Faculdade de Design, Tecnologia e Comunicação
Universidade Europeia

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MATEUS MATHIAS DOS SANTOS BERGAMIN

DOING AUGMENTED REALITY: A DISCOURSE ANALYSIS

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Dissertação apresentada ao IADE - Faculdade de Design, Tecnologia e Comunicação da Universidade Europeia, para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Design de Interação, realizada sob a orientação científica da Doutora Ana Viseu, professora associada da *Universidade Europeia*.

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Palavras-chave

Realidade Aumentada; Head-mounted Display; Human-Computer Interactions; Design de Interação; Discurso.

Resumo

Desde o seu surgimento nos anos 90, a realidade aumentada (RA) tem sido referida como a sobreposição de objetos virtuais na visão do mundo físico, e tem consigo a promessa de mudar fundamentalmente a maneira como interagimos com o universo digital. No entanto, a realidade aumentada nunca foi capaz de atingir tais objetivos e, após o Google Glass Experiment em 2013, o que fica evidente é um conflito entre as visões da pesquisa e as expectativas do consumidor. Vendo que a realidade se faz por meio de práticas e decretos discursivos, esta tese examina como a RA é construída por aqueles que estão envolvidos em seu desenvolvimento, sua promoção e seu uso, por meio da análise textual e do discurso, com o objetivo de compreender a visão por trás de seu desenvolvimento. Analisamos primeiro o surgimento e desenvolvimento da RA, seguindo com a análise do Google Glass Experiment, como uma materialização da tecnologia. Levando em consideração o potencial de mudança de comportamento e estilo de vida no desenvolvimento de RA, entender os discursos e visões subjacentes é de importância crucial à medida que trazemos a tecnologia para nossa realidade. Como resultado, temos uma melhor avaliação da situação atual da tecnologia, bem como percepções para o desenvolvimento futuro e soluções no campo da realidade aumentada.

Keywords

Augmented Reality; Head-mounted Display; Human-Computer Interactions; Interaction Design; Discourse Analysis.

Abstract

Since its emergence in the 90s, augmented reality has been referred to as the superimposition of virtual objects on the view of the physical world, and holds a promise to fundamentally change the way we interact with the digital universe. However, AR was never able to achieve such objectives, and after the Google Glass Experiment in 2013, what is evident is a conflict between the research visions and consumer expectations. Seeing that reality is done through discursive practices and enactments, this thesis examines how AR is done by those who are involved in its development, its promotion and its use, through textual and discourse analysis, aiming to understand the vision behind its development. We first analyse the emergence and development of AR, following with the analysis of the Google Glass Experiment, as a materialization of the technology. Taking into consideration the potential for behavior and lifestyle change held in AR development, understanding the underlying discourses and visions is of crucial importance as we bring technology to our reality. As a result we have a better assessment of the current technology situation as well as insights for future development and solutions in the field of augmented reality.

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1. Introduction

Reality is done through discursive practices and enactments, that is, when we imagine and say things we are effectively bringing them into the world (Fairclough, 1997). Thus, the goal of this thesis is to examine how AR is done by those who are involved in its development, its promotion and its use. More specifically, we aim to understand the discourses and visions behind Augmented Reality development, and how they informed the development of the field and the configuration of the technology.

Augmented Reality (AR) is a term mostly used to refer to technologies that superimpose virtual information or artifacts on one's view of any physical environment. The first AR experiments were done in the 1960s, with Ivan Sutherland's head-mounted three dimensional display (Sutherland, 1968), but it wasn't until the 90's that the concept took off, together with Virtual Reality. At this point, AR was usually presented as an enhancement or aid for physical tasks, bolstering performance and efficiency in different contexts, such as medicine, manufacturing and maintenance. AR was also pointed as a possible answer for the changes in our lifestyle brought by the popularization of microcomputers. Personal computers were deemed to make everyday life more stationary by centralizing content and activities pertinent to both work and domestic environments. AR solutions arose as ways to bring back the user and information to the real world, and ultimately was seen as holding the promise to transform the way users interact and perceive both the digital and physical world.

Many years after its emergence, the dreams of AR continue to live on and are continuously re-materialized, most recently with the Google Glass Experiment, in 2013. However, Google Glass together with most other previously developed AR devices have failed to find an audience. The cited reasons are mostly the same: lack of practical and fashionable value, as well as concerns about privacy and user behavior. Despite being constantly promoted as the next revolution by visionaries and developers, screen-centered interactions remain the dominant format, and the pace of AR advancements is underwhelming.

The concerns surrounding AR development and the struggle for it to become a mainstream technology suggests there is a conflict between the developers' discourse and visions, and the realities of users. In an attempt to examine this gap, this thesis is organized around two main axes: the first explores the development of AR by examining the visions and concepts behind its development. The objective is not to build an exhaustive history, nor is it an attempt to organize or clear historical events. Instead, we seek to point out key milestones and paradigms that shaped augmented reality. We want to understand the process through which the concept of augmented reality stabilized: the main actors (human and nonhuman), recurring visions, main uses, as well as the main controversies and disputes. Then, in its second axis, we critically examine how AR materializes into a particular artifact. Here we strive to perceive the differences between the aforementioned visions and discourse behind AR development and particular materializations of the technology. We do so through a case study of the Google Glass Experiment, not only for the significance of Google as a trendsetter in technology development, but also for its influence and authority in the development of mainstream technology.

Since we do not have access to AR development - historical or contemporary - the primary means of data collection and analysis is discourse and text analysis. This dissertation does not follow an orthodox structure, instead It is organized in the following way: The first chapter details the methods and frameworks utilized for the analysis; The second chapter is an archeology of the development of AR, discussing its emergence and stabilization; The third chapter consists of the case study of the Google Glass Experiment, discussing the translation of AR discourses and vision into a particular artifact, and explore remaining gaps and problems. Finally, in the fourth chapter we present the conclusions and contributions of this study.

Seeing that interaction is a central, not peripheral, point in technology development (Krueger, Gionfriddo & Hinrichsen 1985), the discussions on the process of construction of a technology are relevant to interaction design. Furthermore, exposing and exploring the points of friction in the development of AR between developers' approaches, the artifacts they provide and their implementation, is an important contribution to interaction design. Interaction designers have a critical role in the construction and configuration of technology, as translators of technical knowledge into usable devices and services, and consequently as shapers of reality. Considering the potential for behavior and lifestyle change held by AR, understanding its underlying discourses, visions and materializations is of crucial importance as we create new technology. This thesis then contributes and creates a fruitful conversation between the fields of AR and Interaction Design.

2. Methodology

In this study the analysis is divided in 2 parts: An archeology of augmented reality and a case study of the Google Glass Experiment. Aligned with Foucault's archeological approach (Foucault, 2013), to examine the developers' discourse and visions, and the artifacts that materialize them, this study utilizes as its primary methodology discourse, textual and historical analysis.

