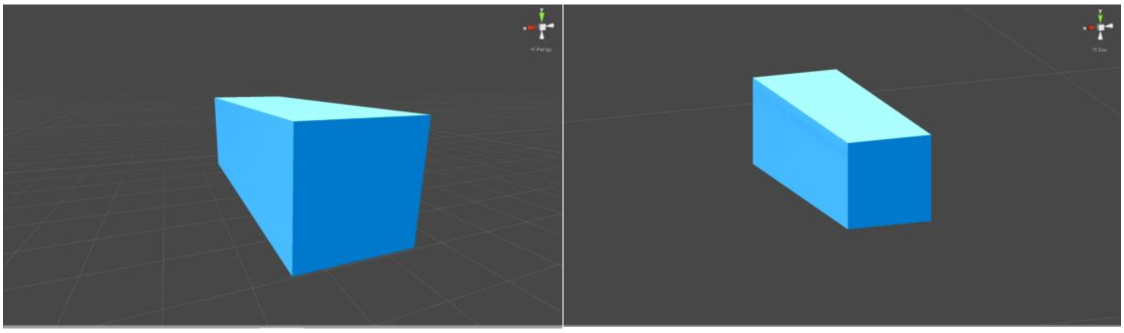

Figure 2: (a): Perspective projection. (b): Parallel Projection.

2.2 Understanding Stereoscopy

Stereoscopy is defined in the dictionary in the following way (Merriam-Webster, 2015): 1) a science that deals with stereoscopic effects and methods. 2) the seeing of objects in three dimensions. **Following the first part of the definition, we now note the definition of the term 'stereoscopic': —used to describe an image that appears to have depth and solidness and that is created by using a special device (called a stereoscope) to look at two slightly different photographs of something at the same time**.

This was first formally described by Charles Wheatstone, a physicist that suspected that a pair of slightly similar images would help the brain to perceive depth. He was the one that first described stereopsis the following way (Wheatstone, 1838):

> *"WHEN an object is viewed at so great a distance that the optic axes of both eyes are sensibly parallel when directed towards it, the perspective projections of it, seen by each eye separately, are similar, and the appearance to the two eyes is precisely the same as when the object is seen by one eye only. There is, in such case, no difference between the visual appearance of an object in relief and its perspective projection on a plane*

surface; and hence pictorial representations of distant objects, when those circumstances which would prevent or disturb the illusion are carefully excluded, may be rendered such perfect resemblances of the objects they are intended to represent as to be mistaken for them; the Diorama is an instance of this. But this similarity no longer exists when the object is placed so near the eyes that to view it the optic axes must converge; under these conditions a different perspective projection of it is seen by each eye, and these perspectives are more dissimilar as the convergence of the optic axes becomes greater. This fact may be easily verified by placing any figure of three dimensions, an outline cube for instance, at a moderate distance before the eyes, and while the head is kept perfectly steady, viewing it with each eye successively while the other is closed. Plate XI. fig. 13. represents the two perspective projections of a cube; b is that seen by the right eye, and a that presented to the left eye; the figure being supposed to be placed about seven inches immediately before the spectator."

When we read the past quote, we notice that perspective and projections are an important factor that create the stereoscopic image. 'Figure 13', cited by Wheatstone, is shown in Figure 3.

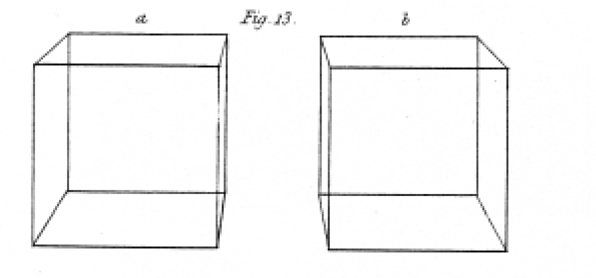

Figure 3: 'fig 13' as drawn by Wheatstone on his article about stereoscopy.

Wheatstone refers to when the optic axes must converge. It is then when we perceive the differences in the images caused by the point of view and the perspective itself. He created a device that allowed him to place these slightly different drawings that were based in perspectives of things he observed. He called the device a "stereoscope", and what it did was that it allowed to fuse two flat drawings into a composition that appeared to have depth. Shortly after came the invention of photography. Stereoscopic pictures, shown in conjunction with the stereoscope, became a popular development, and thus, stereo stimuli and stereo 'hardware' became available. This is the type of 3D that we are pursuing: Stereoscopic 3D. To better understand this, we will explore how stereoscopy works.

Due to the fact that our eyes are horizontally separated, each one captures a slightly different retinal image: the one that corresponds to its point of view. The mind works with diverse depth cues to reconstruct depth from what we see. Of these cues, stereopsis is the binocular cue that refers to the perception of depth that is constructed based on these two points of view. The brain fuses the left and right image and using retinal disparity is able to extract the depth information. Retinal disparity comes from the distance between corresponding points in these retinal images. This implies that when focusing on an object, those points (of fixation) will fall on corresponding parts of the retina, which denotes zero retinal disparity. So defining the horopter (Merriam-Webster, 2015) here, any point that does not fall within this space of corresponding retinal points will incur in retinal disparity. If an object is in front of the defined horopter, then the points will be crossed in disparity and objects located behind it will have uncrossed disparity. A small region around the horopter, called Panum's fusional area (where the two images perceived by both eyes fuse (Puell, 2006)), is the region where binocular single vision takes place, which means that both images are fused into a single image in depth (Marc T.M. Lambooij, 2007). Stereopsis is the most powerful depth cue that we possess, nonetheless, other cues exist that work in aggregation with stereopsis to understand the world around us. For reference, and because these concepts play an important part of the work we have developed, I include the next section focusing on these other monoscopic and oculomotor cues.

STEREOPSIS IS THE MOST POWERFUL DEPTH CUE THAT WE POSSESS, NONETHELESS, OTHER CUES EXIST THAT WORK IN AGGREGATION WITH STEREOPSIS TO

2.3 Depth Cues

Images formed in our retina are two dimensional. All the information regarding distance is inferred from the image and by the visual system. This information is gathered and reconstructed in the brain, and permits localization of objects the same way the auditory system can map the source of a sound. Depth can be inferred from three types of cues (Olshausen, 2015): oculomotor, visual binocular and visual monocular:

- Oculomotor hints include accommodation which is when the lens of the eye changes size in order to focus an object in the retina; objects far away from us require a low concave shape versus a major concavity required for closer ones. Vergence is the other oculomotor prompt that refers to the movement of the eye when focusing distant objects (that tend to go in parallel lines) and close objects (that tend to bend to position inwards). These cues are related to the physiological processes of the eye.
- Binocular cues consist in the horizontal disparity between slightly different images perceived by the left and right eye. Stereopsis, as explained before, is the process by which depth information is extracted from the scene composed in Panum's area. This concept must not be confused with depth perception because we can perceive depth without binocular vision; nonetheless, it is the most advanced state of visual perception.
- Monocular cues on the other hand can be obtained using kinetic vision, such as occlusion, size, perspective, parallax and definition of a terrain (Pipes, 2008). Occlusion indicates depth with superposition of objects. Size and perspective alone can also indicate the distance of an object (if the object is familiar and has an established concept in our brain the process is faster). Finally, parallax is one of the most important monoscopic cues because it relates with movement and different points of view. Parallax is the relative position of an object's image in a set of pictures (Mendiburu, 2009).

All of them play an important role in the way we recognise depth, but none of them, not even stereopsis is required to distinguish depth. Oliver Sacks has documented the case of Sue Barry, who could navigate and live a normal life, while being stereo-blind and not knowing it (Sacks, 2010).

With the review on the physiological process of how we perceive depth, we now focus on the type of content we can perceive.

2.4 S3D Content and Related Research

We now know that the 3D content that we are interested in is the one that is stereoscopic. We are going to take a look at the state of the stereoscopic content to date, and try to extract valuable lessons we can from these different applications of stereoscopy aided by research done in these areas.

2.4.1 Movies

Film is one of the areas that has enjoyed “3D” for a prolonged –combined- period of time. It has seen it come and go every 30 years for several times now. When we think about it, the current wave of 3D we are experiencing in theaters nowadays was started in 2004 with the film “Polar Express” (Zemeckis, 2004). Several films have been praised for their use of stereo 3D. For example, Avatar (Cameron, Avatar, 2009) for its technical push of stereo. James Cameron used composition of faraway and nearby stereo planes, achieving visuals that were unseen at the time. Other movies followed and used 3D as part of the storytelling process, like Gravity (Cuarón, 2013), giving a sense of imprisonment during the capsule scenes, or Tron: Legacy (Kosinski, 2010), using S3D only when in the virtual world.

To understand the current state of 3D movies, we present a table shown at CES 2015 in Las Vegas by the International 3D & Advanced Imaging Society. In this table, we can see the all-time box office revenue measured in billion United States dollars.

1	Avatar (Cameron, Avatar, 2009)	$ 2.782
2	Titanic (Cameron, Titanic, 1997)	$ 2.185
3	Marvel’s The Avengers (Whedon, 2012)	$ 1.511
4	Harry Potter and the Deadly Hallows: Part 2 (Yates, 2011)	$ 1.341
5	Frozen (Buck & Lee, 2013)	$ 1.274
6	Iron Man 3 (Black, 2013)	$ 1.215
7	Transformers: Dark of the Moon (Bay, 2011)	$ 1.123
8	The Lord of the Rings: The Return of the King (Jackson, 2003)	$ 1.119
9	Skyfall (Mendes, 2012)	$ 1.108
10	The Dark Knight Rises (Nolan, 2012)	$ 1.084

Table 1: All-Time box office revenue (January 2015) (International 3D & Advanced Imaging Society, 2015).

The first 7 places, highlighted in yellow, all have 3D versions. The year 2013 was a record box office year for Hollywood, and that was because of 3D ticket sales (Craddock, 2014). The momentum is clear. According to Chabin, every year more 3D movies win more academy awards and more BAFTAs. Financially and creatively 3D has come on its own (Chabin, 2014).

Novelty factor is wearing off, yet 3D has been used as a new emotional tool available for filmmakers. While exploring this emotional effect in movies is out of the scope of this work, I highly recommend to look at the work being done by Dr. Leon Gurevitch (Gurevitch, 2013) (Gurevitch, 2012), Dr. Lisa Purse (presentation description found in (Ravensbourne, 2015)) and Dr. Nick Jones

(Jones, 2015). Directors have artistic freedom to use depth in many different ways. For example, in Life of Pi (Lee, Life of Pi, 2012) Lee uses 3D "to make the water become a character, to involve the audience in a way that they experience what Pi experiences " (Lee, 2013). In a different way, Wim Wenders expresses that 3D "gets you close to the character and you see more into the soul of the person" (Knight, 2015). An interesting article on the future of 3D film technology can be found in (Bredow, 2006). Similarly, many other articles analyse the story and current state of 3D, like (Eisenstein, 1949), (American Cinematographer, 1953), (Lipton, 1982) and (Hayes, 1989),

I understand that many of the references cited before are very new and respond to market behavior, but it is very important to know the frame in which this work was developed, in order to understand the decisions that have affected it. All these, coupled with the explosion of 3D cinema screens in China, increasing TV size, and the availability of new technologies like auto stereoscopic displays, HFR, HDR and UHD (International 3D & Advanced Imaging Society, 2015), are shaping a new beginning –again- for stereoscopic 3D.

Even though the use of 3D and emotional response from users is completely an artistic endeavour from the director, research has been made in more objective areas regarding stereoscopic moving images. Experiments that measure the eye movements of participants who watched clips of a movie in both stereoscopic and non-stereoscopic versions indicate that 2D movie viewers tend to look more at the actors. S3D movie viewers' eye movement patterns were more widely distributed to other targets. Also, tendency to look at actors was diminished, and objects in front of the actors captured interest of the viewers as well. Results suggest that in a S3D movie there are more eye movements which are directed to a wider array of objects than in a 2D movie (Häkkinen & Kawai, 2010).

Also, the effects of watching stereoscopic stimuli have been studied (Ukai & Howarth, 2007) and the impact of vergence-accomodation conflict on visual performance (Hoffman, Girshick, Akeley, & Banks, 2008).

2.4.2 Videogames

The videogame industry can be seen from two perspectives: one where stereo has not made a huge difference in the current lineup of videogame platforms, and another where stereo promises a change due to Virtual Reality (VR). The first point of view has stereoscopy with a very small splash on the current state of technology. NVIDIA's 3D Vision website lists 46 games as of February 2015.

Sony PlayStation 3 counts 77 games with stereoscopic capability. And Microsoft's Xbox 360 lists 30 games that support the feature. Not even Nintendo, with its stereoscopic wielding portable gaming console, the 3DS, can say that it takes full advantage of the technology. Many games don't use it. Table 2 shows the number of available 3D games per platform.

NVIDIA 3D Vision	46
Sony PlayStation 3	77
Microsoft Xbox 360	30

Table 2: Number of available 3D games for different platforms.

Whether it is due to hardware not being capable of displaying the stimuli, the "discomfort" of seeing 3D stimuli and wearing the glasses or the lack of quality coming from the half resolution loss due to the side by side format of the stimuli, the videogame sector has been very shy to give real stereoscopic content. As an example, Zachara and Zagal studied the case of Nintendo's Virtual Boy and its challenges for success in stereo gaming. Among the reasons for failure, they state both technological shortcomings like a "comparatively weak display" and lack of focused design, as well as the need for S3D game mechanics (Zachara & Zagal, 2009). To date, neither the Xbox One nor the PlayStation 4 offer any stereoscopic title.

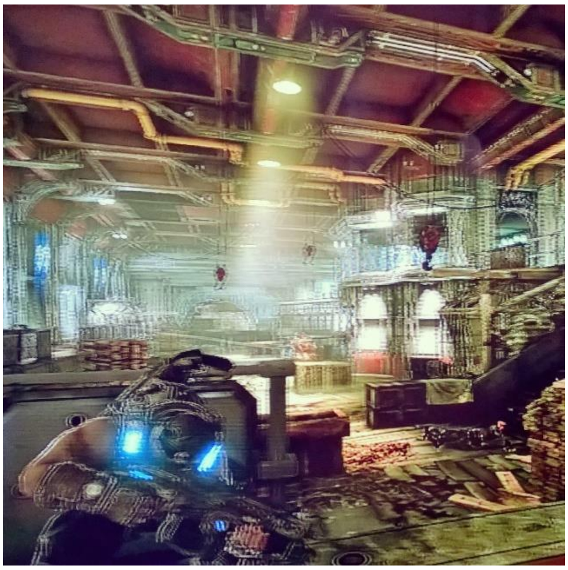

Figure 4: Picture of Gears of War 3 on a Stereoscopic TV.

There is little research in the stereo video game area, nonetheless, researchers has explored the potential of stereoscopic 3D vision in offering distinct gameplay in a S3D game (Schild, LaViola, & Masuch, 2014). There is evidence that stereoscopic 3D vision can change how users play a video game, regarding the decisions and strategy they make during gameplay. S3D vision increases experience of spatial presence. It can also create additional value, as seen by Rajae-Joordens while measuring the response of users playing Quake III both in 2D and 3D. Again, a reported higher positive emotions and stronger feelings of presence were found, all this, with a relatively low amount of depth added to the stimuli (Rajae-Joordens, 2008). Finally, an article that summarizes the fundamentals of 3D game design (Schild & Masuch, 2011), while noticing that to date there are no absolute measures for ensuring visual comfort in interactive games, since physiological (inter ocular distance for example) and technical factors (driver and display) always require evaluation of visual comfort with the target group on target displays. The authors propose an interactive use of S3D camera effects, stereoscopic game challenges/design ideas, S3D game GUI and information visualization and extreme S3D. Hypo/hyperstereoscopy, innovative camera angles (like Nintendo's Super Street Fighter IV 3D Edition (Nintendo, 2011) and its over the shoulder view), and abusive effects (Wilson & Sicart, 2010) of the stereo are all ways of adapting stereo to the content.

2.4.3 Virtual Reality

A VR UI IS IN ESSENCE, A STEREOSCOPIC USER INTERFACE

Virtual Reality is not a new field. By the decade of 1970, primitive computer-generated graphics operating in real time served as visualizations for flight simulators. By early 1980s better hardware and software, coupled with motion-controlled platforms enabled pilots to navigate through highly detailed virtual worlds. This was the decade when videogames boomed, and several devices like the dataglove appeared, allowing direct interaction with virtual environments (The Board of Trustees of the University of Illinois, 1995). But even though the basic elements of VR have existed since 1980, high-performance computers and powerful image rendering capabilities are required to make VR work. In 1999, VR "barely worked" (Brooks, 1999), and it is until this year, 2016, that several consumer version VR headsets are set to make an appearance. Devices like the Oculus Rift (Oculus, 2015), PlayStationVR from Sony (PlayStation, 2015), Gear VR (seen in Figure 5) from Samsung (Samsung, 2015) and reVIVE from HTC and Valve (HTC, 2015) are betting in directly putting the user in a virtual environment, where stereoscopic content can be displayed, thanks to the different views that each eye is exposed to. Taking into account the differences in interactions when creating a VR experience, a VR UI is in essence, a stereoscopic user interface. Among the differences are that a VR experience generally tries to create a virtual environment. Therefore, research in this field is focused in simulation, rehabilitation therapy (Wiederhold & Wiederhold, 2005), interaction techniques in these worlds (Youngkyoon, et al., 2015), (Tremblay, et al., 2016) and creating a more social "virtual" experience (Robb A. , et al., 2015).

Figure 5: Samsung Gear VR

2.4.4 Software

Based on the research we performed we selected tools that allow us to work with 3D and S3D. We are going to go over the file formats that support a 3D environment, and then explore the available software for modelling, coding and developing 3D content *and* stereoscopic 3D content. We will then review research efforts made In the area.

2.4.4.1 3D file formats

The next file formats are stereo file formats.

- **Multi Picture Object File (.MPO):** This is a file that contains a stereoscopic image captures by stereo digital cameras. They contain two .JPG images side by side.
- **Stereo JPEG File (.JPS):** Stereoscopic JPEG is used to create 3D effects from 2D images. It contains two side-by-side images in a single JPG file. They can also be captured by stereo cameras.
- The next file formats are not used only for stereo.
- **JPEG Image (.JPG):** Standardized compressed image format used for storing digital photos. Also used commonly in websites since the compression algorithm significantly reduces the file size of images since it uses lossy compression.

- **Portable Network Graphics (.PNG):** File type that contains a bitmap of indexed colors and uses lossless compression, without the copyright limitations GIF files have.
- **Graphical Interchange Format (.GIF):** Image file that can contain up to 256 indexed colors. They are common in the web for small images. It is a lossless format, since its clarity is not compromised with GIF compression.

When using JPG, PNG or GIF files to create the stimuli, files are in a side by side, top bottom (over/under) or anaglyph format. Table 9.1 found in (Mendiburu, 2009) exposes the 3D format compatibility with legacy 2D systems for video. We can see that both in image and video, the resolution of the stimuli is cut to half.

A full and comprehensive list of 3D related formats can be found in (FileInfo.com, 2015).

2.4.4.2 3D Modelling

When designing and working with stereoscopic 3D, a 3D modelling software is always a good tool for defining models and assets in our projects. They also conform the basic toolset of certain engineering, architectural and product design areas. Programs like Rhinoceros (Rhinoceros, 2015), Blender (blender, 2015) and Autodesk's Maya and 3DS Max (Autodesk, 2015) allow 3D modelling, animation and rendering. Of these programs, we recognize the value of the open source Blender and the education program offered by Autodesk.

2.4.4.3 Research Examples

Though software applications have been shyer to introduce depth, research has shown that 3D is good for aesthetic and functional reasons: when the S3D UI is designed from the beginning for a holistic user experience, that is, one that grants depth a utilitarian function. Mobile application examples, like the phonebook contact app designed by Häkkilä et al. (Häkkilä, Posti, Koskenranta, & Ventä-Olkkonen, 2013), or the in-car infotainment systems presented by Broy et al. (Broy, André, & Schmidt, 2012) show that 3D representations have a potential to improve the user experience and attractiveness of a user interface without a negative impact on their workload. Highlighting and selecting items (Huhtala, Karukka, Salmimaa, & Häkkilä, 2011), changing a user's gaze pattern in familiar UIs like search engine result pages (Gonzalez-Zuniga, Chistyakov, & Carrabina, 2014) and other experiments that measure the desirability factor of the stereo effect in certain UIs prove the benefits of adding depth to graphical interfaces.

2.4.5 Stereoscopic Related Hardware

The association between the moniker "*3D*" and the term "*hardware*" has expanded quite rapidly in the past years. From glasses-free 3D game consoles to 3D printing, hardware was evolved to meet very specific needs. Though hardware is not the main focus of this work, it is essential to it. We are going to mention the displaying methods that we have used for our research. When we say hardware we refer to displays, projectors and the associated glasses that work with them. Knowing that the key to stereoscopy is getting a different image to each eye, the way to accomplish this is by either polarizing or shutting off lenses. The three main types of stereoscopic displaying technologies that we used are anaglyph, passive and active. We will now review them. For an assessment of 3DTV technologies, we can refer to (Onural, et al., 2006).

2.4.5.1 Anaglyphic encoding

Red and cyan are the two colors that represent 3D. This is due to the anaglyphic encoding that has been around for years. It is a way to use a basic color encoding scheme to separate the content that is defined for each eye. While it has limitations of color reproduction and low separation power, they are the cheapest and only true really available method for the broadest distribution of content without any special equipment. The very representative anaglyph glasses are shown in Figure 6. With this technique, two points of view of an image are gathered. The left eye view is then converted to red (blue and green channels set to zero) and the right eye view is converted to cyan (red channel set to zero). These two images are then combined. When they are fully overlapped the result is the itself. This anaglyph therefore contains the left eye view and the right eye view, but as different colours. When the image is viewed through red green spectacles then the two images can be separated. This is because the left eye only receives the red image and the right eye only the green (Kightley, 2015).

Figure 6: Red-Cyan anaglyph glasses.