Text analysis is ideal to obtain an informative and critical synthesis of a particular topic, as it can identify what is known in the subject area, identify areas of controversy or debate, and help formulate questions that need further assessment (Bolderston, 2008). While most qualitative research probably is based on interviews, "naturally occurring" materials such as written texts and recordings also constitute important specimens of the topic of the research and the analysis of these materials puts the researcher in direct contact with the object they are investigating (Peräkylä & Ruusuvuori, 2018). Also, because the research object covers a long span of time as well as historical events, studying already published texts and recorded material is a reliable and efficient approach to explore the themes and visions in the development of AR.

Discourse analysis is, in this particular context, the examination of structures of meaning, expressions, themes and rhetorical devices used in constructing reality (Cunliffe, 2008). Discourse analysis excels in analyzing the aforementioned "naturally occuring" materials, in particular ones resulting from everyday contexts, such as conversations, news, written documents, and social media interactions. Thus, this method is ideal to put in evidence the discrepancies between the envisioned roles for AR by the developers, their materializations and use, through the identification of recurring themes and expressions.

Finally, historical analysis is a method of examining historical material and events to achieve a better understanding of the past (Bricknell, 2008). This method is a good fit to this study as our goal is to have a better understanding of the visions, discourses and context of AR during its emergence. Historical and textual analysis often represent the literature review chapter of a dissertation, as it explores the state of the art and what has been done until the moment. However, in this study the historical and textual analysis consist the main body of the research.

The analysis was guided by the following questions: (1) What are the objectives of the studies (2) What are the roles envisioned and/or designated to AR?; And (3) How is AR defined? Focusing on the definition of the term, and on the developers' visions and their objectives, these questions allow the perception of the purpose behind the development of AR and the envisioned roles for the technology.

Data generation was done through online database searches, using B-on, arXiv, ACM and IEEE Xplore databases - as well as through Google searches - with the expressions: "augmented reality"; "mixed reality"; and "head mounted display". Data was primarily selected based on the total number of citations and/or position in the search results. Selected data included conference papers, journal articles, magazine articles, books, book sections, patents, reports and online media news and posts. Also, additional relevant material was found by backtracking references in the results of the primary search method, in similar fashion to a methodology frequently used in the social sciences commonly known as snowball sampling method (Morgan, 2008). It is important to note that some of the data collected is prior to the formulation of the actual concept of Augmented Reality, but later material continuously refers to it, and therefore, it is used for contextualization and background. Relevant events were then identified and examined, building a historical and discursive development of augmented reality that is, noting emerging themes, points of convergence and divergence between the actors in the field.

Having conducted the discourse analysis, we then proceeded to conduct the case-study of the Google Glass Experiment. Case studies are indicated for the exploratory study of issues about which little is established knowledge, such as the case of augmented reality. Case study research is effective in approaching phenomena that are ambiguous, fuzzy, even chaotic, dynamic processes rather than static or deterministic ones, and includes a large number of variables and relationships which are thus complex and difficult to overview and predict (Gummeson, 2008). However, this case study was not done through collecting empirical material such as interviews, but through textual analysis. While it is not an ideal approach, given that years have passed since the experiment, there is a plethora of "naturally occuring" material produced and collected by others, that are objects of interest for discourse and textual analysis. One of the limitations of single-case studies is that while affording in-depth knowledge they do not allow for generalization, because statistical techniques do not apply (Kennedy, 1979). We are aware of this and yet, different scholars have argued that technologies are materializations of beliefs, values, social organizations, visions and practices (Fleming, 1974; Latour, 1991; Prown, 1982). Thus, while not attempting to generalize, in the scope of this dissertation the Google Glass stands as a materialization of the discourses and visions analysed in the previous section, and as such, its study contributes to a more in-depth understanding of the field as a whole.

The analysis of the Google Glass Experiment is guided by the following questions: (1) What was the envisioned role for the device? (2) How did users utilize the artifact? And (3) how was AR defined within the experiment? These questions allow us to better understand how the visions and discourses pointed out in the previous section translated into a product for the open world. The goal here is in line with Foucault's archeological approach, that is to understand discourses within the context where they were generated, or what was actually said and done in relation to other things that were said and done.

For this section, data generation was done through online database searches using B-on and arXiv databases, and through Google searches, with the expressions: “augmented reality”; “smart glasses”; and “google glass”, with additional material collected through the snowball sampling method (Morgan, 2008). Data was primarily selected based on relevance, meaning the total access number and/or position in the search results. Since our focus was on building the public perspective of the experiment, the emphasis on the “naturally occurring” material, being mass media content and individual experiences with the device, rather than academic material. Selected data included journal articles, magazine articles, magazine news, website and social media posts. It’s important to note that Google engine organizes the search results based on an internal algorithm. Therefore, considering we are analyzing Google Glass as a representation of Augmented Reality discourses, analyzing data sorted by Google can be interpreted in some degree as the company’s vision of Augmented Reality.

3. An Archeology of Augmented Reality

3.1. Background

The first known instance of a device that resembles what today is discerned as Augmented Reality is that of the "Character Marker", which appeared in L. Frank Baum's fiction novel The Master Key: An Electrical Fairy Tale, Founded Upon the Mysteries of Electricity and the Optimism of Its Devotees, in 1901. In this story, the protagonist is an electrical experimenter that is confronted by the Demon of Electricity, after accidentally touching the master key of electricity. The Demon of Electricity awards him three weekly gifts for three consecutive weeks, nine devices in total. One of those gifts is a pair of spectacles capable of displaying indications of other people's character, such as wisdom and kindness, on their forehead, providing an edge for our electrical experimenter. While Baum wrote this story in the context of fiction, it indicates an early desire for access to extrasensory information in a unobtrusive and efficient format, being remarkably close to modern day approaches to the technology.

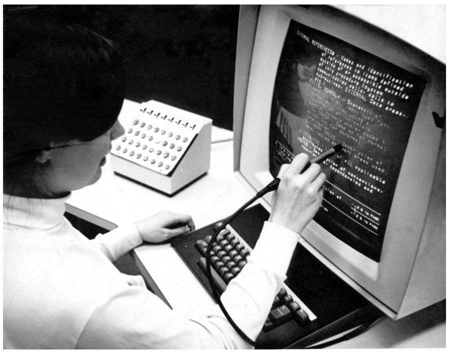
It would be more than 50 years before discussions and the driving ideas about merging digital information into the physical world start to appear. In the 1960s, a post war period which sees a world largely recovered, with increased wealth and production, there is a growing interest in faster training, and in performance and productivity enhancements to feed the thriving economy. It is also when the Cold War between the USA and the USSR starts to gain traction, and the arms race draws attention and investment from government agencies in technology. The military was by far the most significant sponsor of university science research in the United States, with involvement of the Defense Advanced Research Projects Agency (DARPA), Office of Naval Research (ONR) and National Aeronautics and Space Administration (NASA), boosting electronics research and manufacturing. While the involvement of the military is aligned with the increasing interest in efficiency and performance, it's important to note this has other implications in the development of technology, for their prime objectives of control, power and supremacy permeate the configurations and envisioned roles for the systems and devices (Edwards, 1996).