2.4.5.2 Passive Polarized Technology

Display methods that work with passive technology use glasses that have been polarized differently in each lens. They work in conjunction with a micropolarized LCD panel. This technology allowed for 3D flat panels. This type of technology uses low cost glasses to filter the light that each eye receives. Among the advantages that this technology possesses we can note the fact that it is generally inexpensive, works without the need for power, does not require to sync with the source of projection/processing, does not suffer flickering and that it is lightweight. Notice that these characteristics are inherent to the glasses themselves. On the other hand the images built for passive technology need to share simultaneously both images for each eye, which results in a loss of resolution for the same bandwidth or storage capacity. Figure 7 shows a picture in a side by side format. Notice that the image is composed in a way that encodes both side in one frame.

Figure 7: Side by side 3D picture taken from joshuatree3d.files.wordpress.com.

When referring to 3D TVs, the main mean in which consumers will experience 3D, the TV, has a filter that polarizes each line of pixels. This filter makes the odd lines on the screen only visible to the left eye, and the even lines visible to the right eye only.

2.4.5.3 Active Shutter Technology

Active technology presents only the image intended for the left eye while blocking the right eye's view. It then alternates the blocked side. It does this rapidly enough so the user does not notice the interruptions. Both images are fused and the depth illusion is achieved. Commercial systems like the NVIDIA 3D Vision (Figure 8) utilize liquid crystal shutter glasses that have the capability to make itself opaque when voltage is applied, thus, blocking the corresponding frame. This technology works by syncing the displayed image with the glasses. In theory, the information meant for the left eye is blocked from the right eye by an opaque shutter. Televisions require to refresh fast enough so each eye gets at least 60 frames per second. Active technology can be found on plasma, LCD, LED LCD and all front and rear projectors.

Figure 8: NVIDIA's active shutter glasses.

2.5 Why 3D?

It is usually said that stereoscopic media is somehow more exciting than ordinary media. If this is true, then we should be able to define what this positive connotation towards stereo is, and how it enhances the content. According to Mendiburu, in cinematography, what matters is feeling, experience and identification with characters. We read in the past section comments by Wim Wenders and Ang Lee about the benefits of 3D in movies. But the question now is, if 3D is a technical trick, can we put feelings into numbers? The entertainment industry calls it “box office”, and Table 1 is a clear example of this concept. Nonetheless, staying in an artistic and emotional dimension, its closeness to our natural way of seeing brings a sense of realism to the audience, and by reducing the effort involved in the suspension of disbelief, we significantly increase the immersion (Vish, Tan, & Molenaar, 2010) experience. Mendiburu continues to explain the benefits of stereoscopic depth in a film, by mentioning close-ups, since the actor’s head fills the room and increases the emotional charge of the shot. Landscapes are trickier, because you have to map the real depth to the available depth budget of a scene (Mendiburu, 2009). This use of 3D for storytelling is further explored by Block and McNally (Block & McNally, 2013) and Pennington (Pennington &

WE SHOULD BE ABLE TO DEFINE WHAT THIS POSITIVE CONNOTATION TOWARDS STEREO IS, AND HOW IT ENHANCES THE CONTENT

Giardina, 2012).

According to Tam et al., S3D image sequences are preferred to their non-stereo versions, and in a scene with depth, greater depth is perceived in a S3D composition. Sharpness stays lower or the same (Tam, Stelmach, & Corriveau, 1998). Now if we want to quantify this, we could look into measuring increased fun and excitement, increased feeling of reality and solidity (Lambooij, 2005), feeling of presence (IJsselsteijn, Ridder, Freeman, Avons, & Bouwhuis, 2001) and (Freeman, Lessiter, & W. Ijsselsteijn, 2001) or just aesthetic experiences (Kant, 1961) as factors that describe this enhancement (Häkkinen, et al., 2008).

2.6 Summary of the chapter

This chapter talks about the basics of stereoscopic imaging starting by explaining how projections are ways of mapping 3D points to a 2D space to how our brain uses retinal disparity to reconstruct depth from our visual system. The relation of these topics with the different types of visual cues (oculomotor, monocular and binocular), and how they contribute to 3D.

The most powerful visual cue being parallax, and how this technique is exploited by the film industry, videogames and software to create stereoscopic assets. These assets require special software and hardware to be visualized, shared and created. It is in this software space where the main contribution of the current work resides.

Finally, an introduction into the question of why 3D matters, from a creative point of view, to get some inspiration while we start to look into a fundamental part of the 3D app pipeline, and how to create the tools for S3D development.

3 Creating the tools for S3D Development

We have mentioned types of media that take advantage of stereoscopic 3D and reviewed the hardware we need to display it. Now we will explore the alternatives that we have if we want to implement S3D stimuli.

In order to create stereoscopic user interfaces, we tried several technologies to see how capable they were for developing a stereo compatible interactive UI. By studying these platforms, we would like not only to know which one is currently the best option but also, what are the main characteristics that a future platform devoted to that purpose should have. Following we present our findings per tested platform.

3.1 CANVAS

The fifth revision of the Hypertext Mark-up Language (W3C HTML WG, 2014) has now the ‘recommendation’ status by the World Wide Web Consortium. This is a platform that we look upon to create stereo stimuli. This revision is relevant because it introduces syntactic features related to multimedia objects (W3C, 2014). It achieves this while avoiding third party plug-ins, applications and players such as Adobe Flash and Microsoft Silverlight, which rose security, reliability, battery, performance and cross-platform concerns in the past. Some of the newly defined tags are <video>, <audio> and <canvas>. As their names imply, they are designed to facilitate the inclusion and management of multimedia content on the web. It is implemented in a way that the mark-up maintains its readability and consistency among devices.

With this milestone achieved from the platform, we developed a drawing toolkit to create stereoscopic side-by-side 3D stimuli. The toolkit is based in the HTML5 canvas element and drawing is achieved using intermediate stereo scripting methods that correspond to the ‘2d’ context of the canvas. We have named the toolkit ‘canv.3d’ (formerly codenamed SXS3DCNV -Side by Side 3D Canvas) and explain it in the following paragraphs.

As stated earlier, it is based in canvas which is a revolutionary feature present in HTML5 that enables powerful graphics for rich Internet Applications. It represents a resolution-dependent bitmap canvas, which can be used for rendering graphs, game graphics, or other visual images on the fly (W3C, 2014).

Its use consists in a JavaScript API for drawing in an HTML canvas tag. The drawing methods in the API are accessed through a drawing context. It is a low-level procedural model that updates a bitmap, yet keeps no track of the scene graph. The fact that there is no track of the scene-graph makes anything that we draw on the canvas part of the final composition. This is the main difference between HTML5 canvas and Scalable Vector Graphics (SVG).

HTML5 Canvas has two different drawing contexts: (i) the "2d" drawing context and (ii) the "3D" context. The former is invoked by passing the '2d' parameter when acquiring the drawing context and allows scripting to draw geometrical shapes and paths, as well as text, images and video. All this in a flat 2D surface. The latter is invoked by passing the 'webgl' parameter. This different context enables WebGL in the canvas and allows the scripting of meshes to create a 3D model in a virtual 3D scene, with X, Y and Z coordinates. Both contexts are very different in their scopes, in the scripting they accept, and yet none of them are stereoscopic by default.

3.1.1 Benefits

We chose HTML5's canvas element to create the stereoscopic compositions because we immediately gain compatibility with a broad scope of HTML5 devices. Any modern browser capable of rendering HTML5 will most likely support this element. In their latest builds, Edge, Internet Explorer, Firefox, Opera, Chrome and Safari support the canvas tag. Canvas allows for an easy conversion of a webpage into a dynamic web application that uses rich multimedia elements.

Canvas is a native HTML5 element, present in the Document Object Model (DOM) of the page. Because of this, canvas can interact with other elements present in the DOM, which means that even running in its own drawing context, it can communicate with forms and other elements in the page. This rules out the need for third party plug-ins.

Also, the library being written in JavaScript allows for interaction with other scripts and diverse input devices that feature a JavaScript API. Among these devices we can mention the Kinect and the LEAP Motion.

Additionally, since all the compositions created on the canvas are expressed in code, its file size is small. As an example, Figure 9 shows a 1920x1080 full HD composition coded with our toolkit running on Microsoft Edge browser. If we were to use this stereo image on a website, the file sizes would be the ones seen in Table 3. We are comparing file sizes from files saved in optimized for web settings in Adobe Photoshop. Comparing the file size from the JPG, PNG and GIF pre-sets of the same drawing we saw differences of up to 6.47 times more. While file sizes vary depending on the software, compression used and image itself, the library is capable of producing space efficient vector-like compositions that can be animated and interacted with.

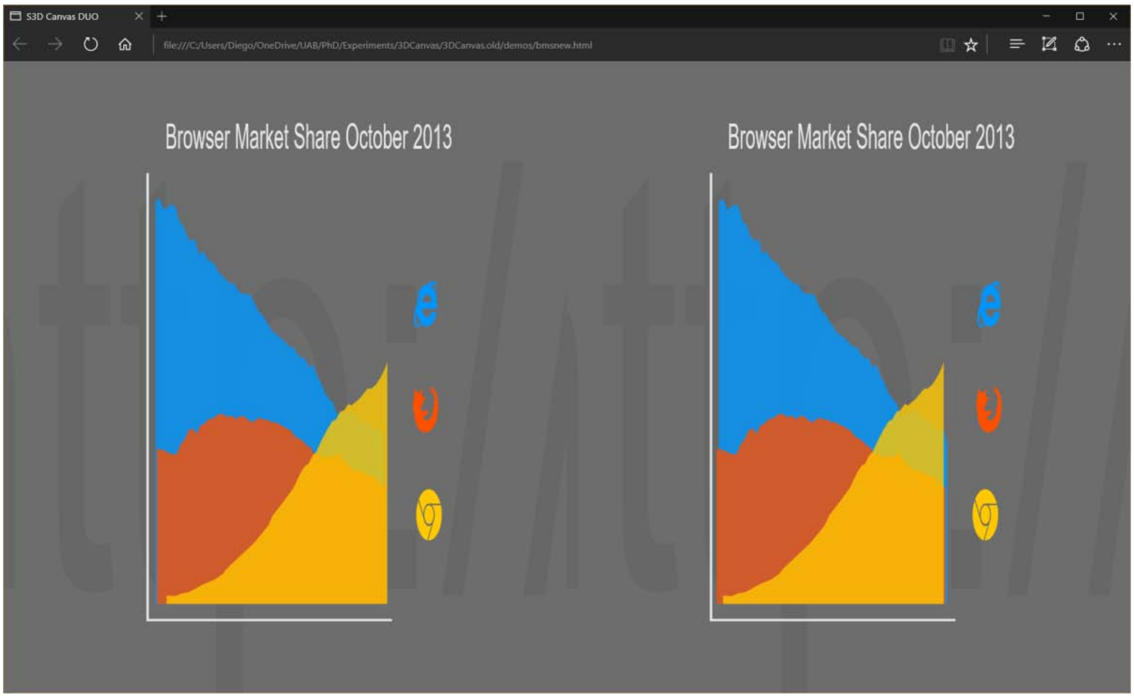

Figure 9: Stereo Composition on a browser with canv.3d.

Web Preset	Size	Ratio
JPEG High	90.59K	647%
JPEG Medium	49.07K	350%
JPEG Low	35.71K	255%
GIF 128 Dithered	63.27	452%
GIF 32 No Dither	51.63K	368%
PNG-8	38.03K	271%
PNG-24	56.17K	401%
CANV.3D	14K	100%

Table 3: File size ratios for composition of image in Figure 8.

3.1.2 Challenges

We must state that we are considering building stereo stimuli only for the '2d'context leaving aside WebGL. Our main focus is to play with depth in different elements of the drawing and not playing with the full 3D model and perspective that a WebGL scene offers. The main reason behind this is that we created this toolkit for the creation of stimuli to perform research on graphical user interfaces, charting and vector-like animations.

The challenges that we faced when tackling stereoscopic visualizations are related to the duplication of the view. In the ‘2d’ context, canvas creates paths for its drawings by clearly beginning a path, moving to different positions in the drawing space and closing the path, as shown in Figure 10.

```
a. context.beginPath();
   (...)
b. context.moveTo(300,100);
   (...)
c. context.closePath();
```

Figure 10: Path operations in a canvas context.

This makes it impossible to duplicate anything in the canvas since a path can be only started and closed once, and we needed to duplicate the drawing. We could not draw one visualization after the other either, because it would not be dynamic nor allow for animations. Both drawings need to be drawn at the same time, or what is closest to this concept.

For us this meant to fork the initial idea and create two different versions of the stereoscopic renderer we wanted in the canvas.

Another challenge is the resolution-dependence of the canvas itself. This is troublesome since planed visualizations should not be rescaled or moved because the bitmap would not keep its ratio and can blur and pixelate. To avoid this a dynamic layout must be coded in JavaScript to handle size change. The entire scene must be repainted also. Yet another challenge was keeping the performance as high as possible, especially for animation purposes. This is relevant because it is not only the fact that we are performing an animation, but because we are performing the animation twice (once per view) and with not all the frame needing to be redrawn.

3.1.3 Implementation

The code name for our drawing toolkit is SXS3DCNV (Side by Side 3D Canvas). As it states, we are working on generating side by side stimuli. This responds to the fact that it is a widespread format on stereo displays and televisions, which are our main means for showing prototype GUIs to test subjects. The way the 3D depth is obtained is by shifting different elements horizontally, and this offset is specified in each one of the methods that draw elements on the canvas. The implementation works optimally in full screen displays, independent of resolution, as long as this resolution does not change.

The drawing toolkit is a JavaScript file that can easily be imported to any webpage. Then another file that contains the user's drawing is set as source. SXS3DCNV defines a set of functions that draw on a canvas (or set of canvases) stereoscopically. Every '2d' context method has a stereo counterpart. These 'stereo' methods, identified by the prefix "s3d", take care of scaling, positioning and drawing what the user codes. This keeps the drawing and the toolkit apart and easily updateable.

The initial prototype consisted of a canvas that allowed the creation of dual sides by clipping the canvas and drawing in each resulting side. This strategy presents some problems as the path operations could not be replicated on each half (since one context can handle one open path at a time, and we require two) and that the clipping implementation was accompanied with painful performance on certain browsers like Firefox 33.1.

To bypass the problems that multiple path drawing represented, we forked the code into SXS3DCNV Solo and SXS3DCNV Duo. The difference between both was that Solo draws on one canvas while Duo draws on two. This is the same as managing one or two different contexts in the same drawing method. It also means that we are able to draw at the "same time" on each one of the canvases.

The current version of the library only features code that draws on a set of several pairs of canvases at once. It is based in work presented in the 3DUI 2015 symposium (González-Zúñiga & Carrabina, Hacking HTML5 Canvas to Create a Stereo 3D Renderer, 2015) and has since then been renamed and released as canv.3d.

3.1.4 Performance

The resulting is a JavaScript library that produces stereoscopic compositions. These compositions are achieved by creating side by side stimuli that shift elements horizontally to generate the depth effect. The toolkit exposes a drawing API that corresponds to methods of the '2d' context of the canvas. Primary uses for this element are games and animations, since it allows the drawing and manipulation of the element area as a blank linen.

We tested performance of animating in this stereo canvas by drawing hundreds up to thousands of rectangles generated each frame. We recorded the number of frames per second that we could achieve in desktop and mobile platforms (both browsers and devices) and the results are shown in Figure 11 and Figure 12. In both figures, the Y axis represents frames per second, while the X axis is number of rectangles drawn in the test.

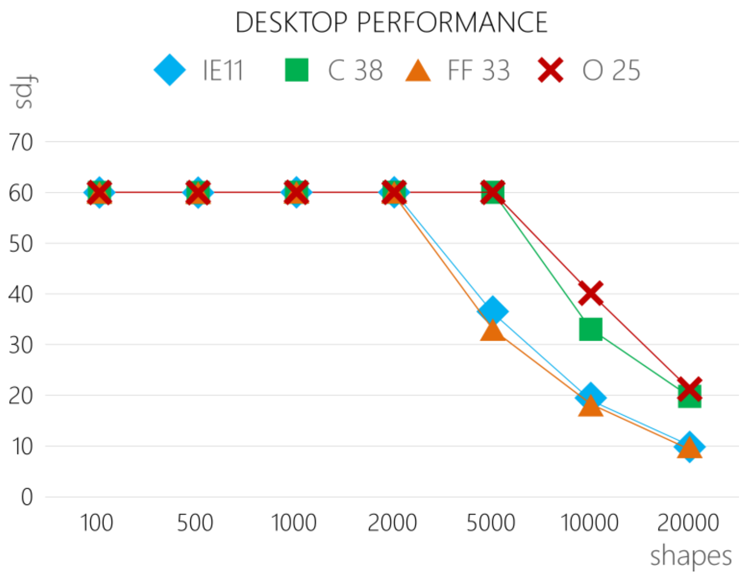

Figure 11: Stereo JS drawing script performance on desktop browsers.

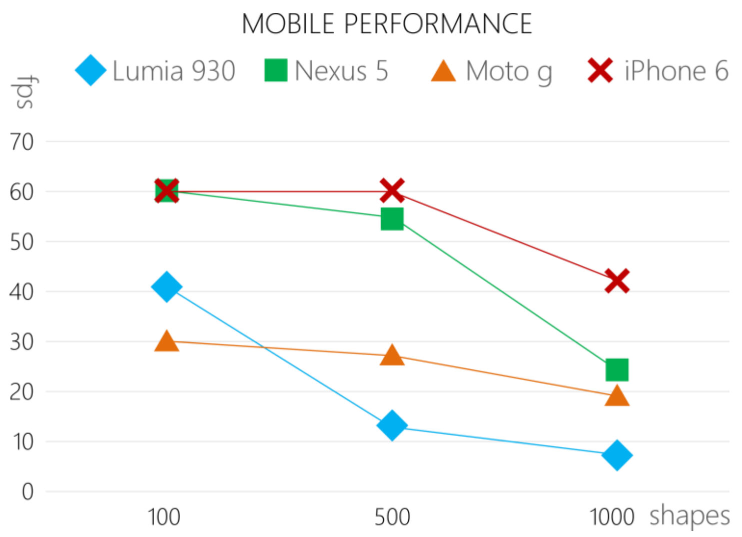

Figure 12: Stereo JS drawing script performance on mobile devices.

Figure 11 shows the performance of our toolkit in all major browsers (Microsoft Internet Explorer 11, Google Chrome 38, Mozilla Firefox 33, and Opera 25) running on an Intel Core i7-4770 (8 CPUs at 3.5Ghz). The PC has 16GB of RAM and is running Windows 8.1 Pro 64bits. The stimulus used to benchmark this toolkit consisted of an animation where constantly a variable number of squares are drawn. We measure frames per second and time of execution of each frame. The test consisted on drawing rectangles repeatedly on the canvas. The position information (X, Y and Z axis) where generated on every frame, simulating changes that each different element might have during an animation. The test consisted of drawing from 100 to 20000 rectangles. We use a JavaScript library called fpsmeter to track how many frames per second and the execution time of each individual frame.

We also tested these benchmarks on mobile devices (Figure 12). These devices are: (i) Nokia Lumia 930 (Quad-Core at 2.2GHz) running Internet Explorer 11 Mobile; (ii) LG Nexus 5 (Quad-Core at 2.3GHz) running Chrome 38; (ii) Motorola Moto G (Quad-Core at 1.2GHz) running Chrome 38 and (iv) iPhone 6 (Dual-Core at 1.4GHz) running Safari.

Performance on these devices cannot be used for comparison since browsers, operating systems and screen resolutions vary on each of them. Nonetheless, having flagship status for mobile experiences, we want to test their performance for the platform.

On the desktop, each major browser maintains a steady 60 frames per second count with up to 500 objects. Frame rate starts declining variably, with Chrome and Opera maintaining a similar performance, which is expected since they share the Blink rendering engine. Overall, Internet Explorer shows a very similar performance to Firefox. Nonetheless, Firefox shows the worst execution times per frame of all the tested browsers.

On the mobile landscape the iPhone's 6 canvas rendering outperformed the other platforms, clearing 42 fps on the 1000 object test. This is the only mobile browser that we tested up to 2000 elements, to find out it could animate at 33 fps.

Canv.3d is available open source in GitHub (diekus, 2015). It is continued to be enhanced and worked upon. Some examples shown in case studies were built with this library. Additionally, a library for stereoscopic charting (Serrano Leiva, 2015) and an automatic warping of items (Acuña, 2015) were developed by third parties and based in this library as well.

3.2 HTML5

The evolution of JavaScript for mobile and availability of coding frameworks for UI and productivity make it possible to manipulate the Document Object Model (DOM) of a web page and mimic a stereoscopic setting. In the past we have been able implement stereoscopic 3D in web pages. Chistyakov, González and Carrabina show a tool that provides HTML developers the possibility to create static and dynamic content that interacts with depth. The algorithm used consists of four parts. First, the content is cloned. Second, the cloned CSS styles are applied to the newly created DOM elements. Third, the interactions are mirrored, including pseudoclasses and mouse position. Finally, different elements in a web page are shifted left or right based on a predefined array of pixel separation (Chistyakov, Gonzalez-Zuniga, & Carrabina, 2013).

For this approach we utilize jQuery to duplicate and modify the DOM and we show the power of client scripting for stereoscopic transformation of existing content. This tool is available from (Chistyakov, 3dsjq, 2015).

3.2.1 Benefits

The main advantage of this type of DOM manipulation is that it is a very straightforward way of creating content for stereo displays. It shares many of the advantages that the '2d' context of the canvas has like cross device rendering. It also has many of the same disadvantages that the same '2d' context suffers. This technique duplicates every element on the page, having to render twice as many DOM objects and dealing with complex interactions. The 3D works well if no script is running that dynamically changes elements on the page (mainly due to ids and classes that uniquely identify elements on the script). In our examples the 2014 3D Creative Summit website was partially cloned, having issues recreating of the interactive banner on top. Also, in our tests creating basic games, canvas proved superior to HTML5 because it is hardware accelerated and is actually just one big canvas instead of several different objects. Having said this, we see the HTML5 toolkit plus the canvas drawing toolkit as a very powerful and easy way to create stereo content. Cloning the DOM elements still represents one of the easiest ways to port existing web content to 3D.

3.2.2 Challenges

Among the limitations we encountered with this implementation is that for HTML5, different browser implementations render content differently. This might produce slightly different results/behaviors on the converted content. Cloning the DOM also duplicates the number of DOM elements the browser handles, having to use twice the amount of resources. It is also difficult to manage dynamic scripts that alter the DOM and CSS styles themselves in runtime.

3.3 Three.JS

THREE is an abstraction layer that stands over WebGL. Its purpose, as stated by its website is to "make WebGL -3D in the browser- easy to use". This because "While a simple cube in raw WebGL would turn out of hundreds of lines of Javascript and shader code, a Three.js equivalent is only a fraction of that".

3.3.1 Benefits

The benefits of THREE are that it allows a simple way to create 3D objects and spaces and render them in different outputs, like WebGL, ASCII and Canvas. This gives THREE a lot of flexibility to adapt to different devices. THREE can use different renderers but ideally using the 'webgl' context of the HTML5 canvas is desired. THREE/WebGL provide a 3D (2.5D) engine that supports rendering of meshes in space. It can also create the stereoscopic scene by adding another camera and projecting to a second viewport. This is better than the canvas/HTML implementations, where every element must be cloned. A final advantage of using THREE is that most modern browsers support WebGL, making the content created with THREE easy to view on desktop and mobile devices.

3.3.2 Challenges

The challenges of utilizing THREE is that it requires to build infrastructure to manage events. If we want to create a user interface that manages events, we must attach the events and handle them appropriately. Also, ray-casting and item selection are more complex when dealing with space.

3.3.3 Implementation

The way we have created a stereoscopic view is by setting two cameras and commanding the renderer to paint a distorted (horizontally scaled) version of each camera in different halves of the screen. This creates the stimuli in a very similar way that the Unity Engine (Unity Technologies, 2016) would accomplish it, and avoids the performance limitations that manually duplicating a view can have, as is the case with the '2d' context of the canvas or HTML5/jQuery solutions.

Three.JS has also recently introduced a collection of effects that include a THREE.StereoEffect and a THREE.OculusRiftEffect. These render side by side and in the case of the OculusRiftEffect include the barrel effect. A THREE scene is powerful and flexible enough to allow the creation of both flat and analog type of applications.

3.4 Windows Presentation Foundation

In 2007 Microsoft presented to the world Windows Vista. This operating system brought some changes to the .NET developer environment introducing WPF, WCF and WWF (Presentation, Communication and Workflow foundations respectively). These technologies would supersede previous implementations of graphical user interface, services and workflow in the .NET Framework. WPF was the new way to build a GUI, and it used a combination of declarative mark-up called XAML (Extensible Application Mark-up Language) and C#. It allowed a more powerful manipulation of multimedia objects, animations, and completely skinnable controls. It also introduced dependency properties, and other features that would live around the concept of (data) bindings, in order to make the collaboration between designers and developers easier.

3.4.1 Benefits

The coding paradigm of WPF incorporates 3D models into a 3D canvas. It comes with advanced support for the events system, and provided one of the most flexible GUI frameworks that has ever existed.

3.4.2 Challenges

Knowing that WPF has a 3D engine built in to create volumes and allows for 3D transformations, we tried to create a stereoscopic container to support depth in a side by side manner. On one hand, Windows Presentation Foundation does allow ways of mirroring (and scaling) elements to create the side by side format. With a simple VisualBrush we were able to clone any visual element and children. Problems arise when we want to shift different independent elements. Also, while the visual properties of the UIElements are replicated automatically on the brush, interactions do not follow, since the brush provides only a graphical skin. Implementing the attached property, as we have done, allows us to duplicate the elements and create several layers of depth (as long as a StereoPanel is not descendant of another StereoPanel). The problem in this implementation lies on the binding between the original element and the clone. Also, the mapping of interactions and events is not straight-forward since there are many inner properties and structures that are tied within the .NET framework.

```
<Viewport3D.Camera>
   <PerspectiveCamera Position="-40,40,40" LookDirection="40,-40,-40 "
                      UpDirection="0,0,1" />
</Viewport3D.Camera>
```

Figure 13: WPF's Viewport3D camera.

On the other hand, WPF supports a 3D Viewport that can host 3D Geometry models. Even with this capabilities, we are not able to utilize WPF for stereo compositions since it only allows one camera. Figure 13 shows the XAML that corresponds to the PerspectiveCamera.

3.4.3 Implementation

In order to achieve the stereoscopic effect in WPF, we created a `StereoPanel` class of type `UserControl` and implemented a `Shift` dependency property. This shift would represent the horizontal offset by which we would translate each element that would go into this panel.

```
public static readonly DependencyProperty ShiftProperty =
DependencyProperty.RegisterAttached("Shift",
typeof(double), typeof(StereoPanel), new
FrameworkPropertyMetadata(0.0,
FrameworkPropertyMetadataOptions.AffectsParentMeasure));
```

We coded a method that would serialize and deserialize a `UIElement` in order to clone it. The most accurate way that we found to keep the majority of properties that an object like a `UIElement` might have was by using a `XAMLWriter` and `XAMLReader`. Subsequent, we created an `addChild` method that would be the way of populating and ensuring that the relevant translation would be applied. Each `StereoPanel` would come with an inner structure composed of two grids that would occupy exactly half the container parent's horizontal size. The `addChild` method would then receive a `UIElement`, clone it, apply a translate transform to each UIElement, and insert the original and the clone into its corresponding inner grids.

While basic at first, this implementation proves useful only for aesthetic components and a reduced quantity of layers. It lacks the bindings that might be present in the original object, and there is no relation between the original and the cloned element. This implies that actions, properties and other behaviours most be mirrored on the other side manually. Also, a `StereoPanel` cannot have another `StereoPanel` inside since it would just start duplicating `UIElement`s.

3.4.4 Result

By cloning and translating `UIElement`s in the `addChild` method, we are able to create a stereoscopic UI. Figure 14 shows a log in screen made in WPF that features the `Label`s, `Textbox`, `PasswordBox` and background in different depth layouts. The complexity in creating more depth layers and making the code work with the .NET framework's built-in features makes WPF a hard choice to recommend for the task.

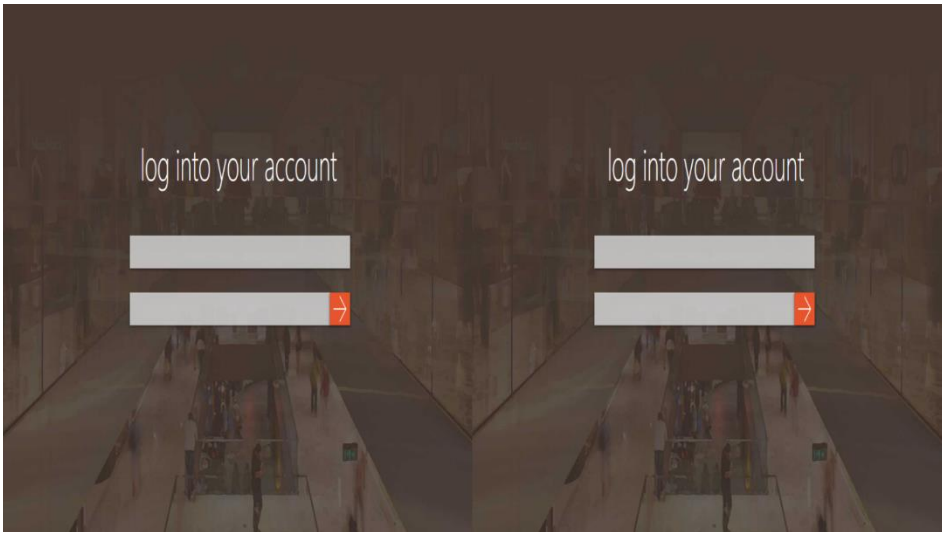

Figure 14: Stereo WPF 3D example. Log in screen.

3.5 Unity

And then came Unity. Videogame development became more accessible when the Unity 3D Engine was made accessible for free for developers. In its latest current version (5.0.1f1), this engine supports 21 platforms ranging from mobile devices to game consoles. Unity is a software engine that features a rendering engine, physics engine, sound, scripting animation, artificial intelligence, networking, memory management, streaming, threading, localization support and a scene graph.

3.5.1 Benefits

Unity can be used to create stereoscopic stimuli. Plug-ins like the FOV2GO are available in the Asset Store and allow the creation of this type of content. Also, by projecting views from two different cameras (with a horizontal offset) onto side by side viewports, we are able to create the depth illusion ourselves.

Unity also has built-in support for platforms that require stereoscopic visualization, like the GearVR from Oculus and Samsung. Furthermore, its versatility lies in the fact that it can compile an application for diverse platforms, and integrates with development tools that make coding stereoscopic assets fit right into an existing workflow, either in C# or JavaScript.

3.5.2 Implementation

The prototype that we developed to create stereoscopic 3D GUIs consists of a C# script that is attached to a camera and some rendering modifications to create the dual side by side of top bottom view.

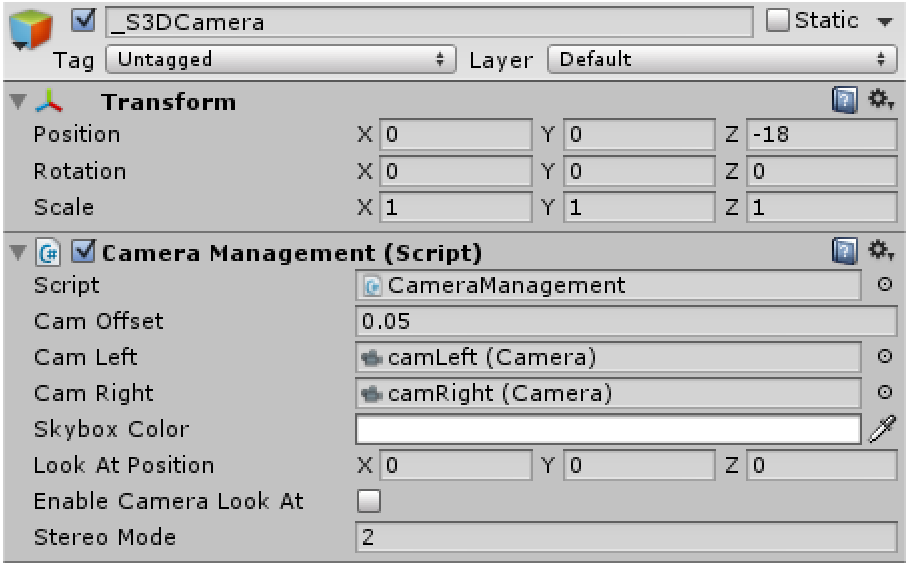

Figure 15: S3DCamera game object properties.

3.5.3 Performance

Unity has been one of the most powerful engines that we have had at our disposal to create stereo stimuli. It's free of charge, C# or JS environment, cross platform support and built-in 3D engine make it a flexible and convenient tool to address the addition of space in a user interface. Figure 15 shows how our script looks in the Unity IDE.

With Unity, we had easy porting and configuration of an application to run on multiple devices, by being able to adjust the graphics settings according to the graphics power of the targeted device. Appendix C. Unity CameraManagement Script shows the basic class that enables the stereoscopic capabilities in Unity.

An added benefit of implementing 3D with a tool like Unity is that the interactions occur from the camera's point of view (or combination of camera and input device like mouse) and relative to the current viewport. This means we do not have to implement nor calculate positions or new elements to interact with.

3.6 Summary of the chapter

This chapter presents the first relevant part of our contribution. To define a pipeline for stereoscopic app development, it is mandatory to have create tools to develop these applications. Therefore, we analyse technologies that are available for developers and evaluate their utility to code stereoscopic apps, for web and native environments. We examine HTML5 Canvas, HTML5, THREE.JS, Windows Presentation Foundation, and Unity.

For HTML5 Canvas, we developed a library that allows the creation of stereoscopic compositions over a web canvas. This tool is made public and open source. HTML5 follows a similar outcome. We explain how a 3D renderer can be set with THREE.JS as well. WPF does not provide the necessary flexibility to create stereoscopic assets so is therefore not recommended. Finally, we present a stereoscopic camera management script for Unity, the video game engine. This script takes two cameras from a scene and creates a stereo rig that can act in a side by side or top-bottom format. Once we have researched and created tools for stereo development, we need to see how we can measure human factors for the out coming applications.

Section Two

In depth Software

In the present section we take the concepts, tools and technologies elaborated in previous chapters and examine how they affect software. We look into the Human Factors for Measurement, focusing in User Experience (UX) constructs that are standard in software development. With these concepts covered in chapter 4 we move into the case studies documented in chapter 5, both in how technology created the stimuli and how the aforementioned human factors behave with the stereoscopic 3D applied to the user interfaces. Chapter 4 presents the existing UX concepts that will be observed in Chapter 5.

4 Human Factors for Measurement

The standard called 'Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems', or ISO 9241-210, "provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems" (ISO, 2015). This revision of former ISO 13407 (Human-centred design processes for interactive systems) changes from recommendations to requirements regarding many aspects of a system in order to be compliant with the standard.

This area, usually called "user experience" (UX, or ergonomics, or HCI, or human-centred design, its denomination changes over time) has evolved in a way that a system "easy to use" is not enough anymore. There is now a focus on more issues to be addressed, if they are important to the user, including aesthetic issues in a system. The six principles that comprise this standard can be listed as follows (ISO, 2015):

- The design is based upon an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centred evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

Debate exists over the terms Usability and UX (Baekdal, 2006), (Spool, 2007), (Nilsson, 2010) and (Stewart, 2015). But there is consensus that User Experience encompasses other aspects as usability and desirability. Figure 16 shows this idea. In general, usability is hard to measure since its concept is intrinsic to the object or system that is been measured.

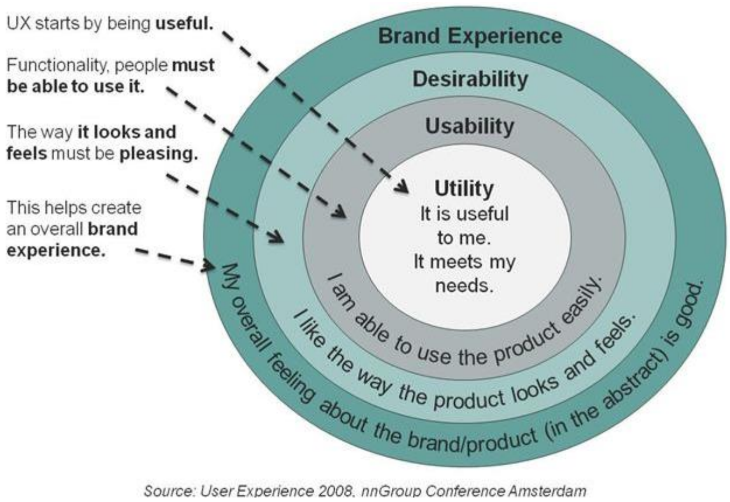

Figure 16: How to define UX

It was mentioned in section 2.5 that we should be able to define what this positive connotation towards stereo is and how it enhances the content. We will attribute these enhancements to constructs related to User Experience (UX) like **usability** and **desirability**. We will also analyse other key performance indicators (KPI) that are related to the task in hand (like **efficiency**, **effectiveness**, **eye tracking**, gaze-time, time-to-completion or depth-perception). As a final part of this chapter, **we will also present a scientific proposal based on a clustering exercise that we performed in order to group terms related to desirability, providing in our opinion a better way to describe an application**.

4.1 Usability

Formally, part 11 of the Ergonomics of human system interaction standard, titled "Usability: Definitions and concepts" (ISO/DIS 9241-11 , 2016) defines the term "usability" in section 2.1.1 as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Other experts in the area, like Nielsen, define usability as being about learnability, efficiency, memorability, errors and satisfaction (Nielsen J. , 1993).These are indicators related with the task as a whole and coherent with the definition given in the standard. We say coherent because errors, learnability, memorability are linked to time to task completion and completion/failure rate, which are linked to efficiency and effectiveness. Measuring usability is complex, since its concept is intrinsic to the object or system that is being measured. In order to achieve this, several methods like the Software Usability Measurement Inventory (SUMI) questionnaire (Kirakowski, 1993), Standardized User Experience Percentile Rank Questionnaire (SUPR-Q) (Sauro J. , The Essential Elements Of A Successful Website, 2011), Single Usability Metric (SUM) (Sauro & Kindlund, 2005), or System Usability Scale (SUS) (Brooke, 1996) can be used.

"USABILITY, AS A CONSTRUCT, CAN BE EMBODIED AS A COMBINATION OF EFFECTIVENESS, EFFICIENCY AND SATISFACTION IN A SPECIFIED CONTEXT OF USE."

4.1.1 How to Measure Usability

We selected SUS to measure usability. Nonetheless, strengths and shortcomings of the alternatives follow. The Software Usability Measurement Inventory (SUMI) is a rigorously tested and proven method of measuring software quality from the end user's point of view. Among its advantages are that it is available in different languages, carefully translated and validated. Since the main target group are students in Spain this was beneficial.

The Standardized User Experience Percentile Rank Questionnaire is mainly for websites and includes in its score factors like Trust & Credibility, Appearance and Loyalty and has a high correlation with more generic metrics like the System Usability Scale ($r = .87$, $p < .001$).

The System Usability Scale defined by John Brooke (Brooke, 1996) provides a simple, ten-item scale giving a global view of subjective assessment of usability. It doesn't require many users to provide reliable results, and it currently stands as the standard way of measuring usability.

We chose SUS since it fulfils the need for a tool that could quickly and easily collect a user's subjective rating of a product's usability (Bangor, Kortum, & Miller, 2008) and because SUS has shown to provide superior assessments of website usability compared to other questionnaires (like QUIS, CSUQ) (Tullis & Stetson, 2004) and "produces similar results to other, more extensive attitude scales that are intended to provide deeper insights into a user's attitude to the usability of a system" (Sauro, 2011). As examples, this correlation is .79 with SUMI and r=.948 with WAMMI scores. Also, a Spanish version of the SUS is available in (Calvo-Fernández, Ortega, & Valls).

Moreover, the validity of SUS with today's systems and technologies cannot be denied. Even if these technologies were nonexistent 25 years ago and radically different from the initial ones it was meant to quickly evaluate, the individual statements in SUS are not particularly meaningful in themselves and are generally applicable regardless of technology. The System Usability Scale was built in a way that the sum of the 10 ratings lead to a general measure of perceived usability (Brooke, 2013). We can choose SUS and be confident it is a valid and reliable measuring tool, with results comparable among them even if the systems are completely different, all this by asking a small number of users.

4.2 Desirability

Desirability. 1 plural: desirable conditions. 2: the quality, fact or degree of being desirable (Merriam-Webster, 2015)*. Desirable. Having good or pleasing qualities: worth having or getting* (Merriam-Webster, 2015).

Desirability is a construct generally associated with the user experience of a system. The reason why we focus in this concept is because if you combine SUS with a more qualitative testing mechanism, we are able to get the most out of what is going on with the UX. Adding desirability provides a layer of qualitative impact of the system.

Desirability is a characteristic that we look for when we develop experiences, yet its subjective nature makes it difficult to quantify. This goes beyond the "is the product usable", therefore, methods like rating scales, list of descriptors and open-ended questions are the most prevalent among the ways to recollect information about this. The methods mentioned before, all share that we ask the user for information, and that is the reason why they are referred to as "Self-Reported Metrics" (Tullis & Albert, 2008). The problem with these self-reported metrics is its inherent subjectivity, differences in interpretations of concepts and openness in the analysis of results.

"THE REASON WHY WE FOCUS IN DESIRABILITY IS BECAUSE IF YOU COMBINE SUS WITH A MORE QUALITATIVE TESTING MECHANISM, WE ARE ABLE TO GET THE MOST OUT OF WHAT IS GOING ON WITH THE UX"

4.2.1 How to Measure Desirability

To measure desirability and the emotional response of a design or a product, we use Microsoft Product Reaction Cards (Benedek & Miner, 2002). These are a set of 118 cards presented by Benedek and Miner that contain adjectives to describe a product. The authors state among its advantages the fact that the method does not rely on questionnaire or rating scales, and that users do not have to generate words themselves. The terms were selected from prior research, marketing materials, and team brainstorming. The set has at least 40% negative terms, in order to avoid the biased positive feedback generally given in a usability lab. The selection of terms is designed to cover a wide variety of dimensions (Benedek & Miner, 2002).

The way the method works is by displaying to the user the terms in different cue cards and asking him to pick the terms that represent how he or she felt using the product. These terms are recorded and then, some additional information on the reason for the card selection can be made. Authors report that participants reveal a great deal of information including "specifics about their interaction with the product as well as their reaction to the product concept and design".

4.2.2 Why Product Reaction Cards

The PRC method has been validated by diverse examples and extended use. It consists of a usability exercise that uses cards to elicit a user's perception of a product (desirability). We found research that measured desirability in stereoscopic applications, which served as a base for our own measurements. This specific case, about designing and evaluating a mobile phonebook with a stereoscopic 3D user interface, was important because depth was used in a utilitarian way (Häkkilä, Posti, Koskenranta, & Ventä-Olkkonen, 2013). Another example that shows the use of the technique was the redesign of the MSN 9 website, where they combined the method with focus groups to assess preference among four designs (Williams, et al., 2004). The Product Reaction Cards are available in Spanish, with an analysis of the quality of translation between different methods (Hinkle & Chaparro, 2013). The quality ratings were not significantly different for translator and user-validated translation, and we use the provided list of Spanish PRCs in this article.

Finally, cards prompt users to tell a rich and revealing story of their experience. Triangulating these findings with post-test questionnaire data and direct observation strengthens the understanding of the desirability factor (Barnum & Palmer, 2010).