Around this same time, we start to witness a development from the computing mainframe model to microcomputing, becoming affordable for the general public in the

1970s with the mass production of the microprocessor starting in 1971, leading to a transformation in modern society. First models of personal computers were capable of computation, text editing, multimedia display, and communication, being recognized as powerful and accessible tools for work and individual use (Horn & Winston, 1977, p. 11). Microprocessors also became part of embedded systems, providing digital control over myriad objects and industrial processes. Since computers required very specialized knowledge for their operation at the time, this development brought attention to a need to close the gap between humans and computers, which gave way to the discussions about data access and manipulation, and human-computer interactions (HCI).

Figures 1 & 2 - IBM mainframe, 1960s (left) and Hewlett-Packard 9100A, 1968 (right).

Ivan Sutherland, a pioneer in HCI research, briefly discussed in an exploratory manner possible methods of interaction and their fitting to display technology, in his article The Ultimate Display (1965). The author notes that the keyboard is normative in human-computer interactions, and then outlines other existing peripherals and their possible uses, such as knobs, joysticks and lightpens (Figure 3), or tablet pens - in particular the RAND tablet, from RAND Corporation, 1964 (Figure 4). Lightpens are devices that resemble a normal pen, but can detect the surface they are touching and transmit signals to the computer, making it possible to point information directly on the computer screen and edit information in a more natural way, similar to our regular act of writing. Sutherland further states that the easiness of interaction with computers using such devices is remarkable, despite their potential being only marginally explored at the time. This array of controllers presented by Sutherland describes how data can be controlled using actions and gestures that most people already have incorporated in their daily lives, increasing the ease of use and approaching the computational world to the physical world.



Figures 3 & 4 - Lightpen,1969, and The RAND tablet, 1964.

While discussing more ideal methods of interactions with machines, Sutherland states that the display should serve as many senses as possible (Sutherland, 1965). While he recognizes the limitations of incorporating smell and taste to digital interactions, he proceeds to conceptualize the kinesthetic display, by describing haptic, force feedback, and motion tracking technology, and how those could be incorporated in the display interaction model. Adding more sensory information to computers and virtual objects closes the distance between the digital and physical worlds, but also could bring drastic changes to the interaction paradigm. For instance, Sutherland suggests a 'language of glances' as a possible way to control computers, seeing that the human eye has really high dexterity and computers with adequate sensors would be able to detect such movements. For him, these modes of interaction would not only lead to new ways of controlling machines but also better understanding of our own senses. Finally, Sutherland adds that his concept in its final form would be capable of manipulating physical matter to display digital artifacts in the physical world:

> *The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked (Sutherland, 1965).*

In this concept, It is important to note the use of the word display, which implies that in this context physical matter itself is considered as medium, whereas the existence and properties of objects within his apparatus would still be determined by software. Sutherland does not mean to simply build physical objects based on virtual models, but to add physical properties to virtual artifacts, changing the way they are perceived and interacted with in the physical world. The ultimate display conveys the desire to access virtual objects beyond the limitations of a regular screen and our sense of vision, effectively bringing them to reality, thus merging virtual and physical worlds.

With the objective of surrounding the user with information, and also sponsored by the United States Office of Naval Research with support from DARPA, Sutherland's research led to the creation of the first head-mounted display with three dimensional graphics and see-through technology (Sutherland, 1968), considered by many to be the starting point of Augmented Reality development (Feiner, MacIntyre, & Seligmann, 1993; Krueger et al., 1985). The system consisted of a device that was able to display three-dimensional virtual artifacts that change according to the user's point of view, position and movement in the physical environment, giving the impression of being present in such space. The device freed users from a static position while the HMD format also kept their hands free, allowing them to perform tasks that required moving or the use of controllers and tools, an unparalleled level of interaction at the time.

Figure 5 - Head mounted three dimensional display by Ivan Sutherland, 1968.

Seeing that the purpose of the system was the observation of digital objects with very limited interaction, the structure of the system was rather large for the desired result, as we can see in figure 5. Making use of mainframe computers, a mechanical arm and sensors to detect head movement, and the HMD prototype, the system went way beyond the boundary of spaces usually occupied by a computer terminal or the human head. However, the translation of the massive infrastructure to the head-mounted display format made the machine itself invisible, by overlaying the information directly on the user's view, effectively merging the virtual and physical world. According to Sutherland (1968), results showed that users quickly adapted to the displayed information, moving naturally to adequate positions for a desired view, and also responses towards the realism of stereoscopic imaging. We will see, though, that devices of this nature are majorly rejected when released to the public, thus questioning Sutherland's predictions.

Richard Bolt, Principal Research Scientist at MIT, conducted studies about human-computer interaction and data manipulation in the 1970s, , tackling an issue that has riddled the computing world for years, namely: How do we find, organize, and manipulate data in a digital age? To answer this question, he introduced the concept of Spatial Data Management, as a way to use virtual space and spatial awareness to organize and manipulate information (Bolt, 1978). Bolt's concept was based on observations that, for example, when an individual looks for a book in a private collection, it is often found by cues in the space itself, like it's position on the shelf and the other books around it, rather than the book's title or author (Bolt, 1978; for more, see also Houston, 2012). To demonstrate the concept, experiments were conducted using a media room, pointed by the author as "an image of the office of the future", named Dataland, an interactive space with a variety of controls for navigation and data manipulation, including joystick, touchscreens, and in the later study "put that there" (Bolt, 1980: pp 262-270), voice and gesture recognition. As we can see in figure 6 below, while the computers have a reduced size, with the infrastructure minimized or partially hidden (the projector behind the big screen), the system occupies the whole room, surrounding the user. Seeing that this study was (also) sponsored by the ONR and DARPA, another interesting aspect of the system is the size of the screen and the single prominent chair impling a position of power and control, and not a workspace as Bolt suggested, resembling much of security and surveillance positions.

Figure 6 - Dataland, Massachusset's Institute of Technology, 1978.

The study's results showed that users were able to quickly learn and navigate the proposed environment, with reduction in cognitive load and gain in "naturalness". The experience of data manipulation is enhanced by using a virtual space (desktop) and the space around the user for information arrangement and hierarchy, and joysticks and touch screens for different gestures and actions as inputs to the operation of the system, being deemed as more "natural" in comparison to the default keyboard method. Similar to Sutherland's HMD, this study brings to evidence the advantages of escaping the limitations of a static display and keyboard interactions to manipulate digital information, by spreading information around the user and providing familiar interactions. In addition, Nicholas Negroponte, the visionary who would later become the face of MIT's Media Lab, wrote in the prologue of Spatial Data Management (Bolt, 1978) a prophetic vision about how user experience, rather than the technical aspects of a computer, would become the most significant factor in human-computer interactions. He states that the new interface from Dataland will bring computers to important political and social figures as well as to children, an important assessment seeing that the system is seen by many as the precursor to the Macintosh OS (Houston, 2012). This implied not only that computers would reach a point that even children, which can be considered very unspecialized users, would be able to operate the machines, but they would do so at the same level as important social figures, which changes the dynamics of power and interactions across different levels in the social paradigm. He further writes:

Such startling advances and cost reductions are occurring in microelectronics that we believe future systems will not be characterized by their memory size or processing speed. Instead, the human interface will become the major measure, calibrated in very subjective units, so sensory and personalized that it will be evaluated by feelings and perceptions. Is it easy to use? Does it feel good? Is it pleasurable? (Negroponte, 1978)

Myron Krueger, an important contributor for the development of Virtual Reality (VR) also, argued that more 'natural' digital interactions would make computers easier to use outside research environments and the computer science bubble (Krueger, 1977, see also Krueger et al., 1985). But his motivations came from a lack of interesting and amusing ways to manipulate computers and virtual information rather than a quest for efficient digital interactions, leading to a different approach to the issue. Discontent with the limitations in computer interaction at the time, he writes:

Man-machine interaction is usually limited to a seated man poking at a machine with his fingers or perhaps waving a wand over a data tablet. Seven years ago, I was dissatisfied with such a restricted dialogue and embarked on research exploring more interesting ways for men and machines to relate. The result was the concept of a responsive environment in which a computer perceives the actions of those who enter and responds intelligently through complex visual and auditory displays (Krueger, 1977, p. 423).