4.3 Effectiveness/Efficiency

We incorporate multiples points of measurement to evaluate user experience since doing so often yields the best results (Zapata, 2011). These are indicators related with the task as a whole; we base these indicators in concepts provided in Part 11 (Guidance on usability) of the Ergonomic requirements for office work with visual display terminals standard. (ISO/DIS 9241-11 , 2016). Among them, task completion (effectiveness), time to completion (efficiency), number of successes/failures, and number of errors committed while performing the task.

- **Time to Complete Task:** Time to complete task refers to the total time it takes to finish a designated task. Nearly half of formative usability tests and 75% of summative tests collect this metric (Sauro J. , 2010). This indicator can be great to diagnose usability problems, since long times are often caused by problems interacting with the interface. The time to complete the task can be reported in three core ways: (i) average task completion time, (ii) mean time to failure and (iii) average time on task. The reason why we look into time is because we know that in movies editing must be done at a slower pace than in 3D (Mendiburu, 2009). Movies are passive stimuli and their 3D versions taking more time to process due to its visual complexity. *We suspect that interacting with an* *application where depth has a utilitarian function can also result in different time management by users.*

- **Task Completion Success/Failure:** This performance indicator logs if the task was accomplished or not. It can also be combined with time to complete task in order to log average failure or success time.
- **Number of Errors:** Number of errors logs the amount of mistakes a user makes while executing a task. Similar to past indicators, number of errors is self-explanatory, but in a game scenario it can refer to number of opportunities or misses to achieve an objective. In this scenario it can refer to health or 'lives'.

4.4 Eye Tracking Measurements

When an eye tracker is used, we have access to gaze dwell time, hit rate and gaze sequence. The relevance of all these indicators is dependent on the case study we are evaluating. Eye tracking is the process of measuring where a user is looking. We will define dwell time, hit ratio and gaze sequence according to the SMI manual (SMI, 2016):

- *Dwell Time:* Dwell time average ms = sum (all fixations and saccades within an AOI for all selected subjects)/number of selected subjects.
- *Hit Ratio:* How many subjects out of the selected subjects looked at least one time into the AOI.
- *Gaze Sequence:* Order of gaze hits into the AOIs based on entry time.

We want to do eye-tracking because when approaching usability, an important factor regarding a user interface is how you look at it. This can reveal cognitive intent, interest and saliency. So while it is known that in news websites *text attracts attention before graphics*, that the common behaviour is to ruthlessly ignore details (Nielsen J. , 2000), and that in web Search Engine Result Pages (SERPs) and other webpages eye movements resemble an F-Shaped pattern, the question that remained was **if stereoscopic depth could change our gaze patterns**. Several studies have shown how this affects shots of a movie (Häkkinen, Kawai, Takatalo, Mitsuya, & Nyman, 2010), but our interest was more into familiar web applications.

4.5 Further Classification of PRC

Section 4.2 introduced the construct of desirability. We said that the way we measure this, based on similar research done in (Häkkilä, Posti, Koskenranta, & Ventä-Olkkonen, 2013) was through Product Reaction Cards. We wanted to have a way of classifying the terms selected by the users in order to identify the connotation of those terms, but with 118 terms the interpretations and analysis of these cards post experiment gets cumbersome. We looked into grouping the

118 terms of the Product Reaction Cards into categories that shared similar connotations in order to more easily describe an application. This marks our first contribution to the software development process chain in general we are looking into.

We resort to a simple technique in user experience design: Card Sorting. This is a method used to help design or evaluate the Information Architecture (IA) of a system. IA refers to the art and science of organizing and labeling web sites, intranets, online communities and software to support usability and findability. In a more general form, according to the Information Architecture Institute, IA is the practice of deciding how to arrange the parts of something to be understandable (IAI, 2016).

Knowing how users group information is optimal for designing menus, navigation, structure and labelling categories of a website. We find this type of clustering also useful to categorize the Product Reaction Cards since the underlying idea is grouping a set of objects in a way that objects in the same group are more similar to each other than objects in another group. All this from the perspective of an expert group of users. This will help understand how users envision the organization of the presented concepts. It will allow us to explore how they group concepts and understand their mental model. We chose this technique because it is effective, it is quick, it is cheap, and it allowed us to use data and methods we already had from the PRCs and it involves the (expert) users in our processes. We get out from this process both qualitative and quantitative results, since we are not only recording the created groupings and generated terminology, but also the frequency items are grouped together.

A group of subject experts were commanded to group the 118 terms of the Product Reaction Cards into different categories. The exercise comes in response to the number of terms to be organized. It is big and no other existing taxonomy can group the span of concepts encompassed. Also, the similarity of certain terms make them hard to divide clearly into different categories, while adding to the same concept the user wants to express.

We conducted a search of computer engineers, user interface (UI) and user experience (UX) designers, mobile developers and computer scientists that had previously work in software development. We recruited 15 users, the minimum recommended by Nielsen (Nielsen J. , 2004) to keep an acceptable correlation between the results and the ultimate results. All participants are professionals related to the area of computer and software engineering, with at least 6 years of expertise in systems/application design and development. Among the responses we had professionals from the United Kingdom, Costa Rica, Mexico, Spain and the United States.

The type of card sorting tested was an open variant, where the participants created their own naming for each group. This was done in order to avoid leading them into the idea that we had of groups and to leverage the expertise that each of them had during their time as UI/UX practitioners or software developer.

To do the card sorting, we used the Card Sorting Editor application by Eduard Porta Miret (Porta-Miret, 2005) from the University of Lleida. This software (shown in Figure 17) provides the functionality to create the initial set of cards and to run the card sorting exercise.

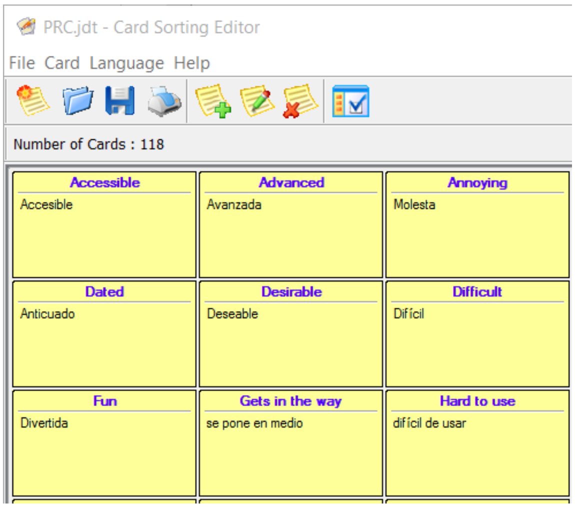

Figure 17: Card sorting editor with Reaction cards added.

Each card is added with its main title being the original English term and the description featuring the Spanish translation of the term. Several words were adapted from the Spanish translations found in to adapt them to a Spanish perspective. This was due to the fact that some of the participants were from Spain.

After the whole collection of cards is introduced into the software, they are saved in a .jdt file ("Juego de Tarjetas", set of cards). This is the file that is distributed along the application. Each participant is instructed to open the file with the application and start a new card sorting exercise. The cards are presented in a random way and they are grouped by dragging and dropping them onto other cards. The process consists of three steps: (i) the user starts grouping the cards by dragging and dropping cards; (ii) once the groups are defined, the user names them (as seen in Figure 18) to finally (iii) get an output file that corresponds to the current sorting session. The generated file is an .ecs (XML format). Another application is used to analyse the card sorting results. Card Sorting Clustering, by Daniel Pardell Mateu (Pardell-Mateu & Granollers, 2006) from the University of Lleida, takes files in an ecs format as input and performs cluster analysis in order to combine the groups created by the users.

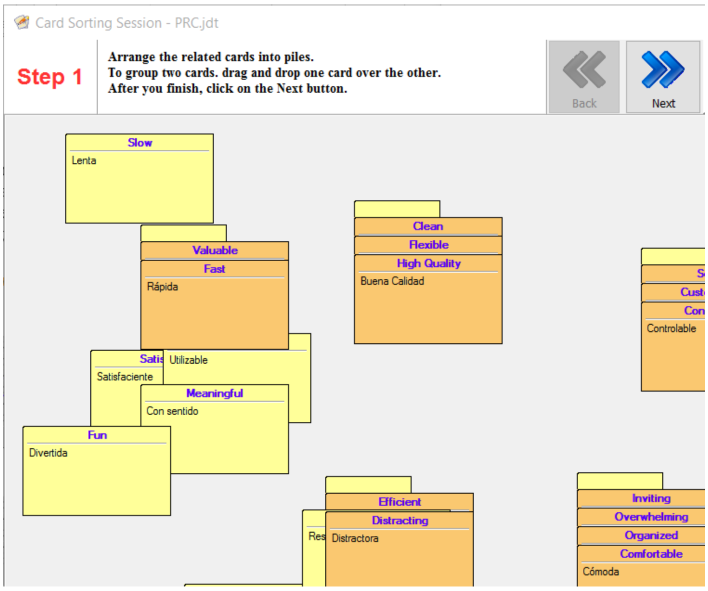

Figure 18: Naming defined groups in a Card Sorting Session.

Similarity between cards is measured by calculating the distance between terms. Being d the distance specified by user u between the terms i and j, we state that:

- $d_u(i,j) = \begin{cases} 0, if\ i\ and\ j\ are\ in\ the\ same\ group \\ 1, if\ i\ and\ j\ are\ in\ different\ groups \end{cases}$
- $d_u(i,j) = d_u(j,i)$,

For our 15 users, the final distance is defined as:

$$D_{(i,j)} = \frac{\sum_{u=1}^{15} d_u(i,j)}{15}$$

The software then creates distance matrixes per user and aggregates them to end up with a value that represents the distance among words taking into account all users. Then, it clusters the minimum distance sets and repeats the procedure, eventually getting to show the number of matches between people that grouped the cards together. Hence, the greater number of people that group two cards together, the shorter the distance between them. Figure 19 shows the tool that contains the card sorting per user.

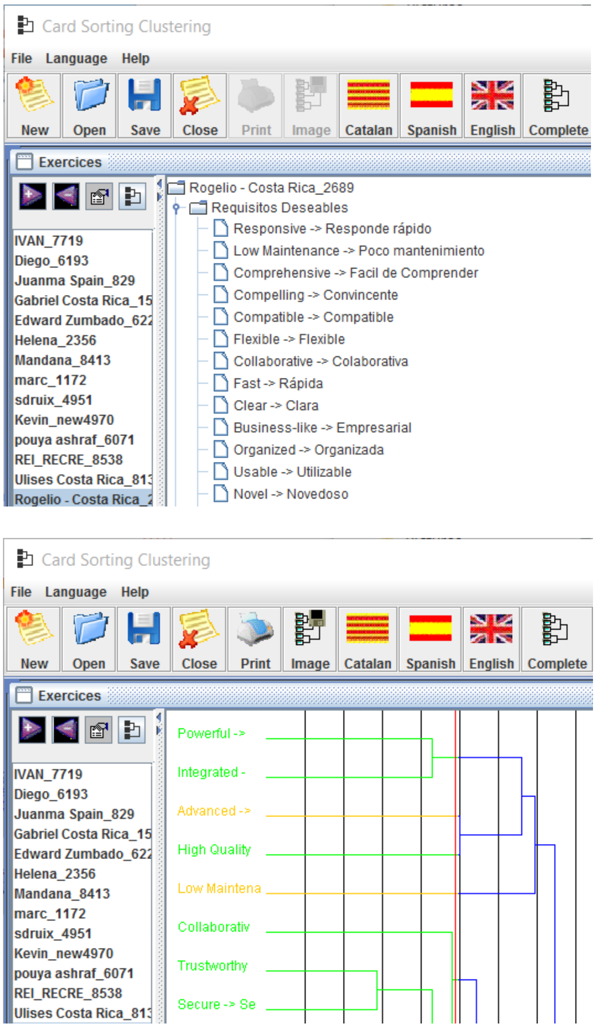

Figure 19: Cluster Analyser.

We discarded 7 result files based on errors with ecs files introduced by the software. The total number of source files we had was 21.

The dendrogram contains all the terms and their degree of separation, measured from 0 to 1. This is the distance. Hence, 0 means that the words are in the same group and 1 otherwise. The method that we used is a common activity to elicit information architecture. As an example, defining menu items and their corresponding groups in a graphical user interface can take advantage of items that are grouped together. In this scenario, an evaluation of the further terms is neither really relevant nor desirable, since it is used for the organization of functions and commands of an application.

4.5.1.1 Groups

We made several cuts alongside the distance measure between all the words. Again, these distances go from 0 being the closest to 1 being the furthest.

Upon moving closer to zero, more groups will appear. When setting the distance factor to 0.85 we notice that 2 groups are formed. One contains 44 terms (37% of the terms), the other one 74 (63% of the terms). This matches the initial term categorization made by the authors of the Product Reaction Cards (40% negative or neutral, 60% positive) (Benedek & Miner, 2002). In our experiment, the one composed by 44 words is populated by negative words, the other one by positive terms. This gives us a clear idea on how usability experts and software engineers understand the employed terminology. For the resulting groups, we will examine the names specified by the participants to reach a proper naming.

The 0.75 distance mark gives us 8 groups. By the words in each group, and the names given to each group by participants, we find the following preliminary categorization, showed in Table 4.

GROUP	DESCRIPTION	Amount of encompassed terms
A	Negative adjectives. Undesired characteristics in a product	37
B	Business like processes. Ideas of a more structured and serious product	3
C	Over the top in a good or bad sense	6
D	Positive terms to describe a product	22
E	What is expected from a software perspective	24
F	Related to attractiveness and emotion	23
G	Calm	1
H	Active	2

Table 4: Preliminary Macro Groupings.

At 0.5 distance, we count 41 groups that branch out of the initial 8. Table 5 shows the resulting group classification inside the preliminary macro groups.

Group A	Group B	Group C	Group D
•Hard •Irritating •Unresponsive •Dreadful •Random •Dull •Ordinary •Disconnected •Old •Fragile •Time wasting •Complex	•Impersonal •Business-like	•Overbearing •Unconventional •Patronizing •Commanding	•Advanced •Low maintenance •Collaboration •Dependable •Meaningful •Confident •Acquainted •Useful •Clean •Essential

Group E	Group F	Group G	Group H
•Good Design •Logical •Instinctive •Satisfying •Anticipated •Simplistic	•Appearance Positive, Emotion •Encouraging •Innovation •Renewed •Approachable	•Calm	•Active

Table 5: Group classification inside macro groups.

The final list of terms by group is presented in Appendix B. We selected the 0.5 measurement distance due to the extensive amount of words which makes the group creation cumbersome in the close end. In a normal information architecture exercise with the selected tool, the recommended similarity index to choose is around 0.3, so we broaden the index to encompass a wider range of related terms.

Only the following words where seen by all participants as very close in meaning (≈ 0.2):

- Difficult / Hard to use
- Unapproachable / Uncontrollable
- Annoying / Confusing / Distracting
- Frustrating / Stressful
- Boring / Dull
- Old / Dated
- Flexible / Customizable
- Time Saving / Comprehensive

- Effective / Efficient
- Appealing / Attractive
- Fun / Entertaining
- Engaging / Enthusiastic

The most complicated words to analyse by users were: impersonal, patronizing, calm, unconventional, meaningful, satisfying, simplistic.

The term "calm" is the only word that was distant from all other words. Therefore, it is feature as the only high level group that contains only one term.

We are using this classification in our experiments when applying the Microsoft Product Reactions Cards to better analyse what the user is communicating. The similarity in meaning and connotations of a set of words, even among a controlled focus group of final users of any software can be large. Therefore, having a tool that allows us to aggregate these potentially similar meanings is of great value towards enhancing the core experience of a product. Additionally, plotting the group results in a radar chart provides a straightforward summary of how users visualize the application. Figures 35 and 46 are examples of the use of this.

The 118 classified terms are shown in Appendix B. Classification of Product Reaction Cards.

4.6 Summary of the chapter

This chapter starts by exploring the concept of User Experience (UX) and how this construct is defined by the ISO. Noteworthy is the fact that UX is a concept that consists of many other constructs, like Utility, Usability, Desirability and Brand Experience. User Experiences goes beyond the question "is software usable?"

The relevant constructs that we will measure in our experiments are Usability, Desirability and Effectiveness/Efficiency. Usability refers to the extent which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. We are measuring it using the System Usability Scale defined by John Brooke in 1986.

Desirability provides a layer of qualitative impact of the system. It concerns how a product "looks and feels". It is a characteristic that we look for when we develop experiences, yet its subjective nature makes it difficult to quantify. This goes beyond the "is the product usable". To measure desirability, we will use Microsoft Production Reaction Cards, a method defined by Trish and Miner in 2002.

Efficiency and effectiveness, are also defined, tied to the task in hand, by task completion, number of errors and time to task completion. Other measurements related to eye tracking and gaze patterns are defined as well.

Finally, our contribution in this chapter, a clustering exercise over the Product Reaction Cards, that results in 8 groups and 41 subgroups that allow a better qualitative analysis of the 118 terms and the ones selected by the user. The classification can be found in the Appendixes section of the present work.

5 Stereo Applications

We have reviewed until now tools that enable the development of stereoscopic user interfaces as well as how to evaluate their user experience. We will now examine these concepts in real stereoscopic software. To do this, we present a pipeline for stereo application development, we talk about discovering the semantics of depth, the types of 3D UIs that we can develop and some case studies around them.

5.1 Pipeline for Stereo App Development

When we started to analyse issues around 3D graphical user interfaces, we came across problems in several phases of a development cycle. We identified them and worked on contributions along this pipeline. Figure 20 is a graphical representation of this pipeline.

Figure 20: Stereo App Development Pipeline

Among the question that we set to answer, we wanted to know if there were differences in the way we perceived stereo content within applications. We know that 3D changes the way a user sees videos and images, but the effect of the inclusion of depth in a familiar user interface was unknown. This was important because a change of eye patterns would require adapting the applications layout accordingly. We also were aware that prototyping these applications was difficult because there is no method that allows the representation of depth in GUIs. Going even further the development line, existing technologies do not support out of the box stereo 3D GUI creation and least in an open technology based, cross-platform way. Concluding the pipeline, little data regarding user experience in S3D GUIs in familiar tasks required a proper comparison between 2D counterparts. We know that this data does not exist because applications that apply stereoscopic depth to their GUIs are themselves scarce. Display technology and current trends in the use of S3D in both computers and television sets have distanced from the use of S3D application-wise. However, we believe that with the current push in Virtual Reality these concepts become relevant as many of the them apply directly to experiences built for VR.

When creating this pipeline, we followed three principles of design that ensured it would be designed for usability; our contributions should be able to seamlessly mix with a process that incorporated an early focus on users and tasks, allowed for empirical measurement of the created interfaces and blend with an iterative approach (Gould & Lewis, 1985).

Another different subject, yet one related with the pipeline, is how do we make use of this depth. Following we discuss on the possible semantics of depth.

5.2 Discovering the Semantics of Depth

As I discussed in section 2.5, in terms of storytelling, 3D brings a whole new toolset to film directors. There, the important thing is that the film interprets reality in a way that is more suitable for the story. Similarly, there are many ways in which we can interpret depth presented in an application. They vary from task to task. Examples span from visualization of air traffic control (Dang, Le, & Tavanti, 2003) to real-time 3D GPU Simulation (NVIDIA, 2016). We have chosen to focus on utilising depth to imply importance, rating and hierarchy.

The use cases presented in the following section 5.4 measure the impact of depth in usability and desirability while having different utilitarian applications. The following list shows how we use depth in our study cases.

- **Rating importance:** Elements closer to the user have higher relevance.
- **Selecting/Highlighting elements:** Visual cue to selecting a specific element.
- **Grouping elements:** elements that belong to different positions in the z axis belong to different groups.
- **Enhancing aesthetic:** models of elements can benefit from the 3D effect.
- **Guiding the user:** we use saliency to try to lure the user towards certain graphic elements.

5.3 Types of 3D UIs

We started working with the idea of differentiating the applications we would build from the type of interfaces that certain games had. With this we mean that the types of graphical user interface we want are neither spatial nor volumetric, like most modern videogames. The main reason for this was that our main objective has been to enhance "traditional" GUIs with depth. These traditional applications spawn across more day to day tasks, like word processing, painting, information visualization, and retailing, to name a few examples. We had to deal with an event-driven model and think about how to introduce depth to these interfaces. We came up with a terminology that would allow us to identify a type of GUI we wanted to build, that allowed us to refer to the type of stereoscopic depth we would apply to it. We now discuss discrete and analog S3D GUIs and what have we developed to create them.

5.3.1 Flat or discrete

This type of graphical user interface features interface elements that are flat. It can contain traditional UI elements like buttons, dropdown boxes, checkboxes, menus, lists, images but positions them in different discrete layers of the z axis. Generally, these layers are defined, equally separated and then populated with elements following a semantic grouping. The only technique that creates depth is the one based on applying different offsets to each image generated for each eye. As examples, we can think of the way we enhanced a search engine result page with depth, or how we set the layout for the cursor and toolbox in the S3Doodle web application. This kind of user interface works best for elements that should not be projected in a perspective way. It is also tightly coupled with the kind of development platform that is chosen. Among these platforms we can cite WPF, HTML5 Canvas and any other framework that works by shifting elements horizontally in each view. This also translates into a more traditional event-driven model based on the programing platform that is used.

5.3.2 Analog/Open Space

Analog GUIs introduce models to the Z axis. These 3D models are not flat and mix with the flat elements on the UI. In a similar manner, the 3D models are not restrained to specific layers, and can occupy a volume on the UI. This means that the GUI must have a 3D mechanism to manage a scene which represents the space on which the UI elements are positioned. This changes the way the coding is done for this applications into a more game-like environment, and brings along collision detection, lighting and the perspective projection. Based on our experience with the coding platforms available to implement this kind of interfaces, we recommend an environment capable of working with a 3D scene and dual viewports that render images from different cameras.

5.3.3 Limitations

The limitations of all these types of interfaces are that they do not represent a real 3D environment. We are working with stereoscopic content, so we are limited to two different views of the content.