It points to a concern about how the relationship between users and computers is being shaped by dull methods of interaction. By the use of the term man-machine interaction, it recalls production lines, repetitive tasks and minimal, discrete interactions, but with devices that now have immense power over media and information.

Krueger's concept of Responsive Environments (Krueger, 1977, p. 423, see also Krueger, 1985), is of computer generated contexts that play with the user's expectations by performing unexpected interactions based on the user's actions. The environment senses and responds "intelligently" to the user with visual and auditory displays, creating a hybrid interactive space where real and digital worlds coexist. While what intelligence is, or is not, is never acknowledged, its value is unquestionably positive.

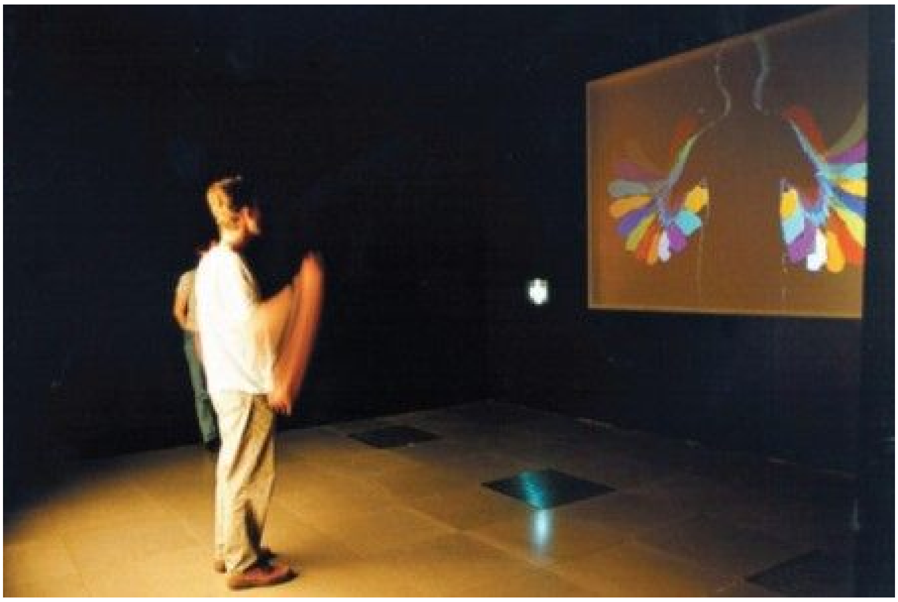


Figure 7 - VIDEOPLACE by Myron Krueger, 1985.

Krueger states that these experiments give rise to "an interactive art form" (Krueger, 1977, p. 423), as it creates a new level of interaction between artists and their audiences. The user is now a performer, a crucial part of the piece, as the system responds to the user inputs, with the power to change and adapt to given attention and interest. The system has extended chances at communicating with the audience, overcoming the one-shot, hit-or-miss character of art, providing not just a new meaning to the art piece, but to the relationship between computers and the physical world. Krueger also states that Responsive Environments could be used beyond art, suggesting "education, psychology and psychotherapy" as possible fields of application, steering away from common ideas in the computer sciences, about efficiency and productivity. What is envisioned is a new role for the machines, beyond the standard data manipulation, as mediators of the space surrounding the user, reacting to their physical and psychological states, and redefining conditions of the environment.

The general concern in the development of computers is often their technical capabilities, such as processing power, memory, and the activity they are made for. The studies mentioned however can be characterized as exploratory approaches, not a common sight in the field of Computer Sciences (Krueger et al., 1985), that focus on stretching the dialogue between humans and machines rather than solving any specific problem. While advantages in the addition of familiar, intuitive gestures and interactions from the human universe to the virtual world come to evidence, what is envisioned is the usefulness of the space surrounding the user for potential interactions, extending the reach of the digital universe beyond the boundaries of machines' displays and keyboards, into the physical world. This new paradigm of interaction reconfigures the relationship between humans and computers, as the lines of the physical and digital environments start to become blurred, whereas the implications of such vision are still unfolding.

3.2. The Emergence of Augmented Reality

With the release of the first mass marketed models in 1977, and the advent of the internet in the 1980s providing the critical communication capabilities, computers became popular devices in homes and workplaces alike. While the keyboard and display combo remained the default method of interaction, many concepts of the physical world made their way into the design of human-computer interactions. The computer background is referred to as a desktop, where files can be arranged and organized in the virtual space or using folders, peripheral devices are used as pointers to click, drag and drop virtual objects, and actions are named as cut, copy and paste, metaphors for corresponding actions in the physical world.

At the same time, striving from the advancements in computer hardware and power, from the demands for training and performance enhancement and potential uses in entertainment, the world of simulation took significant leaps forward, with virtual reality (VR) establishing itself as a field of research. The term, coined by Jaron Lanier, CEO of VPL and visionary in virtual reality development, was used to refer to projects that provide immersive experiences of simulated environments. The systems usually involve data manipulation using head-mounted displays and other controllers such as a reality glove (Krueger, 1991; see also Wright, 1987; Zimmerman, 1983), bringing much of the interactions present in the physical world into the digital universe. The potential of virtual environments for tasks in remote environments, and as a tool for creativity and communication between people made VR recognized as game changing technology (Wright, 1987).

With nuances of the virtual universe growing more complex and rich in content, computers dominate home and work environments by containing much of the relevant information and performing most activities pertinent to those contexts, drastically changing our everyday lives. The immense power of computers to manipulate and process data, as well as the convenience of the digitization of information made computers an essential device to desktop workers, giving way to dreams of, for instance, the 'paperless office'. The concept was a massive failure, as computers, together with more modern and efficient printers, facilitated creating, sharing and printing more documents. At home, computers were powerful tools for studying and working remotely, as well as a font of entertainment. But even while carrying over many concepts of the physical universe in its design, the interaction paradigm with computers made life a lot more stationary, dedicating a lot of time and effort to sit on a desk, looking into a screen and clicking buttons. In this context is manifested a desire to take the digital universe and the power of computers away from the desk, to different areas and activities, and with them the user, bringing them back to the 'real' world. It is at this point that we see the emergence of augmented reality.