5.4 Case Studies

5.4.1 Eye Tracking Preliminary Test

For exploratory purposes with eye tracking (ET), we performed in conjunction with Anna Maszerowska an experiment to analyse how the presence/absence of color in stereoscopic video would affect the deployment of attention. For this, we selected several clips from the film "Transformers Dark of the Moon" (Bay, 2011) in Full HD and defined several areas of interest (AOI) based on color. We gave the users the task to watch these clips and explain the plot. The next figures show the types of clips that we chose for the task. Figure 21 focuses on near movement and action. Figure 22 pays attention to the bright red color on the robot's eyes, and Figure 23 focuses on foreground and (mountain) background elements.

Figure 21: First clip of ET test.

We tested 10 participants in an in between subjects, counterbalanced experiment. We measured gaze dwell time in specific areas of interest (AOI) seen in Figures 19, 20 and 21, of approximately 3 seconds each.

Figure 22: Second clip of ET test. Red eyes.

Figure 23: Third clip of ET test. Environment.

Figure 24 shows the comparison of dwell time (the time a user's gaze is inside the studied area) in both 2D/3D stimuli for Figure 23. This shows the differences that depth can contribute to a video, but further analysis is required for stimuli different than a video clip. We are interested in measuring how a user perceives depth in software.

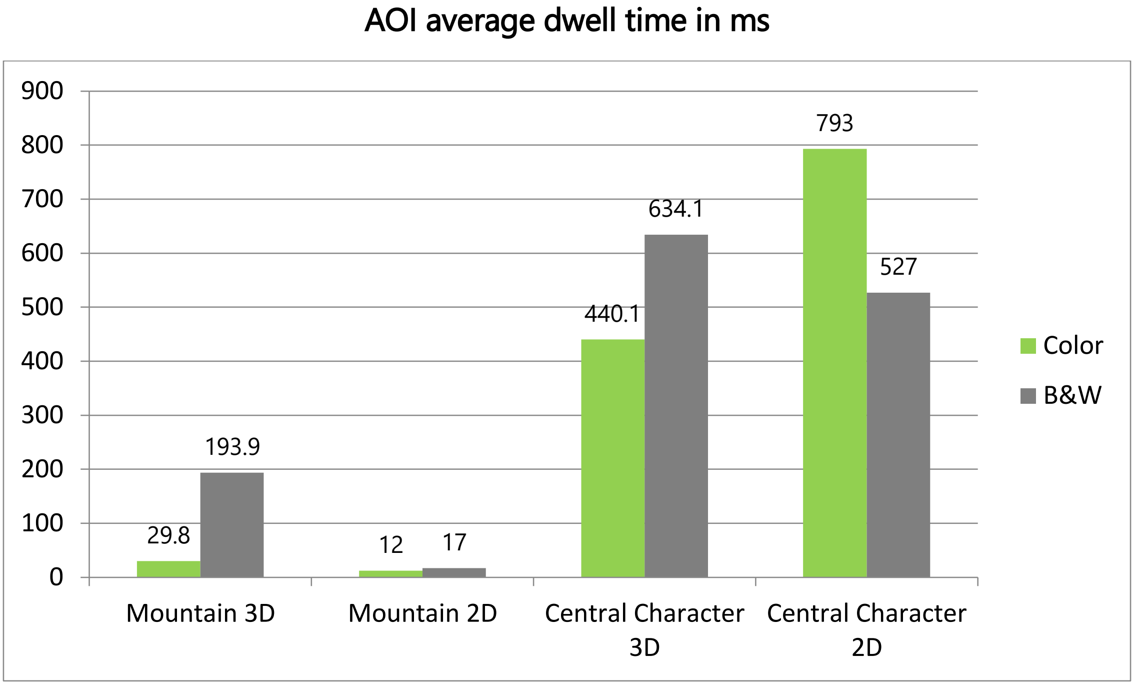

Figure 24: 2D/3D AOI relative dwell time for Figure 21.

As seen in Figure 24, dwell time changes how long elements in the scene are perceived. This is relevant for us because we create stereoscopic stimuli. Dwell time for the central character is around 20% more in the 2D version and similarly, the mountain in the background grabs eye attention 30% more than its 2D counterpart.

In order to achieve eye tracking, special equipment is required. We have used two different models. A standalone SMI RED (SensoMotoric Instruments, 2015) tracker and a TheEyeTribe (TheEyeTribe, 2015) device to gather information on scan paths, gaze patterns and saccade movements.

5.4.2 Stereoscopic Search Engine Result Page (SERP)

In our first case study, we will evaluate the gaze patterns and dwell time of users while applying depth to a familiar user interface. We chose a search engine result page (SERP). We performed an experiment to see if depth affects the way we use a SERP. Understanding how a user visualizes search results is important because gaze data can show patterns which can then be used to improve the layout of information. They can also work to better understand the placement of relevant content. Also, ocular information can provide a more accurate interpretation of implicit feedback than methods like click-through (Granka, Joachims, & Gay, 2004).

It is in this vein that Google's golden triangle (PRWeb, 2005) and the F-shaped pattern (Nielsen, 2006), (see Figure 25) provide information on the way in which users scan the information on a web site, and thus on how content should be positioned (for example, placing the most important information on the first two paragraphs).

Figure 25: Graphical representation of the Golden triangle and the F-shaped pattern.

Having performed research and conducted a literature review in the fields of ET and SERPs, it is of our interest to explore the inclusion of a new variable to these scenarios: that of depth. We now present the next experiment, where we use stereo to vary the behaviors seen in Figure 25.

5.4.2.1 Stimuli

Having in mind that the main focus of the experiment is to use existing UIs to trigger familiarity with the task, we based the creation of the web page on real screenshots of the search result pages for a specific query. This query would be associated with a task. This implies that the prototypes are not dynamic, which allows us to maintain controlled information and that they comply with the familiarity we are looking for and our depth allocation. We developed two stimuli: ‘F’ (Flat) and ‘S’ (Stereo): they mimic a Google SERP showing results on a “Costa Rica hotels” search query. ‘F’ is a standard ‘flat’ web page and ‘S’ has the same content with S3D depth applied on some elements. Both stimuli were built in strict correspondence with World Wide Web Consortium (W3C) HTML recommendations and contains valid HTML and CSS code.

The ruling for depth allocation in the stimuli was based on the semantic weight of each result on the page: the results that are considered by the search engine’s algorithm as more relevant appear on a higher position than the ones ranked lower. At the same time ‘S’ has the same semantic structure, but additionally highlighted with 3D depth: the results that are considered more relevant stays closer to the user while the results considered less relevant closer to screen plane This classification of relevance was based in the PageRank of the results. The stimuli featured two different ad sections. One was treated as a first search result, in order to detect if we could attract the user's gaze to it. The elements were distributed amongst 3D depth and limited to the 3 percent "depth budget" as defined by Sky3D technical guideline (Sky3D, 2015). In order to build 'S' we created a 2D-to-3D HTML conversion algorithm and developed a jQuery based framework preliminary called 3DSjQ (Chistyakov, Gonzalez-Zuniga, & Carrabina, 2013). The framework exploits this algorithm to achieve S3D depth illusion.

Two areas of interest (AOI) were defined in order to aggregate data obtained from the participant's saccades and fixations (see Figure 26). These are 'results' (R) and 'ads' (A). A third AOI contains everything outside the two AOIs and can be considered as `white space' (W).

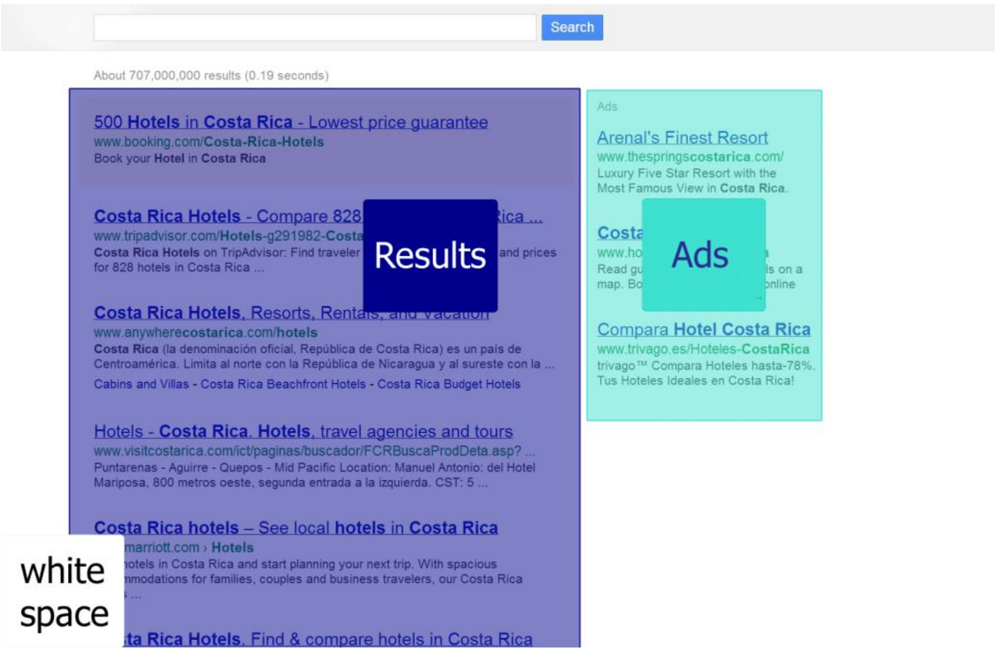

Figure 26: Areas of interest. Indigo (Results) represents 'result AOI', turquoise (Ads) 'ads AOI'.

5.4.2.2 Test Subjects

We passed 31 participants of the academic community of the university (students and staff) between the ages of 19 and 57 into our research lab (The average age for test subjects was 28 years). Several were discarded because of the ET's inability to track due to eyeglasses or other reason. The chosen users were 20 participants, which were split in half for each stimulus (2D/3D) visualized. We chose participants in a way in which each group would have a similar age and gender distribution. None of them was a frequent consumer of 3D content. The majority of participants (58%) needed to wear their eyeglasses during the experiment for proper 3D viewing.

After participants were exposed to the stimuli they were given a questionnaire to get their opinion towards it and the level of comfort they experienced during the experiment. The questionnaire consisted of two sections. The first identified if the participant was familiar with the GUI and to see if they experienced any problems understanding the purpose of the page. The second gathered the opinion of the participant towards 3D hardware, perception of S3D used on the web page, and level of comfort experienced during the experiment.

5.4.2.3 Hypothesis

For this experiment we wanted to trigger familiarity of a GUI and apply depth to see if it would change the way a participant perceived the web page. Our hypothesis was:

$H1_0$: 3D does not influence the way a user observes the web page.

$H1_1$: 3D influences the way a user observes the web page.

5.4.2.4 Experiment Setting

The main objective is to analyse the introduction of depth to a SERP UI. Will it change a user's gaze pattern compared with the same interface in 2D? Will this variation also affect the dwell time for different hierarchical (semantic) elements?

The experiment consisted in displaying a search engine result page and giving the user a task to simulate everyday use. A search query was defined and a SERP was created in a 2D and 3D side by side format. Then, participants would see a stimulus and answer some questions, while their eye movements were logged using an eye tracker.

The hardware configuration for this experiment consisted on data collection and data display equipment. To collect data from the users, an SMI RED infrared eye tracker was used. This includes the eye tracker and a workstation with data analysis software. On the displaying side, a passive-polarized 47 inch LG 3D TV was used. An external computer was used as a source for the TV, since the ET work-station was not equipped with a modern browser capable of running a web page coded with HTML5.

5.4.2.5 Results

The results come from the data recorded by the eye tracker. From the different variables logged, we selected dwell time. The definition, according to the SMI BeGaze manual is the "average in milliseconds", which is equal to the sum of all fixations and saccades within an AOI for all selected subjects divided by the number of selected subjects." Other specific data as sequence (order of gaze hits into an AOI), entry time (average duration for the first fixation into the AOI), revisits and hit ratio (how many participants have entered the defined area) to the AOI are compared to reinforce the former data.

The observed results were segmented by time. Since we are interested in studying the gaze pattern and attention to the UI itself, we split the stimuli and look at the data at 5, 10 and 20 seconds (see Table 6). This allows us to compare how the attention is dispersed across time in both stimuli. The following table shows the selected key performance indicators.

Stimuli	**5s**		**10s**		**20s**	
	ads	***results***	***ads***	***results***	***ads***	***Results***
'F'	352ms (7%)	2375ms (47%)	1604ms (16%)	4526ms (45%)	3340ms (17%)	10330ms (52%)
'S'	141ms (3%)	2847ms (57%)	631ms (6%)	6439ms (64%)	1752ms (9%)	12953ms (65%)

Table 6: Dwell Time indicators in results (R) and ads (A).

The first five seconds exhibit a difference in sequence and hit ratio. In 'F', sequence starts in the *white space*, followed by the *results* and finishing in the *ads*. Hit ratio is similar in *ads* and *results* (around 80 percent). On the other hand, 'S' exposes a different behavior: Sequence starts in the *results* and finishes in the *ads* while hit ratio for the results accounts for 100% of the participants, in contrast with only 20% for *ads*.

On the 10 second mark, hit ratio on the ads AOI reaches 100% in 'F', but does not surpass 30% in 'S'. Therefore, it could be considered that stereoscopic depth is distracting the participant away from the flat ad AOI in 'S'.

Upon ending the 20 seconds, we can observe that the sequence is different between 'F' and 'S': The 2D ('F') stimulus shows a sequence of '*results*', '*ads*' and finally '*white space*', while in the 3D ('S') stereoscopic one, '*white space*' precedes '*ads*'. Also, 'S' only got 70% hit ratio on the ads AOI, which implies that not all participants looked at this AOI during the whole experiment. Figures 27 and 28 show the sequence charts for each user on each area of interest. Colors correspond to the areas depicted in Figure 26.

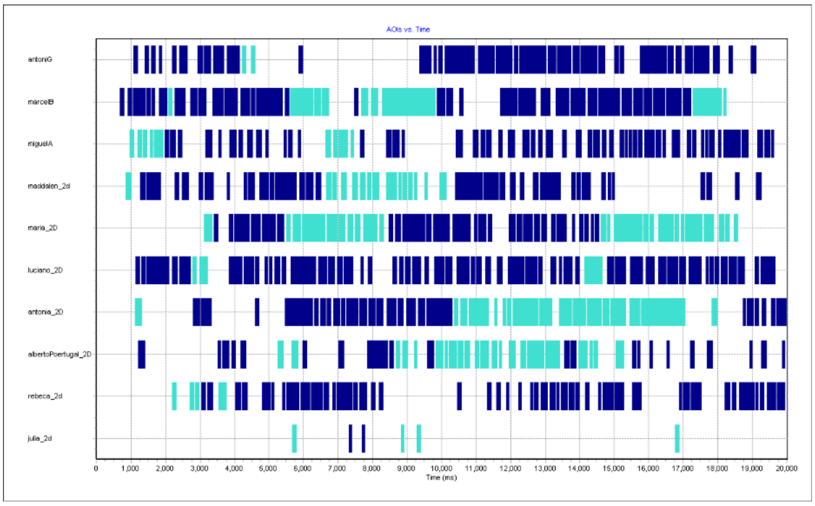

Figure 27: AOI Sequence charts. Each row in the Y axis represents a user. X axis time (0-20s). Indigo color refers to ('R') results and turquoise to ('A') ads. 2D stimulus.

According to figures 27 and 28, it is noticeable that dwell time in *ads* on 'F' and 'S' are similar in all time lapses, participants looked in the right ads twice as much in 'F' than in 'S'.

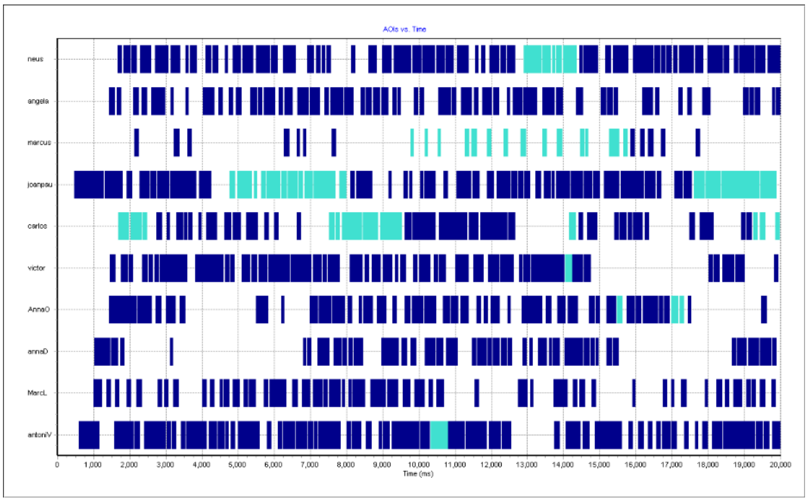

Figure 28: AOI Sequence charts. Each row in the Y axis represents a user. X axis time (0-20s). Indigo ('R') results and turquoise ('A') ads. 3D stimulus.

From the conducted questionnaire, we know that all the users were able to identify the page purpose and intention. This ensured that the task was obvious and the GUI was familiar to all the participants. They were generally excited with the experience; 57% liked it, while 23% said that they didn't like the experience and 20% were indifferent to it.

While being exposed to the stimuli, 30% of the participants felt no discomfort at all. Twenty percent felt slightly discomfort only during the first couple of seconds (typical focus, vergence and accommodation issues). A 37% reported feeling a little discomfort, stating "difficulties focusing all the time" or "annoyed by the 3D glasses". Only 10% of the participants actually felt uncomfortable during the experience. The rest of the participants found it hard to tell how they felt.

Nonetheless, the majority of participants said that they would consider using 3D websites for browsing through any type content browsing only pages containing media content; 27% of the participants said that they would not use 3D for web browsing at all and 10% of the participants said that they would consider using 3D web if no glasses were required.

The overwhelming majority of the participants answered that 3D influenced the content on the page; 60% thought it was a positive influence. On the other hand, 10% said that 3D influence was a negative one, making the text hard to scan or read. Twenty-three percent said that 3D did not influence the content on the page in any way. The rest of the participants found hard to tell if 3D influenced the content or not.

Overall, we noticed a higher dispersion, longer times to gaze through the contents of a page and altered gaze order. This corroborates the different viewing pattern in 3D software, important since it impacts effectiveness and efficiency in the applications. Figure 29 and 30 show the aforementioned dispersion. Not only does it clearly show a much higher dispersion on the stereoscopic version of the stimulus, it also shows how the F shaped pattern is lost in this same version. Another thing to note in Figure 30 is how the edges of each div in the html that represents a result attract visual attention, which is one of the reasons for the higher dispersion of gaze as well.

Figure 29: Heat map on 2D stimulus at 20s mark

Figure 30: Heat map on 3D stimulus at 20s mark

5.4.3 Stereo 3D Memory Game

"Pairs" is a card game where cards are laid down and every turn two are flipped face up. The objective of the game is to turn over pairs of matching cards. This application is an implementation of a solitaire Pairs card game with 12 opportunities to match all 6 pairs. Our interest here is to compare time to completion and number of mistakes made by users between both 2D and S3D versions of the game (González-Zúñiga, Acuña-Silvera, Martí-Godía, & Carrabina, 2016).

5.4.3.1 Stimuli

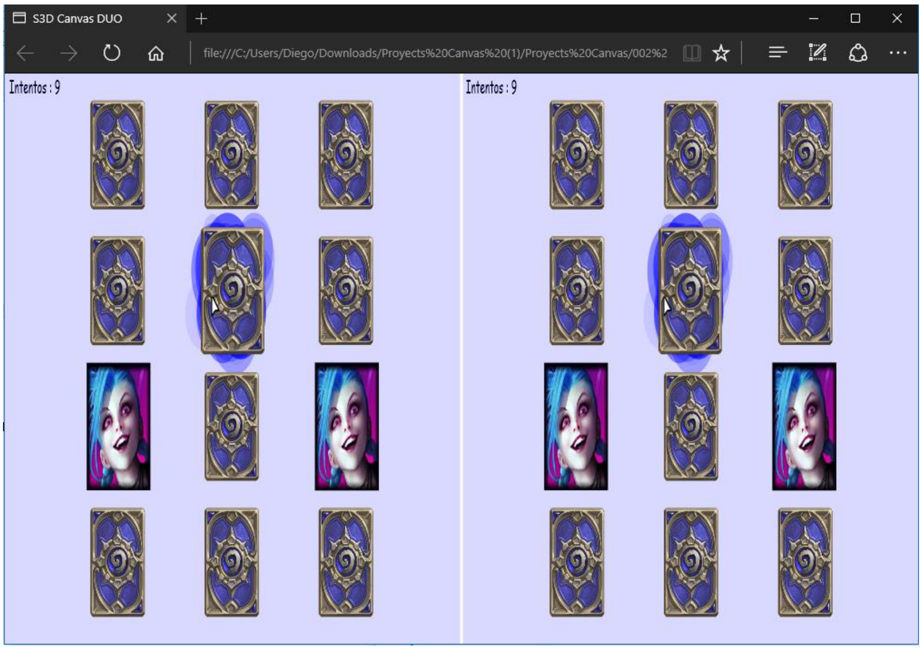

Figure 31: S3D Memory game

The utilized stimulus for this experiment is a stereoscopic 3D Memory Game developed by Acuña (Acuña, 2015). The game can be seen in Figure 31. This application uses depth to highlight selected cards and to indicate pairs that have been found. This application is web based and was developed using the canv.3d tool presented in section 3.1.

5.4.3.2 Test Subjects

We recruited 40 test subjects which each played the game in 2D and 3D. We got 80 records of users playing the game. Their age mean is 28.25 years old. They are members of the academic community of the Autonomous University of Barcelona. We queried participants for their previous experiences with 3D stimuli, in the form of movies or videogames, and only one participant had not experienced 3D assets.

5.4.3.3 Hypothesis

Given the simple task in hand, and the use of depth only for selection and highlighting of cards, we define two hypotheses.

$H1_0$: 3D does not influence the game completion rate.

$H1_1$: 3D influences the game completion rate.

$H2_0$: 3D does not influence the efficiency of the game completion process.

$H2_1$: 3D influences the efficiency of the game completion process

In order to test hypothesis H1 the process is straightforward, since we can compare the rate of completion per stimulus. For H2, we define a score per user that takes into account remaining time and how many interactions did the user take to accomplish the game.

5.4.3.4 Experiment Setting

From a hardware perspective, we used a 42-inch stereoscopic passive display connected to a PC that ran a browser with the stimulus. Two versions of the stimulus, one with elements depth 0 (monoscopic) and another one with active depth were presented to the users in a Latin-square configuration.

Participants signed a Consent Release Form, and then were explained with the rules of the game. All their attempts at beating the game were timed, as well as if they could complete the game and how many attempts did they have left upon completing the task.

5.4.3.5 Results

We compared the samples of the 2D and 3D stimulus regarding time, left opportunities and efficiency using a t-Test with unpaired samples. We define efficiency as time per turn taken. The next table shows the data related to the two samples taken, each of n=33. Data can be seen in appendix D.1.

Mean and Standard Deviation Pair Game

	2D Sample	3D Sample
Time (Mean)	47.52s	42.33s
Time (Std. Dev.)	9.65s	8.64s
Rem. Opps. (Mean)	0.82	1.48
Rem. Opps. (Std. Dev.)	1.13	1.37
Efficiency (Mean)	3.62	3.41
Efficiency (Std. Dev)	0.77	0.73

Table 7: Pairs game GUI statistical description

Results show that time is affected by the inclusion of depth in the GUI. They also show that the number of remaining opportunities to complete the game also varies. For time and opportunities with 78 degrees of freedom, $t_1=2.30$ and $t_2=2.15$ respectively. With a level of confidence of 95%, we can say that there is a difference when considered separate.

Nonetheless, for the construct of efficiency, where we measured time for each opportunity, there is no evidence of overall change between the 2D and the 3D GUI.

5.4.4 Sketcheo 3D

An inconvenient when creating stimuli for the experiments was that it was not easy to visualize the depth in a UI without creating the stimuli as a whole. Therefore, we looked into creating a tool that allowed to sketch UIs to better assess the allocation of the 3D effect. According to Buxton (Buxton, 2007) and Fällman (Fallman, 2003), design is a complex word to define, so an insight towards its definition can be found towards the archetypal activity of design. Independent of the area where design is done, the common action of designers of all kinds is sketching. The importance of sketching can be linked to different areas of software development. For rapid concept development, basic composition layout, client communication, visual exploration, or refining visual solutions, there is no quicker method to explore several solutions than sketching.

Sketching allows to define, in a hasty way, a concept that is made as a preliminary study. The outputs that this process delivers can be converted into mock-ups, which would give a clear idea of the full size scale model of the UI that is been considered. Sketching is generally done using pen and paper. More and more sketches and mock-ups blend in software that is designed to wireframe websites and mobile apps.

"INDEPENDENT OF THE AREA WHERE DESIGN IS DONE, THE COMMON ACTION OF DESIGNERS OF ALL KINDS IS SKETCHING"

Our objective is to be able to represent a sketch of GUI on a stereo capable device and easily assess its depth factor and to have the ability to change and sketch more elements on the fly: the concept of prototyping, fast drafting for 3D UIS. Our challenge is to "sketch" a tool that sketches 3D GUIs. Related work has been made by Broy et al. (Broy, Schneegass, Alt, & Schmidt, 2014) where transparent acrylic glass "frameboxes" are built using laser cutters to reference automobile dashboards and mobile screens. Another way of prototyping stereo GUIs, proposed by the same authors is denominated "MirrorBox", which uses a number of aligned semi-transparent mirrors that generate three virtual layers on which to position UI elements. While these methods allow the prototyping of S3D UIs, we wanted a method that could be extrapolated to bigger screens and that allowed the saving and sharing of concepts for later consumption in stereo screens or projectors. The main challenge was to create an app that could easily create sketches that would support the application design process, independent of screen size, desired allocated depth and proprietary technology.

5.4.4.1 Setting

Our sketching tool, dubbed "Sketcheo3D" (González-Zúñiga, Granollers, & Carrabina, 2015) is a browser application that allows to easily create a mock-up of the graphical user interface of a stereoscopic application. It creates these mock-ups by drawing in several layers of pairs of canvases. Drawing elements in the z-axis is achieved by using the SXS3DCNV JavaScript library (González-Zúñiga & Carrabina, Hacking HTML5 Canvas to Create a Stereo 3D Renderer, 2015), which allows to draw geometric shapes, paths and images using HTML5 canvas. This framework exposes JavaScript functions that allow to directly manipulate the bitmap on the canvas by calling them on the browser console. The tool includes pre-built UI elements (see Figure 32) that can be inserted to create the sketch. It can also be 'hacked' to use external created images to replicate a design, which gives the tool a lot of versatility since it can represent a final "look", layout and depth effect of a user interface before building it.

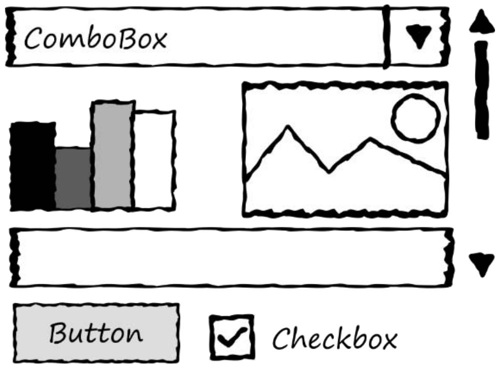

Figure 32: sketch UI controls

This tool is proposed as an open and extendable way to create 3D UI sketches. It achieves this by providing several operation modes that give full control of the bit-map to the developer or designer. The most common way of utilizing the tool is by directly placing elements on the canvas using a mouse and visualizing the sketch live in a stereoscopic device. The application toolbar allows to change the offset between elements that will be positioned on screen, thus, creating the depth effect. This offers a way to sketch full GUIs very rapidly, which is one of the main characteristics of sketches. Figure 33 shows a sketch of a login screen in the designer. The menu toolbar sits at the bottom and exposes the available UI controls (from Figure 32).

Another operation mode involves using the browser's console to on the fly add elements and perform more complex instructions, like drawing paths, and altering the drawing context's style, which allows changing colors, translating elements, cloning parts of the current bitmap, etc. This is done with a combination of functions defined by the application itself, functions from the SXS3DCNV drawing toolkit and even direct access to variables from any underlying script. Using the console allows rapid creation of refined prototypes. Figure 34 shows a more distinguished version of the log-in screen sketched in Figure 33, by directly adding a custom background using a function of the 3D JavaScript kit.

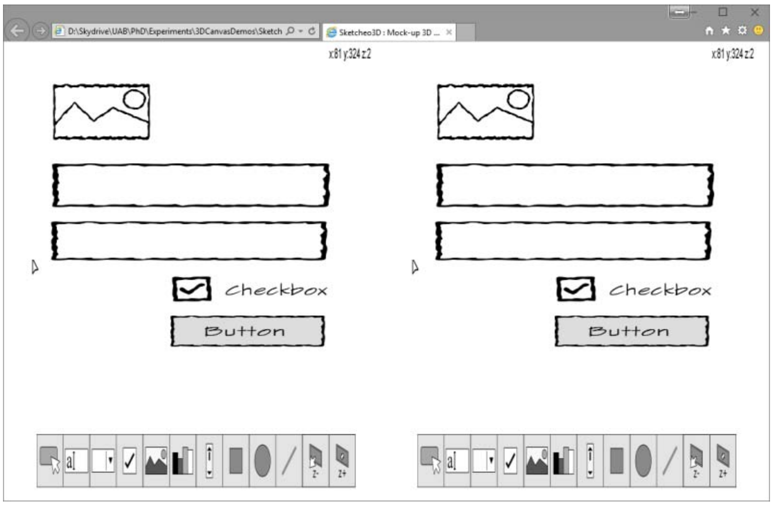

Figure 33: Login screen sketch made in the application.

Another form of further customizing the end results and adapting the application outcome to a brand's look and feel is to create a theme. Themes consist in images that correspond to each basic UI control and that replace the default provided sketch-like imagery. Figure 34 also shows a custom theme made to match a more specific look, while maintaining the depth and functionality of other sketches. With this we want to state that Sketcheo3D is built as a sketching solution, but at the same time is itself a sketch, a draft of how can we use technology to build modular and expandable solutions that help with managing new features presented by new media.

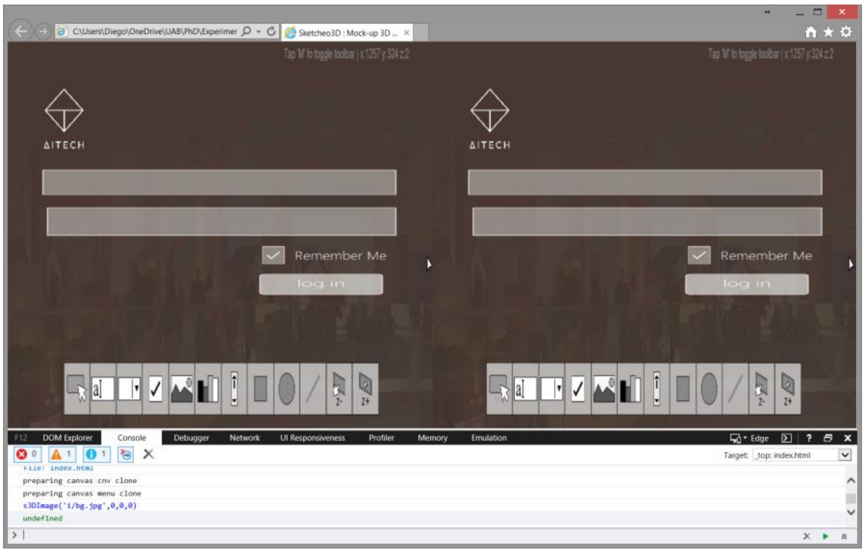

Figure 34: Skinned login screen mock-up

Finally, the created sketch can be saved as an image, to be distributed, shared or visualized in any stereoscopic display capable of showing side by side stimulus. We see this beneficial as it allows the generated ideas easily make their way into meetings in an array of different formats, from printed to projected. They can be stored, disposed of, and most importantly, iterated upon.

5.4.4.2 Results

This tool is a sketch. As such, it is rapidly evolving and helping us not only test the layout of different 3D graphical user interfaces, but is also built in a way that allows it to adapt to different scenarios, from basic sketching to being able to feature custom in-house design. It is built using only open technologies, and based in the latest standards while adapting the stereoscopic principles to create innovative software UIs. The core technologies are HTML, Canvas and JavaScript. We have sketched a tool that allows the creation of sketches of graphical user interfaces. It uses current web technologies to draft layouts that use depth. The benefits and differentiator of this tool is based primarily on the fact that it can show actual stereoscopic images, with the positions defined by parameters defined by developers or designers. The tool is flexible and can adapt to different window (screen) sizes, and is able to run on different platforms (Windows, Mac) and different devices like tablets and phones.

5.4.5 Stereoscopic 3D Garment Desirability Test

When we presented a clustering exercise to group the Product Reaction Cards, we also did a small experiment to apply the newly defined groups and evaluate the results. This preliminary test shows the use of our MRC groups, and serves as a base to further iterate on another experiment.

5.4.5.1 Stimulus

The stimuli created are based on the analysis of existing leading online retailing catalogs. The resulting application consists of a menu for selecting the desired garment and a correspondent product detail page for each product. Figure 35 shows an example product detail page in 2D.

Figure 35: Initial Garment Stimulus

In order to create the elementary shopping catalog used in the experiment, it was necessary to take into account the use of a technology that easily allowed us to create several variants of the same screen while mixing different types of media. We worked with the stereoscopic camera management script presented in section 3.5.

Building the final stimuli consisted of:

1. tweaking the garments exported from Marvelous Designer 4 (MarvelousDesigner, 2015) in blender 2.71;
2. importing them into Unity 4.5.4f1;
3. creating the scene and
4. setting the stereoscopic parameters.

A decision was made towards perspective cameras instead of the orthographic type, since the parallax and volume were inherent to this type of visualization. It also allowed us to have one scene and two cameras instead of two independent viewports or code cloning like in a previous implementation found in (González-Zúñiga & Carrabina, Hacking HTML5 Canvas to Create a Stereo 3D Renderer, 2015).

On the other hand, perspective affects our layout scheme and may create key-stoning, which we correct in a similar way stereoscopic videos are treated: shooting parallel and converging the images in post-production. In our configuration, this means both cameras looking at infinity, positioning the elements further from the stereo camera object and adjusting the inter-axial distance in the script later on.

With the technical 3D configuration ready, the positioning of objects is next. This step is crucial because it is where we emphasise objects in the z-axis. Based on existing online retail web sites and product description pages, we extracted a list of elements from a page to assign into the depth available. Those elements are the ones marked with red circles in Figure 35.

5.4.5.2 Test Subjects

We worked with a company called AITECH and one of their projects that focuses on retailing systems. Due to the fact that the theme of the experiment is related to shopping for dresses, we decided to limit the test subjects to female participants. The experiments took place at the media and engineering schools of our university campus, as well as incubator offices also inside UAB. We recruited 27 women with an age mean of 28.2 and standard deviation of 8.4. Figure 36 summarizes more information from the participants in this study.

Figure 36: Participant profile

5.4.5.3 Hypothesis

The hypothesis of this preliminary experiment is that 3D will change the desirability perceived in the GUI of an application. This experiment serves as a testbed for the clustering presented in section 4.5.

5.4.5.4 Experiment Setting

From a hardware perspective, the setting consists of an active shutter Samsung 46-inch 3D TV, and a PC where we ran the stimuli. We sat the participant two meters away from the screen and positioned a table with a mouse so she would interact with the GUI. On a separate table the 118 terms that correspond to the Product Reaction Cards were laid in a matrix to facilitate their visibility. The survey and Likert scale were also on the table, to log the responses from the user and gather additional information. We also submitted all users to a 3D training before the experiment to assess their stereoscopic vision (Random-Dot

Stereogram). The experiment is a between-subjects study, each participant saw only one of the three possible stimuli: (i) 2D version (control group), (ii) stereoscopic top-bottom version with 3D garment rotation (treatment group), (iii) stereoscopic top-bottom version without garment rotation (treatment group).

The experiment consisted in several phases. First, the participants would fill in a survey in which we would enquire their shopping habits and 3D familiarity. Second, they proceeded to view a Random-Dot Stereo acuity test. This RDS test was defined by us and featured three regions that were out of and into the screen. They consisted on two rectangles and an "O" shape. The participants were asked to describe what they saw and in what depth did they perceived it. After this, they saw the main stimulus. The type of stimulus was randomly selected by an application. There were three variations of the stimulus: (i) the monoscopic 2D version, (ii) the stereoscopic top-bottom version and (iii) the stereoscopic top-bottom where the 3D model of the garment rotates. We gave the user the task to at least add one dress to the shopping cart. They explored the GUI and all of them completed the task. Once the participant expressed she was done, we communicated to her that she must choose 5 words from the ones presented in front of her. These words corresponded to the Product Reaction Cards and would express what she thought of the graphical user interface. The selected terms are logged and the participant proceeds to fill out a post-experiment survey and a Likert scale. We asked some participants for the choice of terms they made, in order to explore in depth what they meant and corroborate their answers. This concluded the experiment.

5.4.5.5 Results

The main reason for using a shopping UI was measuring desirability. The Likert scale results show that the shopping experience (that of dresses) was interesting for the participants, with an average score of 4.07 out of 5. In the same vein, we wanted to know if participants felt comfortable during the experiment: the scale reported a 4.59.

The total number of product reaction cards used by the participants is 59. For each of the three stimuli shown to users the most used words are detailed in the next figure:

2D	3D w rotation	3Dw/o rotation
• Easy to use (4x) • Clear (4x) • Organized (3x) • Intuitive (3x) • Usable (3x) • Accesible (3x) • Eficient (2x) • Direct (2x)	• Innovative (3x) • Appealing (3x) • Novel (3x) • Usable (3x) • Fast (2x) • Time-saving (2x) • Impersonal (2x)	• Novel (4x) • Appealing (3x) • Easy to use (3x) • Fun (3x) • Useful (2x) • Creative (2x) • Accesible (2x) • Organized(2x)

Figure 37: Word appearance by stimuli.

As Figure 37 shows, the most used words in each stimulus vary in connotation. While set of words related to the 2D stimuli tend to be more related to productivity and layout of the graphical user interface, both 3D variations share a more aesthetic and expressive stance, with words such as appealing and novel as the top chosen words to describe the GUI. Finally, the groups of words selected by the users can be seen in Figure 38.

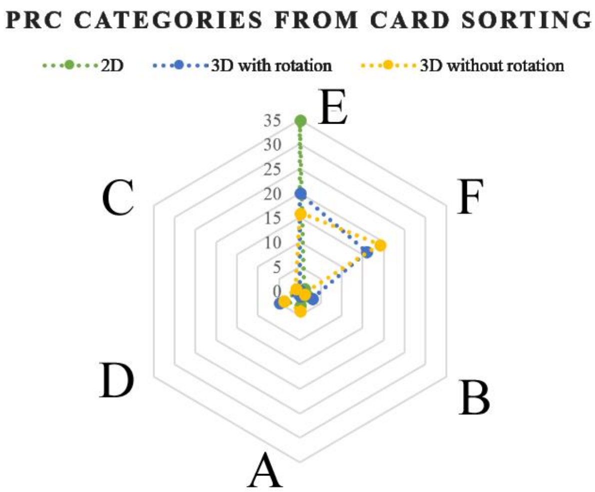

Figure 38: Desirability result from PRC analysis

In Figure 38 we can see that the versions of stimuli that feature 3D come closer to groups of terms E and F, which relate to good software design, attractiveness and emotions.

5.4.6 Stereoscopic 3D Garment Catalog

The ubiquity of the internet combined with the increased connectivity of mobile devices, are changing shopping patterns in consumers. Now more than ever, creating a shopping experience related to a brand is important to attract clients; and offering fluid and highly relevant interactions is vital to keeping them in the brand experience (National Retail Federation, 2014). The concept of cross-channel shopping is prevalent and desired (Fretwell, Stine, & Louks, 2012) even inside store walls, with examples of this being beacons and the ever growing availability of displays and kiosks. This in-store digital content is an important buying influencer. Creating an emotional connection with the user is important since it enables and triggers his/her buying decisions (Fretwell, Stine, & Louks, 2012). This is a reason why in many retail applications, the trend is to create experiences that surround the user, using technology to keep the user in the "brand experience" and seamlessly jumping between digital and physical concepts. These concepts are referred by Cisco IBSG as "Mashops" (Fretwell, Stine, & Louks, 2012). Also of relevance are the trends that this cross-channel shopping behaviour is prevalent and desired –even inside the store. Moreover, the emergence of well informed, social shoppers or "Digital Divas" with a fragmented shopping style forces a change of strategy from the retailers. These Digital Divas comprise 22% of fashion shoppers and own more than two-thirds of fashion purchasing power (Bhappu, Lawry, & Garf, 2013), and they expect a shopping experience that is both fluid and highly interactive (Häkkinen & Kawai, 2010). In this regard, the main idea is to bridge different experiences to attract and maintain customers.

"CREATING AN EMOTIONAL CONNECTION WITH THE USER IS IMPORTANT SINCE IT ENABLES AND TRIGGERS HIS/HER BUYING DECISIONS"

Our objective is to try to obtain this emotional response mentioned earlier, to apply it to interactive applications. This in order to create the level of immersion and engagement that movie and game makers are achieving. To translate this emotional response to an application's user interface, we address additional challenges since applications are not passive and input devices are not made for these "3D UIs" (Bowman D. , Kruijff, LaViola, & Poupyrev, 2001).

The decision to make an application related to retailing/fashion was that it represents a paradigm of a known application area for consumers: many people shop online or on their mobile devices. For this, we examined websites of leading retailers to extract layout patterns. We altered the final purpose of the application, from buying to rating garments, to provide a task that we could measure more accurately. Figure 39 shows the detail view of a garment 'detail' page.

Figure 39: S3D Garment Stimulus

5.4.6.1 Stimulus

The created stimulus was based on existing leading online retailing catalogs. The resulting application consists of a 1 x 4 grid menu (Figure 40) for selecting the desired garment and a correspondent garment visualization page for each product. These stimuli are based on the ones created for to test the clustering of Product Reaction Cards.

Figure 40: Application menu in top-bottom format

As was the case with the initial experiment, this stimulus used the stereoscopic camera script (see section 3.5) and allocated GUI elements in depth (González-Zúñiga & Carrabina, 2016).

The 'detail' page stimulus, shown in Figure 41, displays (i) a logo of the brand and navigational 'back' button, (ii) a model of the garment, (iii) title, (iv) ratings stars and (v) a button to rate the specified piece of clothing. Additionally, it has (vi) a notification banner for system messages or pop-up dialogs (Figure 42). In a similar way to the original experiment, all of the mentioned UI elements were positioned in different depth layers. Several basic guidelines for designing 3D UIs were considered to place the elements along the available depth. These are based both on our previous experience and also on recommendations found across (Huhtala, Karukka, Salmimaa, & Häkkilä, 2011), (Broy, Alt, Schneegass, Henze, & Schmidt, 2013) and (Broy, Schneegass, Alt, & Schmidt, 2014).

Figure 41: Garment detail page

Following these guidelines, we established that there could not be more than 6 different layers of depth. Additionally, to ensure the separation to be perceived by the user, distance between layers was maximized (always in an acceptable depth budget). Also, to provide the best readability, text was kept parallel to the screen. The highlighting of elements (present in the experiment when hovering over relevant elements) was done by combining salient cues: size, occlusion, movement and z-position. One final detail regarding the way we layout available space is that the area between the user and the screen was reserved for notifications or important system messages. A marker with (vi) in Figures 42 and 43 denotes this.