The term "Augmented Reality" was coined in 1992, by Thomas Caudell and David Mizell (1992) who first used it in a project they developed for Boeing, envisioning a system that sought to overcome the need for physical guides and information access on the manufacturing space, arguing that it would minimize errors and increase production efficiency. Created with the objective of enhancing performance of non-automated tasks, the system consists of a see-through HMD that senses the environment and the objects present at the scene, then displays virtual instructions for the respective activity over the user's view (Figure 8).

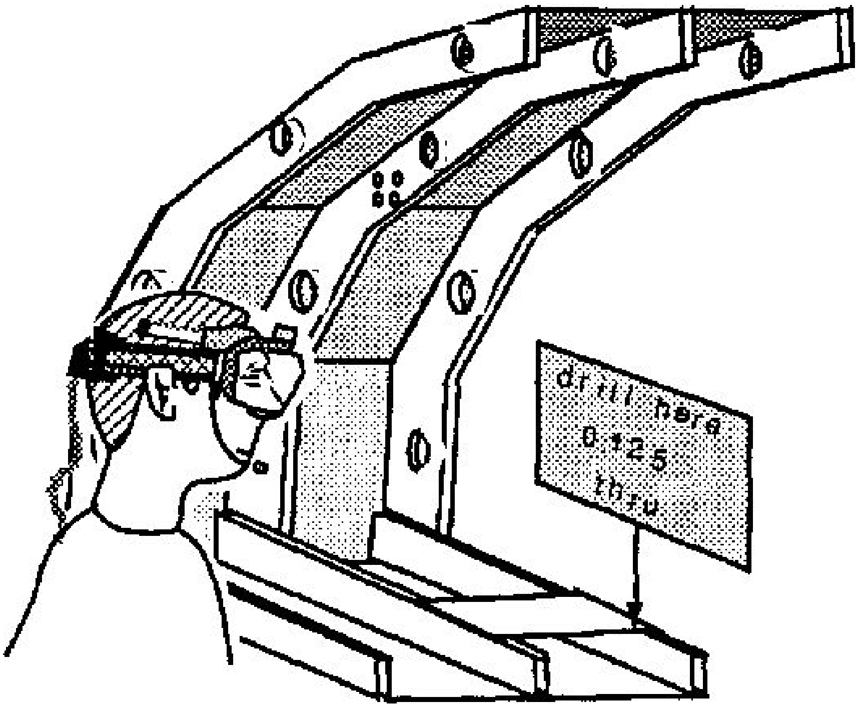


Figure 8 - Diagram of “Augmented Reality”, by Thomas Caudell and David Mizell, 1992.

A noticeable aspect of Caudell and Mizell’s study (Caudell & Mizell, 1992) is the system configuration, that does not seem practical or very natural for the user, which is somewhat conflicting with the initial quest for more natural interactions that led to AR development. The mess of wires strapped around the operator (Figure 9) seems to add a new layer of complexity to what can be considered a simple task, of making holes and tightening screws.

Figure 9 - Researcher demonstrating the Augmented Reality prototype, Boeing, 1992.

Besides the change to user's perception, It also brings a significant impact to the users reality in terms of the configuration of the work environment and how the user is perceived by their peers. In addition, while the study is sponsored by industry investment, Boeing has a profitable relationship with the military sector as a major supplier for the USA air force. Nevertheless, there is a shift in priorities, once the system is applied to the benefit of the company behind the research and not the system's user, even more considering the user also has little decision power in this context. Seeing this as the pioneering study in augmented reality technology, the shift in priorities and the requirements for AR systems conditioned following development.

When arguing for the use of the term 'augmented reality', the authors state the following:

> *This technology is used to "augment" the visual field of the user with information necessary in the performance of the current task, and therefore we refer to the technology as "Augmented Reality" (AR). (Caudell & Mizell, 1992)*

The term is presented in a vague and descriptive manner, lacking a proper definition and relying on the system properties and features for its meaning. It sets system configuration or features as requirements to be classified as AR, while also not offering insights on the experience or effects of the use of such systems. While Augmented

Reality (Caudell & Mizell, 1992) was the debut of the term that would later refer to the whole field of research, the descriptive nature of the first definition made room for earlier systems that had similar configurations to be classified as such. An example is Virtual Fixtures, created by Louis Rosenberg (Rosenberg, 1992), which consists of a virtual interface that is used for aiding in remote telerobotic operation, overlaying virtual guides on the user's view of a physical environment. Like many of its predecessors, Virtual Fixtures had the main objective of increasing the performance in the execution of tasks in remote environments, and was funded and aimed for the use in military contexts, thus continuing a long tradition of collaboration between the field of VR (and now AR) and the military complex.

Figure 10 - Demonstration of Virtual Fixtures, by Louis Rosenberg, 1992.

The project made no use of the term 'augmented reality' and was originally created under the umbrella of virtual reality, being applied to a telepresence device. When presenting the theme of telepresence, which stands for the sense of presence in a remote environment, Rosenberg points out the importance of transparency in such systems and finding ways to deliver information more naturally to the operator to achieve that goal. However, while not striving for the transparency aspect, his system could be able to expand and enhance the operator's ability beyond their natural capabilities, by providing extra sensorial information. (Rosenberg, 1992).

This development brings up interesting discussions to AR development as it establishes itself as a field of research, indicating overlapping aspects with the field of VR, and ambiguity in experiences from both fields. VR systems strive to make simulated worlds seem like they are real by manipulating the user's perception through hardware. AR, by the same means, changes and enhances the user's perception of the physical environment. While both studies mentioned enhance experiences in the physical world, one enhances the perception of the user's immediate surroundings and the other enhances the sense of presence in a different environment, even if not virtual, cutting the user from the surrounding space. Thus, in this first definition of AR, we can infer that reality is regarded as any scene in the physical world, that the user or the system can perceive, as opposed to an artificially generated or digitally modified environment. This is a drastic simplification of the concept of reality, considering that it comprehends more than just what the eye can see. It is not to say though that the user's reality is not augmented, but AR presents itself rather as a system-oriented concept, that makes it easier to explain devices and mechanisms, but does not offer anything about the experience or impact of their use.

James Steuer, a VR researcher, pointed the problem of system focused definitions for the field of Virtual Reality, as well as its consequences for other areas outside the material conception of those systems:

> *A device-driven definition fails to provide any insight into the processes or effects of using these systems, fails to provide a conceptual framework from which to make regulatory decisions, fails to provide an aesthetic from which to create media products, and fails to provide a method for consumers to rely on their experiences with other media in understanding the nature of virtual reality (Steuer, 1992).*

The descriptive nature of the first conceptualization of Augmented Reality points to a similar path, leading hardware to become a defining aspect of the technology. While there is somewhat interest in the seamless interaction between virtual information and the physical world, the vision shifts from the earlier exploratory discussions about the human-computer interaction paradigm to a more pragmatic approach, to aid in the performance and efficiency in specific tasks. Also, technology is used to enhance the user's sense of vision, changing his perception of reality, but leaving the environment itself unchanged. Virtual and physical are superimposed, and not merged, an illusion to an individual perception, to be seen as real and not to be part or integrated in the physical world. This vision not only informed systems configurations, but also objectives for the field, and ultimately boundary definitions and the form augmented reality is presented to the world.