Figure 42: Pop-Up message

The final stimuli consisted on 6 levels of depth. Figure 43 shows the accommodation of each one of the 5 elements across these six layers.

Figure 43 shows the 3D depth model that represents the main model for the product description page balanced in the center and taking up the whole space (volume). The foremost elements are (vi) notification, (iii) garment name and (v) rate button. This is intentional, as users evaluate closer objects as more important. Noticeable is the fact that we have arranged the rating stars coming closer to the user the higher the rating.

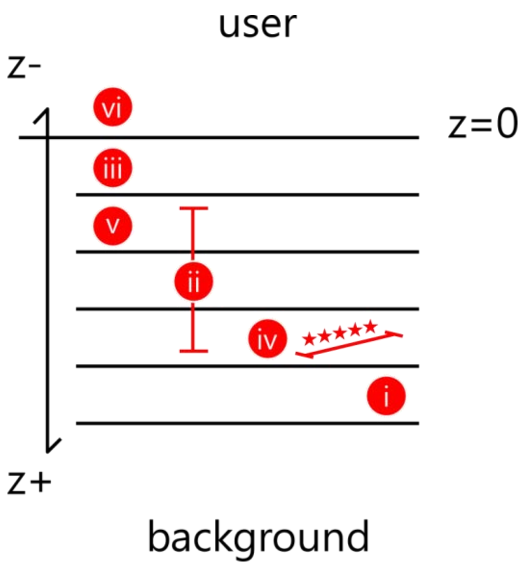

Figure 43: Positioning of elements from Figure 28 in the available depth.

5.4.6.2 Test Subjects

We recruited 40 test subjects. Seven were discarded because the eye tracking information was lost or not reliable. Each participant passed through the several phases of the experiment. Their age mean is 28.25 years old (standard deviation of 4.62). They are members of the academic community of the Autonomous University of Barcelona. We queried participants for their previous experiences with 3D stimuli, in the form of movies or videogames, and only one participant had not seen 3D assets at all. The rest had occasional (1-3 times per year) experiences with 3D.

5.4.6.3 Hypothesis

Four hypotheses have been defined for the current experiment as follow:

$H1_0$: 3D does not influence the perception of the garment.

$H1_1$: 3D influences the perception of the garment.

$H2_0$: Stereo does not influence the usability of the system.

$H2_1$: Stereo influences the usability of the system.

$H3_0$: 3D does not influence the desirability of the app.

$H3_1$: 3D influences the desirability of the app.

$H4_0$: 3D does not influence the distribution of eye movements for the image.

$H4_1$: 3D influences the distribution of eye movements for the image.

To test these hypotheses, we take into account the ratings that users gave to the garments using the application, the perceived usability of the application itself and the selected terms of the desirability exercise. Both the System Usability Scale and Product Reaction Cards are the selected methods for measurements.

5.4.6.4 Experiment Setting

For the experiment we setup a space where the user would sit about 1.5 to 2 meters away from a 42inch passive 3D TV. The display is connected to a PC that runs the stimuli in form of an executable. This setting, shown in Figure 44, accommodates an eye-tracker, space for performing some exercises on paper and a mouse for interaction with the application.

The experiment consists in several phases. First the user would sign a consent form regarding the recollection of data with the eye-tracker. Then he/she would see 8 images that correspond to 4 pairs of screenshots of the garments to rate (formed of the 2D and 3D format). After this, they would be shown the main stimulus where they would rate each garment in a scale from 1 to 5 according to how much they liked it. Once they finish rating the garments they proceeded to fill in a document with two exercises. This document consisted of the System Usability Scale (SUS) and the Product Reaction Cards, from which they were instructed to select 5 terms.

During the eye tracker part of the experiment, calibration was done in 2D and then the TV was set to 3D mode. This was done in order to properly calibrate the equipment with a full frame screen. The stimuli for this part was designed in a way that would adapt to the side by side stereo format. Figure 47 shows how the eye tracker captures the information. Figures 45 and 46 show how this information is perceived by the user when seeing the 3D stimuli.

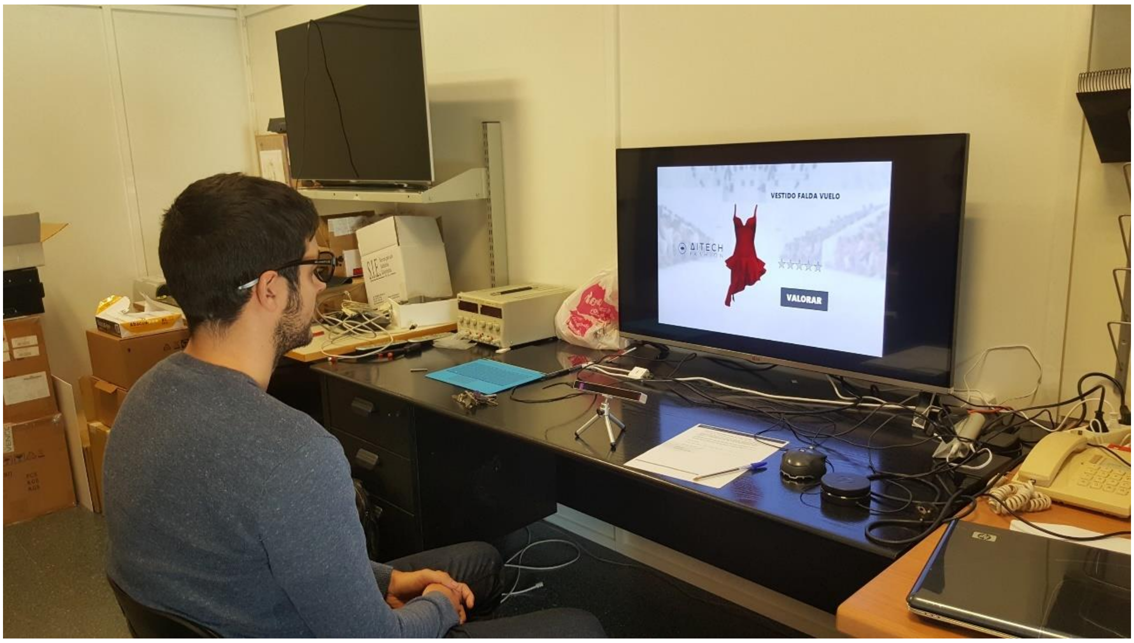

Figure 44: Experiment Setting for S3D Catalog

5.4.6.5 Results

We tested several elements in this experiment: (i) perception of the garment, (ii) usability of the system, (iii) desirability of the GUI, and (iv) distribution of eye movements. We now look into these factors. The stimuli were presented in a Latin square arrangement to minimize a biased response. Comparison of samples was made using a t-Test with unpaired samples.

To measure the perception of the garment, we put the user the task of rating from 1 to 5 stars the garments displayed. We compared then for each garment the data from the 2D sample and 3D sample. With a 95% confidence, there was no significant change in the perception of the garments. Nonetheless, as a side note, using a 90% confidence interval two garments (number 2 and number 3) did show difference in user perception. The first null hypothesis $H1_0$ is not rejected. The ratings for the garments can be seen in appendix D.2.

Perception	2D Sample	3D Sample	t value
Garment 1	2.62	2.97	1.17
Garment 2	2.60	3.17	1.74
Garment 3	2.70	3.23	1.76
Garment 4	2.74	3.00	0.76

Table 8: Garment perceived attractiveness means (n=40)

We also tried to influence the rating on the garments by positioning the rating mechanism for the garments closer to the user based on the rating itself. This means the star that represents the higher rating was place closer to the user, and the one with the lower rating further away, creating a subtle gradient effect with the depth of the UI elements. Overall this did not cause any significant differences between stimuli, hence, no difference was noted.

Passing to H2, we compare the results from the System Usability Scale for each participant and the difference in among the samples for each 2D (mean x_1=78.23 std.dev=14.22; mean x_2=79.85, std.dev=9.03) and 3D. No significant change was registered regarding to usability in this specific use case.

Desirability on the other hand, measured with the Product Reaction Cards, did show an increase in terms with a connotation related to aesthetics and emotion. For 2D, the most selected terms were "easy to use" (7x), "intuitive" (6x), and "fast", "usable" and "clear" (5x). On the other hand, for the stereoscopic version participants chose most the words "attractive", "creative" and "advanced" (8x), "fun" and "innovative" (7x). Data gathered in this experiment can be seen in appendix D.3.

Figure 45: 2D eye tracking heatmap of garment in overlay format.

Figure 46: 3D eye tracking heatmap of garment in overlay format.

Finally, the eye tracking comparison of each garment shown to the participants portray a larger dispersion of gaze and eye movements in the 3D version of the application (partly appreciated in Figure 47). It also reveals a longer average fixation duration (as seen in Table 9 and Figure 48).

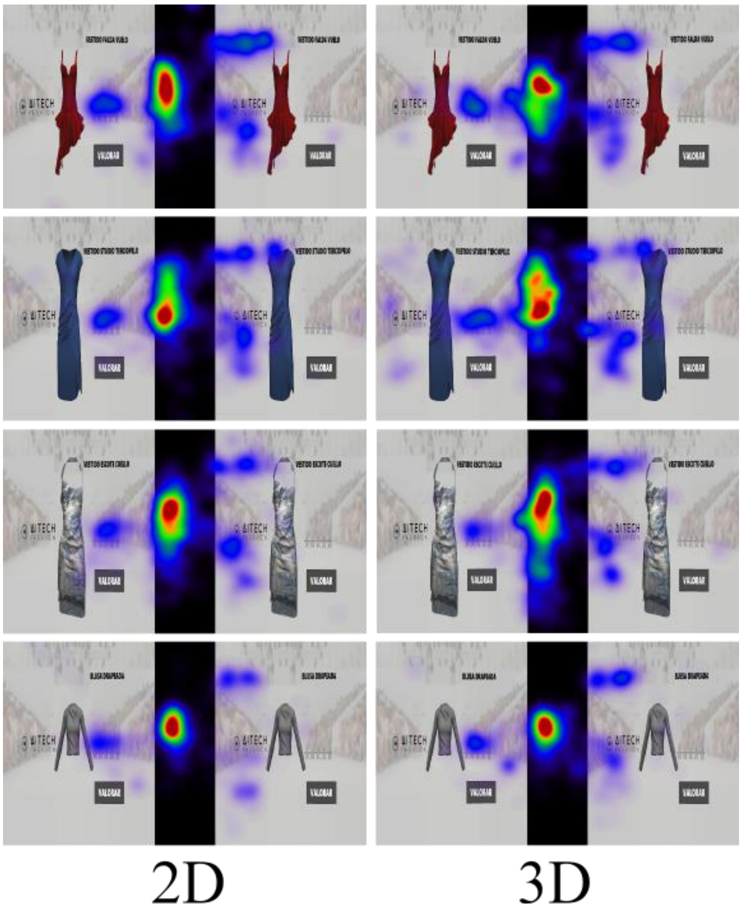

Figure 47: 3D eye tracking heatmap of all garments in original format.

	2D total duration (ms)	3D total duration (ms)
G1	3326.7	3518.8
G2	3479.0	4497.1
G3	3232.9	3588.3
G4	3279.8	4137.9

Table 9: Average total duration in AOI in milliseconds.

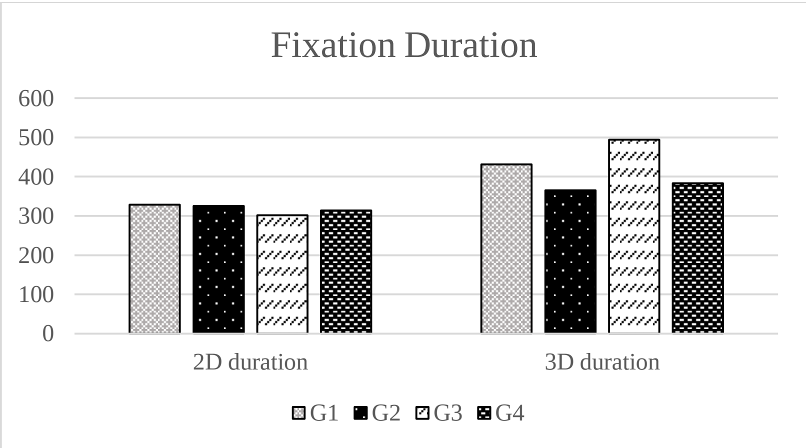

Figure 48: Fixation duration average per garment.

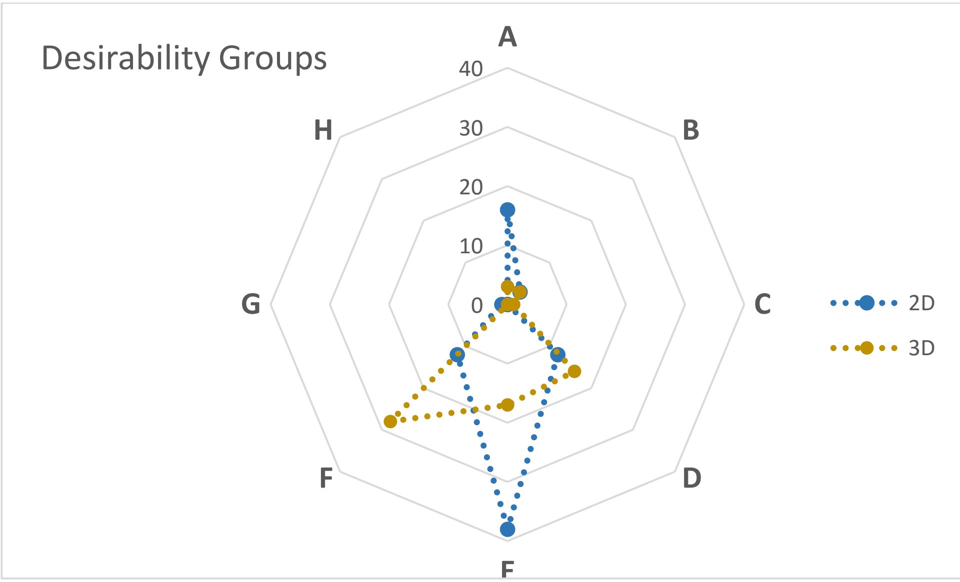

Figure 49: Desirability results from PRC analysis

Finally, addressing H3, the analysis derived from the clustering of terms performed in section 4.5 reveals the different connotation in desirability expressed by the participants of the case study (Figure 49). The terms used for the stereoscopic version of the application tend to go towards more aesthetic and emotional which reside in groups E and F, more than doubling the amount of terms in comparison to the monoscopic version. Meanwhile terms on the 2D version of the same stimulus focuses more on good software design and productivity found in groups D and E.

5.5 Summary of the chapter

This chapter assembles the concepts presented in previous chapters and shows a graphical representation of a stereoscopic application pipeline. This pipeline (theory, prototyping, development and evaluation) is the central part of the present work, were we present contributions and measure changes achieved in our 3D generated scenarios.

An important part of our work as well, is the exploration of the changes in human factors triggered by depth. It is agreed that this is completely dependent on the task, and that many authors and developers use it in different ways. According to the tasks at hand, we decided to use depth as a cue for selected/highlighted elements. Also, to indicate importance or rating, and to separate toolbars and menus from the working area.

Discrete and analog applications are presenting, making clear how can we create different types of applications. This is important to take into account while choosing among the tools available.

The present chapter also takes technical concepts presented in chapter 3 and human factor concepts from chapter 4 to present 6 case studies where the changes of a graphical user interface due to the introduction of depth are measured. These cases are composed of 2 preliminary tests (eye tracking and desirability) and 4 experiments that introduce depth in different ways. A stereoscopic search engine result page that rates results using depth, a stereo 3D memory game that highlights selected cards using depth, a sketching application that uses depth to position elements in space and separate the menu bars, and a stereoscopic 3D garment catalog that combines 3D models and GUI elements in space to poll usability and desirability. We now examine the results of these case studies, and lay the conclusions to the present work.

Section Three

Making sense of depth in software

Stereoscopic depth has not been fully exploited in software, yet its benefits can be seen across its use to enhance tasks and guide the user. The lack of a pipeline to create this type of stimuli is an issue that needs to be tackled in order for this type of software to expand, and the reason for this type of software to expand and exist is that it can provide better user experience than 2D versions. All examples and uses of depth vary and are related to the task in hand. We have developed and documented cases where introducing depth enhances the UX.

6 Conclusion

The present PhD work explores the introduction of depth in graphical user interfaces. The initial objective was to detail a pipeline (depicted in Figure 50) that enables the creation and evaluation of stereoscopic graphical user interface content by providing a set of tools and evaluation criteria using state-of-the-art software technologies. We have presented several tools to fulfil this pipeline that promotes the development of stereoscopic applications and case studies to test these tools. Depth was used in similar 2D and 3D stimuli to measure if changes were produced as a result.

Figure 50: Stereo App Development Pipeline

Concerning prototyping, we reviewed the concept of sketching to quickly represent depths on which we will put different GUI elements. We have sketched a tool that allows the creation of sketches of graphical user interfaces. It uses current web technologies to draft layouts that use depth. The benefits and differentiator of this tool is based primarily on the fact that it can show actual stereoscopic images, with the positions set by parameters defined by developers or designers. The tool is flexible and can adapt to different window (screen) sizes, and is able to run on different platforms (Windows, Linux, Mac, Mobile) and different devices. The tool itself is a proof that current desktop and web technologies can be effective at creating stereoscopic applications and in this case do things that a normal application with a traditional user interface can't. This is enabled by our efforts and is a hypothesis we refute. This is an important part of the pipeline that is mentioned in the first hypothesis, since it explores how depth can be used in a GUI before investing in development.

> *"THE TOOL ITSELF IS A PROOF THAT CURRENT WEB TECHNOLOGIES CAN BE EFFECTIVE AT CREATING STEREO APPLICATIONS AND IN THIS CASE DO THINGS THAT A NORMAL APPLICATION WITH A TRADITIONAL USER INTERFACE CAN'T."*

Regarding tool development, among the technologies we tested, HTML5 Canvas was the most performant, flexible and functional due to its inherent JavaScript background, compatibility (Deveria, 2014), and the uniformity of its implementation. The fact that canvas is a feature built into the web specification guarantees execution of the code in a wide range of platforms. Nonetheless, of the two contexts of the canvas ('2d' and 'webgl'), none is stereoscopic out of the box and the 'webgl' has partial support due to some video drivers and an experimental context on browsers like Microsoft Edge. We developed a solution that wraps the standard '2d' context providing a side by side solution proved to work in a broad set of devices. The implementation duplicates drawing commands and manages to draw up to 20000 shapes per frame (and more on hardware accelerated browser). Table 3 showed us an average of 392% difference in size ratio between common image file formats and our canvas representation for a stereoscopic representation of a chart. In this way, we can **store vector-like images in smaller sizes than with raster formats.**

On the desktop platform, the Unity game engine allows the creation of dual viewports assigned to different camera, creating the stereo effect. The engine does not provide a stereoscopic configuration out of the box (except for third party plug-ins). Similarly to our approach for the 2D context, we coded a stereo camera management script that takes two cameras and builds a rig wrapper that handles the 3D parameters. **Overall, the efforts in development represent a base on to which new experiences can be created and targets a gap where no easily accessible methods exist that enhance both utility and aesthetics, always noting the differences in user behavior when introducing depth**.

Concerning evaluation, and to prove our hypothesis, we developed 6 case studies to test different repercussions of depth. First, a Preliminary Eye Tracking test and a Stereoscopic Search Engine Result Page. From them, we inferred that **there is a change in viewing patterns, both dwell time and viewing sequence order**, and this must be taken into account when positioning elements in the GUI. We also noticed that both dwell time and fixation duration are greater when experiencing 3D stimuli. Following, a Stereo 3D Memory Game, where we learnt that **greater dwell times do not necessarily mean lower performance.** In this case, we measured effectiveness and efficiency to show that participants were able to complete the tasks faster when using depth to separate elements with an average difference of 5.19 seconds (faster in the 3D stimulus). This separation in different groups was achieved by using different z-axis positions. On the other hand, if time is not a defining element in the task at hand, **3D still changes the gaze order in an application and can be used to direct the user towards content in different depth**.

Finally, we explored two test cases based on a Stereoscopic Garment Catalog. In this example, changes are visible in the perceived desirability of the software.

Remembering that desirability is related to the way something looks and feels, it encompasses constructs that are not easily measured by usability tests. Product Reaction Cards can get a reliable portrait of a system's desirability, but the management and analysis of word appearance among 118 terms can be cumbersome and costly timewise. Therefore, we have grouped PRCs to measure desirability in an application using a traditional clustering exercise.

We can now get a snapshot of a user interface's desirability by counting words that have similar connotation. We can apply this classification to the results collected from participants in order to analyse the inclusion of stereoscopic depth in a graphical user interface. The created classification is an initial effort to provide UI and UX practitioners with an additional layer of information extracted from PRCs.

When plotting the results in a radar chart, we can see in a preliminary test and case study that the stereoscopic versions of the application tend to go towards more aesthetic and emotional terms (found in groups E and F, terms like "attractive", "creative", "advanced", "fun" and "innovative"). These terms more than double the number of terms in comparison to the 2D version in those groups. Meanwhile terms selected for the 2D versions of the same apps focused more on good software design and productivity (found in groups D and E, specifically "easy to use", "intuitive", "fast", "clear" and "usable"). Worth noticing also is the fact that participants tended to select a wider set of terms for the 2D version of the stimulus. The similarity in meaning and connotations of a set of words, even among a controlled focus group of final users of any software can be large. Therefore, having a tool that allows us to aggregate these potentially similar meanings is of great value towards enhancing the core experience of a product.

"HAVING A TOOL THAT ALLOWS US TO AGGREGATE THESE POTENTIALLY SIMILAR MEANINGS IS OF GREAT VALUE TOWARDS ENHANCING THE CORE EXPERIENCE OF A PRODUCT."