3.3. Drawing Boundaries

With AR definition describing mostly hardware, that being specifically the use of see-through head-worn displays to overlay graphics on the physical world, projects working with similar configurations adopted the term. Development however is decentralized, with studies spread across different institutions, as it is possible to find many studies through snowball data collection, but individual databases show few results. For instance, the ACM and IEEE Xplore databases show 0 results for 'augmented reality' in the year 1992, and 6 results for the years 1993 and 1994 altogether. Nevertheless, with the expanding number of projects using the terminology, the process of demarcation of the field of augmented reality started to take place. This process can be observed through boundary works (Gieryn, 1983), that is, the process where professionals attempt to create an identity by creating boundaries and borders from other disciplines, to also secure material and symbolic resources, as well as scientific authority.

The Communications of the ACM is a source of such works, as it stands on the boundary between science magazine and scientific journal, providing peer reviewed material, but also summarized research, news and opinions suitable for a broader audience (*About ACM Publications*, n.d.). In the particular year of 1993, the 36th volume of the magazine had a special issue about computer augmented environments, (Wellner, Mackey & Gold, 1993), examining the merging of electronic systems and virtual information directly into the physical world to augment its properties. Introducing the publication, the editors bring to attention the changes computers had brought upon the office context, indicating the aforementioned approach as a possible answer to those changes. With computing resumed to sit in front of a machine and execute tasks formatted to overlapping windows, there is a concern to bring the individual back to the 'real' world, by connecting the digital world to the diverse spectrum of interactions we have with the physical environment. While the main discourse of bringing technology to the physical world is similar to earlier studies, this approach places human behavior and user experience in the center of the discussion. It does not mean to simply propose a better use of technology, that enhances efficiency and performance, but interesting computer interactions that strive to make our lives better, looking at everyday environments and activities asking how their capabilities could be augmented. It is an important step in defining experiences AR can deliver and its role in our daily lives, centered on the user and not on the technology itself.

Computer augmented environments are presented in contrast with VR, noting it's an attempt to enhance the real world instead of replacing it (Wellner et al., 1993). They also recall the Augmented Reality concept and the approach of embedding computers into the objects and environment surrounding the user, known as Ubiquitous Computing (Weiser, 1993), terms that have been used in most recent works in the field. While pointing out they differ in methods, the authors state the concepts share the same goal: the primacy of the physical world and the construction of appropriate tools that enhance our daily activities (Wellner et al., 1993). At this moment, with the term appropriated by other studies focusing on hardware properties and specifically about the use of see-through head-mounted displays, communicating the experiences provided by AR systems and adjacent technology is done by comparison with other known similar or opposite experiences, what leaves an impression of antagonism towards VR, despite the ambiguities between the fields presented by the previous studies.

With AR presenting itself to the open world, specifically to the office environment where the authors foresee promising applications, came together industry investment from companies such as IBM, Xerox and Hewlett-Packard, breaking the dominance of the military complex in the field. While this further informs objectives and configurations for AR development, aiming for specific segments and contexts with their systems, it helps bring technology closer to open world scenarios and applications, helping with the process of translation from research to practical value for the final user. It is also acknowledged the social impact that such systems would bring to the workplace and home environments, a theme that needed more study since most studies were dedicated to technical aspects of the technology, leaning away from the usual techno-centric approach in the field.

Among the works published in that same issue of Communications of the ACM (Wellner et al., 1993), Feiner, an important voice in the development of computer graphics and user interfaces, together with MacIntyre and Seligmann, present their approach with Knowledge Based Augmented Reality (S. Feiner et al., 1993). They introduce AR as an opposed concept to VR, that presents a virtual world that enriches, rather than replaces, the real world, annotating reality to provide valuable information, such as descriptions of important features or instructions for performing physical tasks (Feiner et al., 1993). In comparison with the first definition provided by Caudell and Mizell, there is no longer emphasis on hardware configuration at first, but still has a descriptive nature, telling what AR does, not what it is, remaining a device-driven concept. The authors refer to the concept of Ubiquitous Computing (Weiser, 1993) and extend that vision to include see-through (and hear-through) wearable displays to craft AR experiences that break the limitations of screens in static or mobile devices. While this reinforces the use of see-through technology as an essential part of AR systems, there is not a limitation to the sense of vision, which means a small change in the notion of what reality represents inside this context. In addition, their definition carries some roles for the technology, that is annotate reality and display instructions, what they consider a great potential for the use of technology: provide explanations and assistance to complex 3D tasks. Their vision is illustrated in their system KARMA - Knowledge-based Augmented reality for Maintenance Assistance - a HMD see-through display that shows information and instructions for maintenance of office printers.

Figure 11 - KARMA, by Feiner, MacIntyre and Seligmann, 1993.

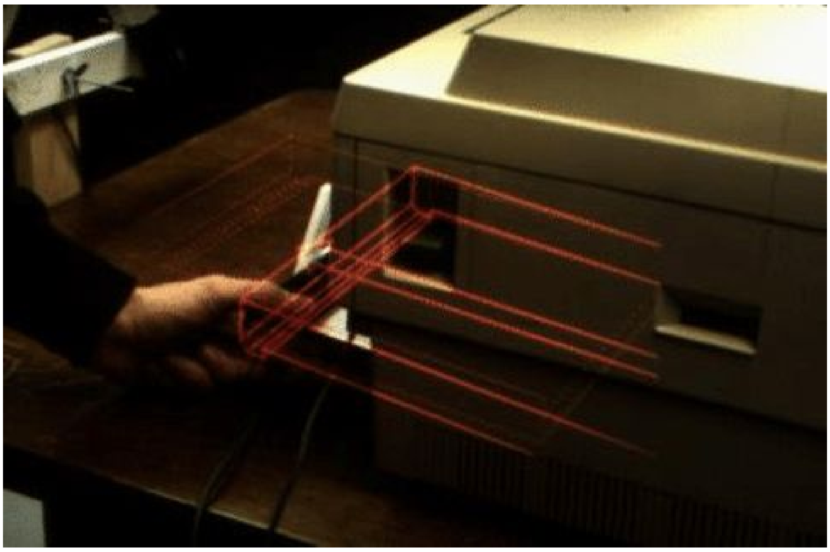


Figure 12 - User view, KARMA, by Feiner, MacIntyre and Seligmann, 1993.

Probably one of the first systems to be seen by (or directed to) a broader audience, and we can see how the system infrastructure is reduced and more streamlined in comparison to its predecessors, despite presenting foreign objects, the tracking sensors, to the context. It is also interesting how this system occupies space not only on the user's body, as the HMD, but also in the environment, bringing significant changes to the space of its use.

The HMD format was not, though, the only approach introduced with the concept of computer augmented environments. Wendy Mackay presented her vision "Augmenting Reality: Adding Computational Dimensions to Paper" (W. Mackay et al., 1993), vocalizing her frustration towards the myth of the "paperless office" and outlining possibilities of paper augmentation. She presents her projects Digital Drawing Board and Mosaic, focused on image manipulation and storyboard design, exploring possibilities for designers and artists to add digital interactions and information to their analog work.

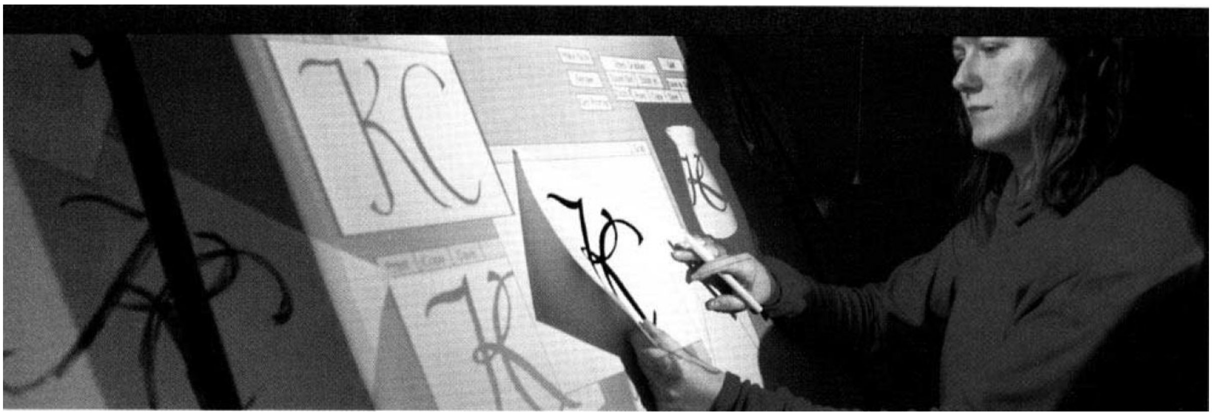


Figure 13 - Digital Drawing Board, by Mackay, 1993.

Figure 14 - Mosaic, by Mackay, 1993.

These projects offered more complex interaction in terms of data manipulation, with interactive virtual objects instead of just virtual guides and interfaces to physical tasks, as seen in the other approaches. Also, these didn't make use of HMDs, but displayed information directly in the environment, providing multi-user interactions and easier to share experiences, following closely the proposed philosophy of computer augmented environments. This poses a significant difference in terms of user perception, as information is not superimposed on their field of view, thus not surrounding the user and remaining contained in the boundaries of the projections. It is arguable however that multiple projections could provide coverage for the whole space, and considering the interactions would be available for all present users, a much more adequate representation of an augmented environment in comparison to individual HMD based systems.

Mackay's vision points to another paradigm in the development of AR technology, with emphasis in enhancing the properties and behavior of physical world objects and environments with digital information instead of directly changing the user's perception. In addition, the meaning of reality is broader, related to the physical environment and its contents themselves, the collective construction that is real for multiple actors, rather than to individual perception or any raw information captured from the physical world. Interesting enough, Mackay does not refer to her systems as augmented reality, despite augmenting the capabilities of the physical world with digital information, another indication that the term is not related to effectively enhancing the properties of the physical world, but to the specific method of using through see-through HMDs to change the user's perception of the physical world.

There is still another approach to consider, that of "ARGOS: A Display System for Augmented Reality" (Drascic et al., 1993), a system that overlays virtual graphics over video of the physical world.

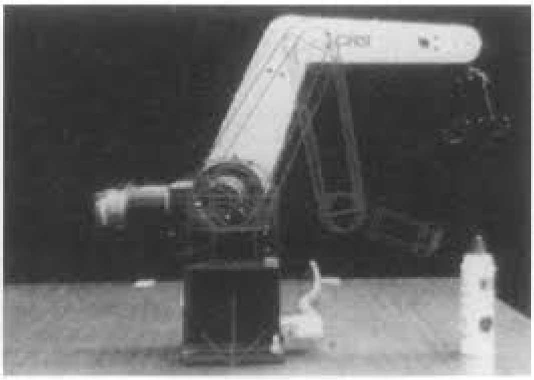


Figure 15 - ARGOS demonstration, by David Drascic and Paul Milgram, 1993.

Similar to Virtual Fixtures (Rosenberg, 1992), ARGOS focuses on telerobotic operations, enhancing video images of a remote scene in the physical world with virtual information. Following the other technologies discourse, the project is presented opposing virtual reality:

> *Rather than trying to create a virtual or artificial reality, ARGOS serves to give operators sufficient and necessary information for carrying out tasks in a natural, spatial manner. By enhancing the reality of the SV displays with our SG images, we augment their usability and functionality. (Drascic et al., 1993)*

Interestingly though, this system configuration presents ambiguity with VR, for while it augmented scenes of the physical world, it also enhances the sensation of being present in a different space, other than the immediate surroundings. Considering that the enhancements are applied to video images, which could be pre-recorded footage, reality in this context is disconnected from the user's perception, and is differentiated from virtuality solely by the level of computer generated information in the scene captured from the physical world. While this can be considered the most techno-centric vision from the ones pointed out, natural interactions and the use of spatial awareness are mentioned as concerns in the development of the system.

With the use of the term "augmented reality" increasing among works without a consistent definition, varying configurations and results, some researchers saw the need for surveys and taxonomy, to gather and classify what had been done until that point. The most significant effort in terms of classification was A Taxonomy of Mixed Reality Visual Displays, by Paul Milgram and Fumio Kishino's (1994), introducing the Reality-Virtuality Continuum, in which virtual reality and augmented reality are classified as variations of a single spectrum instead of antagonizing ideas. The virtuality continuum has the real world and the complete virtual environment as the ends of the spectrum, with the space in between comprehending expressions of mixed reality (MR).

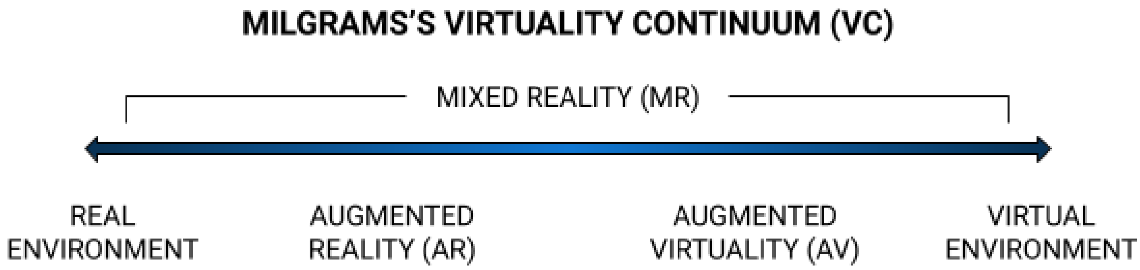


Figure 16 - Milgram's Virtuality Continuum

With the objective of clearing some aspects as well as strengthen the boundaries of the field, the study presented a definition of augmented reality capable of accommodating different system with distinct characteristics and functionalities:

> *As an operational definition of Augmented Reality, we take the term to refer to any case in which an otherwise real environment is "augmented" by means of virtual (computer graphic) objects. (Milgram & Kishino, 1994)*

This definition is able to contain systems present in the different paradigms of AR development, including remote environments or immediate surroundings, as well as wearable hardware or spatial systems. However, the taxonomy model does not contemplate projectors in the classification, leaving projects that don't overlay information on the view of the physical world, such as the ones presented within computer augmented environments (Wellner et al., 1993) out of the field of mixed reality. This suggests that in their view, augmenting reality is restricted to augment views of the physical world and not the environment or objects themselves, limiting the paths the technology can take on further development.