Nonetheless, this is not the same experience with our tests on perception of products/items in the application itself. One of the studies involved rating garments which were shown to the users as 3D models. Similarly to previous studies, both monoscopic and stereoscopic versions were shown, but there was no solid evidence of higher resulting ratings between the samples taken from the two stimuli. Another aspect that did not influence the ratings of garments was the position of the rating mechanism, which consisted of 5 stars that came closer to the user in accordance to the represented rating. This served as a repetition cue, along with color.

Finally, we demonstrate that there is an opportunity to use stereo 3D images not only for image and videogames but also for interactive applications. Hardware, software and consumer trends have not made possible a big explosion of the technology, so our research can be considered a pioneering one. As such, the design, implementation and testing of our hypothesis show novel results, not comparable with any other previous implementations. With this said, in a close future new 3D UI interfaces will appear for this kind of applications that will create more radical and innovative user experiences than those expected by classical navigation and mouse actions present in our prototype.

As a summary, we believe this research is contributing to enhance the theoretical basis concerning development of stereoscopic graphical user interfaces. For each part of the explored pipeline, we have presented tools and knowledge that directly impact the process and insight we have for 3D on applications. By using eye-tracking technology we have shown that gaze changes, both in order and dwell time. This is fundamental, since the way we experience 3D in passive stimuli like movies change, and adding interactivity influences other human factors. We have explored these human factors, in cases that range from usability to desirability, producing at the same time tools that enable an easy creation and evaluation of assets to measure these UX constructs.

6.1 Future Work

The environment around stereoscopic assets has evolved greatly in the past years. Nowadays, the revolution in multimedia experiences, which is being powered by VR, brings a lot of relevance to the presented work. This relevance is not because of the virtual environments that have existed (but are being adapted into VR) long before in videogames but because of the migration of more traditional and familiar tasks into VR. Future lines of research that can build upon the present work span across different subjects like: (i) Virtual Reality and Augmented Reality, (ii) different task examples of other traditional apps, (iii) comparison of different depth layouts for tasks, (iv) interaction with gestures in 3D apps, (v) innovative use of depth for interfaces and (vi) areas where depth will enhance a task.

- **Virtual Reality and Augmented Reality:** an obvious line of future work since VR itself needs stereoscopic images. But getting away from virtual environments, videos, games and experiences, lies the question of how can 2D elements take advantage of the immersion in more traditional applications. More and more examples of experiments that replicate desktops or browsers are coming out, yet have undermined concepts based on 2D interaction. A good way to start would be to have a way to convert a 2D application that features content to VR.

- **Different task examples of other traditional apps:** we studied the case of a search engine, a pairs game and a garment catalog. But many other types of applications should be explored with depth. The exploration of depth in different tasks can lead to defining patterns and common practices in software, like the ones that already exist for 2D apps. Productivity applications, data visualization and dashboards are good examples.
- **Comparison of different layouts for tasks:** manipulating the depth budget in an application can lead to very different results. We can use depth to change where the user is looking, and we can guide a user by the amount of depth that we utilize in a GUI. Measuring the impact of depth and different layouts of 3D for tasks can yield different results that could change the user experience.
- **Interactions with gestures in 3D apps:** Stereoscopic applications have the advantage of using depth to modify a task. But this introduction of depth brings its own challenges regarding selection, navigation and manipulation of content, and modification of underlying technology (both hardware and software) to interact in space. Mapping and defining these gestures to commands in the application provides a challenge since the threshold for depth, stability and physical positioning requires adaptation to available space and task in hand.
- **Innovative use of depth for interfaces:** a novel and creative line of research and future work is related to how do you use the available depth in a better way. Overlaying content, playing with transparencies, and making a better use of the space, thinking outside the 2D layout box can improve the use of depth. This can mean breaking away from familiarity of layouts, interactions and paradigms to test ideas. As an example, creating a layered graphical interface that can semantically separate information on layers and use transparency to augment the layers beneath can be very useful as a mean to interchange the working context of information.
- **Areas where depth will enhance a task:** While it might be possible that some tasks will be enhanced by the introduction of depth, others won't. It is important to determine which areas and tasks are suitable to be used with depth. This can identify subjects in which it makes sense to use depth, like math, science and multimedia. Whether a word processor or spreadsheet require stereoscopic 3D in their GUIs is something that is yet to be seen.

Finally, depth can have positive effects on a user interface and new mediums are adopting stereo as an essential part of their platforms. To research where is it suitable to utilise 3D, as well as how to utilize it will change our way of interacting. It might start as elements that seemed to go into a TV screen, but the market is already dictating the virtual environments that will house near future interactions, all which base experiences on blank canvases ready to have elements positioned in front of behind them. Augmented reality is following similar steps, where menus and information interact with the environment. These experiences have one common denominator: Stereoscopic 3D user interfaces.

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Appendix

A. Author's biography

Articles

- Gonzalez-Zuniga, D. & Carrabina, J. (2016). **Clustering to Categorize Desirability in Software: Exploring Cluster Analysis of Product Reaction Cards in a Stereoscopic Retail Application**. *Proceedings of the Digital Media Industry and Academic Forum.*
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B. Classification of Product Reaction Cards

A	Hard	Difficult, Hard to Use, Incomprehensive, Not Secure, Inconsistent, Unapproachable, Uncontrollable, Ineffective, Not Valuable, Disruptive
	Irritating	Annoying, Confusing, Distracting, Gets in the way, Intimidating, Frustrating, Stressful, Undesirable
	Unresponsive	Poor quality, Slow
	Dreadful	Unattractive, Irrelevant, Unrefined
	Random	Unpredictable
	Dull	Boring, Dull
	Ordinary	Ordinary, Sterile
	Disconnected	Disconnected
	Old	Old, Dated
	Fragile	Fragile
	Time wasting	Time Consuming, Busy
	Complex	Too technical, Complex, Rigid
B	Impersonal	Impersonal
	Business	Business-like, Professional
C	Overbearing	Overbearing, Overwhelming
	Unconventional	Unconventional
	Patronizing	Patronizing
	Commanding	Powerful, Integrated
D	Advanced	Advanced, High Quality
	Low maintenance	Low maintenance
	Collaboration	Collaborative, Trustworthy, Secure, Connected, Consistent
	Dependable	Reliable, Relevant, Convenient, Helpful
	Meaningful	Meaningful
	Confident	Confident
	Acquainted	Friendly, Comfortable, Personal, Familiar
	Useful	Useful, Valuable
	Clean	Clean
	Essential	Essential
E	Good Design	Flexible, Customizable, Stable, Compatible, Accessible, Time-Saving, Comprehensive, Easy to use, Organized, Fast, Effective, Efficient, Straight-Forward, Responsive, Clear

	Logical	Understandable, Usable
	Instinctive	Intuitive, Effortless, Controllable
	Satisfying	Satisfying
	Anticipated	Predictable, Expected
	Simplistic	Simplistic
F	Appearance Positive, Emotion	Compelling, Appealing, Attractive, Inviting, Optimistic, Fun, Entertaining
	Encouraging	Engaging, Enthusiastic, Stimulating, Desirable, Motivating, Impressive, Inspiring, Exciting, Exceptional
	Innovation	Creative, Innovative, Cutting Edge, Novel
	Renewed	Fresh, Sophisticated
	Approachable	Approachable
G	Calm	Calm
H	Active	Energetic, Empowering

C. Unity CameraManagement Script

```
using UnityEngine;
using System.Collections;

public class CameraManagement : MonoBehaviour
{

    public float camOffset = 0.05f;
    public Camera camLeft;
    public Camera camRight;
    public Color skyboxColor = Color.white;
    public Vector3 lookAtPosition = Vector3.zero;
    public bool enableCameraLookAt = false;
    public int stereoMode = 1; // 0: none, 1: sidw by side (default) , 2: top/bottom
    Matrix4x4 cp;

    // Use this for initialization
    void Start()
    {
        DefaultOptions(); //sets initial common configurations to all display formats
        cp = GameObject.Find("camLeft").GetComponent<Camera>().projectionMatrix;
        Set3DCamMode();
    }

    private void Set3DCamMode()
    {
        switch (stereoMode)
        {
            case 0:
                MonoscopicCameraSetting();
                break;
            case 1:
                SideBySideCameraConfig(); //sets side by side camera parameters
                break;
            case 2:
                TopBottomCameraConfig();
                break;
        }
    }

    private void TopBottomCameraConfig()
    {
        this.camRight.enabled = true;
        this.camRight.pixelRect = new Rect(0, 0, Screen.width, Screen.height / 2);
        this.camLeft.pixelRect = new Rect(0, Screen.height / 2, Screen.width,
Screen.height / 2);
        cp.m11 *= 0.5f;
        camLeft.projectionMatrix = cp;
        camRight.projectionMatrix = cp;

    }

    void SideBySideCameraConfig()
    {
        this.camRight.enabled = true;
        this.camLeft.pixelRect = new Rect(0, 0, Screen.width / 2, Screen.height);
        this.camRight.pixelRect = new Rect(Screen.width / 2, 0, Screen.width,
Screen.height);
        cp.m00 *= 1f;
        camLeft.projectionMatrix = cp;
        camRight.projectionMatrix = cp;
```

```
    }

    private void MonoscopicCameraSetting()
    {
        this.camLeft.transform.position = new Vector3(0, 0, -40);
        this.camLeft.pixelRect = new Rect(0, 0, Screen.width, Screen.height);
        this.camRight.enabled = false;
        //aspect ratio.
        float nRatio = camLeft.pixelWidth / camLeft.pixelHeight;

        //Debug.Log("current ratio: " + nRatio);
        this.camLeft.aspect = nRatio;

    }

    // Update is called once per frame
    void Update()
    {

        if (Input.GetKeyDown(KeyCode.Z))
        {
            this.camLeft.transform.position = new
Vector3(camLeft.transform.position.x - camOffset, camLeft.transform.position.y,
camLeft.transform.position.z);
            this.camRight.transform.position = new
Vector3(camRight.transform.position.x + camOffset, camRight.transform.position.y,
camRight.transform.position.z);
        }
        else
        {
            if (Input.GetKeyDown(KeyCode.X))
            {
                this.camLeft.transform.position = new
Vector3(camLeft.transform.position.x + camOffset, camLeft.transform.position.y,
camLeft.transform.position.z);
                this.camRight.transform.position = new
Vector3(camRight.transform.position.x - camOffset, camRight.transform.position.y,
camRight.transform.position.z);
            }
        }
    }

    void DefaultOptions()
    {
        //defines the color of the skyboxes
        this.camLeft.backgroundColor = this.skyboxColor;
        this.camRight.backgroundColor = this.skyboxColor;

        if (enableCameraLookAt)
        {
            this.camLeft.transform.LookAt(lookAtPosition);
            this.camRight.transform.LookAt(lookAtPosition);
        }
        else
        {
            this.camLeft.transform.LookAt(new Vector3(0,0,int.MaxValue));
            this.camRight.transform.LookAt(new Vector3(0,0,int.MaxValue));
        }
    }
}
```

D. Experiment Data

6.1.1 D.1 Pairs Game

Participant ID	Stimuli	time to completion	Turns left	turns used	Task completed	efficiency	age	real efficiency		
0	2D	49	2	12	1	4.083333	31	4.083333	SD TIME	9.650522
1	2D	40	0	14	1	2.857143	27	2.857143	SD TURNS LEFT:	1.130668
2	2D	39	2	12	1	3.25	24	3.25	SD EFFICIENCY	0.766347
3	2D	50	4	10	1	5	38	5		
4	2D	35	3	11	1	3.181818	33	3.181818		
5	2D	37	0	14	0	2.642857	32	0		
6	2D	48	0	14	0	3.428571	27	0		
7	2D	36	3	11	1	3.272727	39	3.272727		
8	2D	53	0	14	0	3.785714	29	0		
9	2D	44	0	14	0	3.142857	31	0		
10	2D	42	2	12	1	3.5	34	3.5		
11	2D	69	0	14	0	4.928571	35	0		
12	2D	45	0	14	1	3.214286	28	3.214286		
13	2D	55	2	12	1	4.583333	21	4.583333		
14	2D	56	0	14	1	4	21	4		
15	2D	43	0	14	0	3.071429	21	0		
16	2D	48	1	13	1	3.692308	44	3.692308		
18	2D	44	1	13	1	3.384615	21	3.384615		
19	2D	50	0	14	0	3.571429	22	0		
20	2D	46	0	14	0	3.285714	26	0		

21	2D	38	2	12	1	3.166667	25	3.166667		
22	2D	55	0	14	0	3.928571	21	0		
23	2D	72	0	14	0	5.142857	26	0		
24	2D	44	0	14	0	3.142857	22	0		
25	2D	42	0	14	0	3	23	0		
26	2D	42	1	13	1	3.230769	29	3.230769		
27	2D	38	1	13	1	2.923077	31	2.923077		
28	2D	48	0	14	0	3.428571	30	0		
29	2D	73	2	12	1	6.083333	30	6.083333		
30	2d	44	0	14	0	3.142857	31	0		
31	2d	42	0	14	0	3	25	0		
32	2d	58	0	14	0	4.142857	22	0		
33	2d	43	1	13	1	3.307692	33	3.307692		
		47.51515	**0.818182**	**13.18182**	**17**	**3.621722**	**28.24242**	**1.900942**		
			3.604598							
0	3D	62	0	14	0	4.428571	31	0	SDTIME	8.63737
1	3D	41	1	13	1	3.153846	27	3.153846	SD TURNS LEFT:	1.37207
2	3D	46	0	14	0	3.285714	24	0	SD EFFICIENCY	0.725747
3	3D	43	2	12	1	3.583333	38	3.583333		
4	3D	40	0	14	0	2.857143	33	0		
5	3D	38	0	14	0	2.714286	32	0		
6	3D	47	1	13	1	3.615	27	3.615		

						385		385		
7	3D	48	0	14	0	3.428571	39	0		
8	3D	51	0	14	0	3.642857	29	0		
9	3D	34	1	13	1	2.615385	31	2.615385		
10	3D	38	1	13	1	2.923077	34	2.923077		
11	3D	45	4	10	1	4.5	35	4.5		
12	3D	48	0	14	0	3.428571	28	0		
13	3D	54	0	14	0	3.857143	21	0		
14	3D	58	0	14	0	4.142857	21	0		
15	3D	38	1	13	1	2.923077	21	2.923077		
16	3D	34	3	11	1	3.090909	44	3.090909		
18	3D	28	4	10	1	2.8	21	2.8		
19	3D	45	1	13	1	3.461538	22	3.461538		
20	3D	33	2	12	1	2.75	26	2.75		
21	3D	39	4	10	1	3.9	25	3.9		
22	3D	36	3	11	1	3.272727	21	3.272727		
23	3D	66	3	11	1	6	26	6		
24	3D	35	1	13	1	2.692308	22	2.692308		
25	3D	34	0	14	0	2.428571	23	0		
26	3D	40	3	11	1	3.636364	29	3.636364		
27	3D	39	1	13	0	3	31	0		
28	3D	37	3	11	1	3.363636	30	3.363636		
29	3D	45	3	11	1	4.090909	30	4.090909		
30	3D	35	1	13	1	2.692308	31	2.692308		
31	3d	33	1	13	1	2.538462	25	2.538462		
32	3d	42	2	12	1	3.5	22	3.5		
33	3d	45	3	11	1	4.090909	33	4.090909		
		42.33333	**1.484848**	**12.51515**	**22**	**3.406317**	**28.24242**	**2.278611**		

6.1.2 D.2 Garments Opinion

User ID	Stimuli	G1	G2	G3	G4								
								g1	1.166355	num1	0.337037	den1	0.288966
0	3D	3	5	4	4			g2	1.744017	num2	0.574074	den2	0.329168
1	3D	1	3	2	5			g3	1.75728	num3	0.52963	den3	0.301392
2	3D	1	4	3	4			g4	0.759029	num4	0.259259	den4	0.341567
3	3d	3	1	3	2								
4	3D	4	2	4	3			gAll	0.679609	numAll	0.425	denAll	0.62536
5	3D	4	3	4	4								
6	3d	4	5	2	2				NO CHANGE IN GARMENT OPINION				
7	3d	3	2	4	2								
8	3d	4	3	2	5								
9	3d	3	5	4	2								
11	3d	2	2	3	1								
13	3d	4	4	4	3								
14	3d	1	2	1	4								
15	3d	3	4	3	3								
17	3d	3	3	2	1								
18	3d	5	1	3	3								
19	3d	3	4	5	3								
20	3d	2	5	4	1								
21	3d	4	2	4	3								
23	3d	4	4	4	3								
24	3d	4	3	3	5								
25	3d	2	1	3	1								
26	3d	1	2	2	1								
27	3d	3	4	2	4								
28	3d	3	4	2	4								
29	3d	3	3	4	4								
30	3d	3	4	3	1								
31	3d	3	2	4	5								
32	3d	3	4	5	5								

33	3d	3	4	4	2							
30		2.96 6667	3.16 6667	3.23 3333	3	3.09 1667						
0	2D	3	5	3	4							
1	2D	0	3	1	5							
2	2D	0	2	2	3							
7	2d	3	2	4	2							
8	2d	4	2	1	4							
9	2d	3	5	4	2							
10	2d	4	3	4	3							
11	2d	2	1	1	2							
12	2d	2	3	2	4							
15	2d	2	3	2	2							
16	2d	4	4	3	2							
18	2d	4	1	3	3							
19	2d	3	4	5	3							
20	2d	2	5	4	1							
21	2d	4	2	4	3							
22	2d	4	3	3	3							
24	2d	4	3	4	3							
25	2d	2	1	2	1							
26	2d	1	2	1	1							
27	2d	3	2	3	3							
28	2d	2	1	1	2							
29	2d	3	1	4	4							
30	2d	3	2	1	1							
31	2d	3	1	3	5							
32	2d	2	3	4	4							
33	2d	2	3	3	2							
34	2d	2	3	1	2							
27		2.62 963	2.59 2593	2.70 3704	2.74 0741	2.66 6667						

6.1.3 D.3 SUS values and PRCs for Garment Catalog

Chosen words per user and SUS score per user

id	age	format	w1	w1	w2	w2	w3	w3	w4	w4	w5	w5	SUS			
2	21	2d	approacha	F	easy to us	E	helpful	D	intuitive	E	useful	D	85		t value sus	-0.39593
4	25	2d	boring	A	clear	E	fast	E	old	A	stable	E	92.5			
6	23	2d	accessible	E	boring	A	easy to us	E	ineffective	A	old	A	65			
8	35	2d	responsive	E	familiar	D	comfortab	D	attractive	F	approacha	F	95			
10	29	2d	comfortab	D	compatibl	E	easy to us	E	friendly	D	intuitive	E	85	A	16	
12	33	2d	clean	D	fast	E	energetic	H	time savin	E	unrefined	A	90	B	3	
14	28	2d	complex	A	dull	A	impersona	B	unattracti	A	usable	E	42.5	C	0	
16	28	2d	businesslik	B	easy to us	E	fast	E	simplistic	E	understan	E	87.5	D	13	
18	28	2d	advanced	D	customiza	E	desirable	F	friendly	D	empatheti	G	75	E	45	
20	22	2d	clear	E	consistent	D	easy to us	E	intuitive	E	understan	E	75	F	6	
22	29	2d	businesslik	B	easy to us	E	effortless	E	intuitive	E	usable	E	87.5	G	1	
24	31	2d	accessible	E	controllab	E	stable	E	unattracti	A	usable	E	82.5	H	1	
26	31	2d	boring	A	intuitive	E	not valuab	A	predictabl	E	simplistic	E	85			
28	29	2d	organized	E	stable	E	fast	E	friendly	D	fresh	F	77.5			
30	39	2d	clear	E	effortless	E	irrelevant	A	predictabl	E	dated	A	50			
32	35	2d	appealing	F	advanced	D	comprehe	E	clear	E	distracting	A	80			
34	29	2d	clean	D	straightfor	E	boring	A	usable	E	effective	E	75			
17													78.23529	14.2183		
1	21	3d	advanced	D	exciting	F	inspiring	F	powerful	C	stimulating	F	75			
3	25	3d	easy to us	E	exciting	F	fun	F	impressive	F	slow	A	90			
5	23	3d	attractive	F	connected	D	exciting	F	impressive	F	usable	E	65			
7	35	3d	attractive	F	impressive	F	innovative	F	creative	F	useful	D	82.5	A	3	
9	29	3d	businesslik	B	distracting	A	engaging	F	intuitive	E	timesaving	E	92.5	B	3	
11	33	3d	appealing	F	businesslik	B	fast	E	helpful	D	high qualit	D	87.5	C	2	
13	28	3d	controllab	E	effortless	E	intuitive	E	simplistic	E	innovative	F	85	D	17	
15	28	3d	advanced	D	businesslik	B	comfortab	D	easy to us	E	understan	E	90	E	19	
17	28	3d	advanced	D	creative	F	fun	F	innovative	F	stimulating	F	67.5	F	41	
19	22	3d	advanced	D	clear	E	fun	F	innovative	F	usable	E	65	G	0	
21	32	3d	advanced	D	creative	F	easy to us	E	predictabl	E	useful	D	75	H	0	
23	30	3d	advanced	D	attractive	F	comfortab	D	entertainir	F	helpful	D	90			
25	31	3d	attractive	F	creative	F	easy to us	E	not valuab	A	unconvent	C	82.5			
27	29	3d	attractive	F	innovative	F	fun	F	creative	F	clean	D	80			
29	39	3d	attractive	F	effortless	E	fresh	F	innovative	F	responsive	E	80			
31	32	3d	creative	F	innovative	F	fun	F	relevant	D	compatibl	E	70			
33	29	3d	advanced	D	cutting edg	F	attractive	F	creative	F	fun	F	80			
17													79.85294	9.034249		

Used terms:

3d		2d	
attractive	7	intuitive	5
creative	7	accessible	2
easy to us	4	clear	4
advanced	7	compatibl	1
appealing	1	responsive	1
exciting	3	usable	4
innovative	6	fast	4
inspiring	1	easy to us	6
fun	6	stable	3
fast	1	advanced	2
intuitive	2	compatibl	1
		understan	2
		simplistic	2
		comprehe	1
		effortless	2
		controllab	1
		customiza	1
		organized	1
			43