Milgram and Kishino pointed out that the term augmented reality is appropriate to describe enhancement of video images of real environments, based on their conviction (Milgram & Kishino, 1994), suggesting awareness of the ambiguity between AR and VR systems regarding the application of stereoscopic video. The fact that this issue is addressed directly in this study indicates that it is a point of conflict and importance in the field, as it affects the definition and classification of the technology, and consequently resource distribution and authority in the field. The statement is an imposition from the researchers, suggesting a clear attempt to secure a position of power in AR development. Another factor that draws attention is the emphasis on computer graphics, adding new restrictions to AR projects. While the authors mention that the study focuses on display systems, suggesting the possibility of AR systems that don't necessarily rely on visual graphics, the specific mention of computer graphics in the definition makes it a requirement, making any system that does not prefer visual information not classified as augmented reality. While this study aims to identify and clear misconceptions and possible configurations for AR technology, it is significant the amount of limitations imposed to systems to fit this model.

Milgram and Kishino also created a framework for the classification of mixed reality systems, defined in three axis: Extent of Knowledge, which is a variable for the level of reality or virtual modeling of the scene in view; Reproduction Fidelity, which is related to the realism or visual quality of the information displayed; and Extent of Presence Metaphor, that relates to the type of display technology being used and it's capacity to emulate our perception, that impacts the sense of immersion or presence at the particular environment. It's important to note that the taxonomy model englobes both VR and AR, therefore the values are generalizations capable of describing systems in both categories, thus the importance of an attribute such as immersion despite its potential incompatibility with some AR configurations, that enhance their immediate surroundings. We can see in the axis definitions that the concept of reality is still system-oriented, one dedicated to the amount of computer generated information in the raw captured scene, and that there is bias to sensory enhancement rather than environment augmentation, indicated by the third axis that focuses on the system's ability to simulate the user's natural perception. While the study goes to great extent to describe and define features and aspects of AR systems, human related themes are left aside, further reinforcing the techno-centric vision in the field, which is intriguing considering AR background of striving for better and more natural human-computer interactions. It is not to say the topic was completely ignored though, as one aspect that remains common to all methods is the aim for seamless integration with the user senses, thus possibly resulting in more natural interactions.

Another important effort in the indexation of AR, Azuma published a survey presenting a summary of current AR development, with areas of development, systems and possible applications (R. T. Azuma, 1997). AR is presented as a variation of "Virtual Environments", or Virtual Reality, the difference being that AR allows the user to see the real world instead of being immersed fully in a virtual environment. Azuma defines AR as a system that (1) Combines the Real and Virtual World, (2) is interactive in real time and (3) registered in three dimensions (Azuma, 1997). This is a key milestone in AR development, as this definition is more specific in the way AR systems work, but still broad enough to englobe different types of systems, remaining the most dominant and influential definition in AR development, with the survey boasting more than 10,000 citations at the time of this writing. Azuma's study also supports the technocentric vision in the field, by focusing on system characteristics and capabilities. While it does not restrict AR definition to display technology, it creates new boundaries by introducing interactivity and three dimensional registration for the virtual artifacts as requirements for AR systems. It is not specified what "interactive" is or is not, if the virtual information reacting to user movement is enough interactivity, or if it should respond in more complex ways.

This scenario puts to evidence the inconsistencies surrounding the emergence of AR, even more with the lack of a proper definition that contains all of those visions that effectively augment properties of the physical world regardless of the chosen system configuration. The two major attempts to organize the field reinforced the dominance of display technology in the development of augmented reality, by disregarding other types of input and output. As Augmented Reality grew as a field of research, there was an overwhelming amount of studies dedicated to AR HMD systems hardware issues, such as tracking, registration and calibration. Consequently, we see the emergence of complementary terminology to AR, to accommodate concepts and technologies excluded from the prevalent category, as well as new visions that oppose the nenin definition.

3.4. Disputes and Parallel Development

The classification models set up strict boundaries for AR systems, which led to the emergence of complementary terminology and disputes in the field, as other studies tried to take part in AR research, but diverged from the HMD format. Those studies question the methods and boundaries defined in earlier research, while also putting into perspective other properties relevant to what means to augment the physical world.

Interactivity, which was newly added by Azuma's definition, is questioned by Vallino, who argues that most AR research offer graphic interfaces with shallow levels of interaction:

> *Until recently, it has presented a passive interface to its human users, who were merely viewers of the scene augmented only with visual information. In contrast, practically since its inception, computer graphics—and its outgrowth into virtual reality—has presented an interactive environment. (Vallino, 1998)*

As discussed in Azuma's definition, interactivity is a requirement for AR systems, but what is interactivity is left open for interpretation. A 3D virtual object that changes its position according to the user's view is interacting with user positioning in the physical world, but if it does not offer similar interactions as objects in desktop computers or virtual reality, for instance being moveable or editable, is it really interactive?

Another example, Amplified Reality is a complementary concept that refers to the public aspects of Augmented Reality, meaning to enhance the publicly available properties of a physical object, by means of using embedded computational resources (Falk et al., 1999). The idea behind this concept is to make personal computers less relevant by placing small computing devices in the environment, removing the need to move the computer to a task, or a task to a computer, a vision compatible with the ideas presented in computer augmented environments (Wellner et al., 1993), but that doesn't contemplate the definitions established by the classification studies. Authors also make an important assessment about the user's perception in those systems, a theme usually not tackled in AR development:

> *Regardless of how personal or communal the augmented experience is, the "reality" it creates is not real per se. Computer-rendered virtual properties are superimposed on real objects in such a way that the user's impression of the real world is enhanced or otherwise altered. Hence, the properties of an augmented world are associated with the observer's interpretation of the Augmented Reality system, rather than with the objects themselves. (Falk et al., 1999)*

This means that AR systems that augment the individual perception of the physical world are limited to that individual's interpretation, thus augmenting their particular reality but not the physical world itself. In the authors' view, reality refers to the physical world, regardless of its relationship to a particular user or group, being the environment and physical world objects the focus of augmentation, rather the user's individual perception. Amplified Reality differs from the concept of AR in the sense that the information is not superimposed, but embedded in the objects and environment, altering its expression beyond the control of the perceiving system, being equally available to all users. In this vision, reality escapes its system-based definition from previous studies, as raw unmodeled information captured from the physical world, to a more collective and social interpretation.

A similar approach to Amplified Reality is taken by Ishii and Ullmer's. Their Tangible Bits concept (Ishii & Ullmer, 1997) focuses on transforming the environment and objects' surfaces in interfaces with the digital world, bringing attention to background activities as well as the foreground ones. The authors mention AR and other related concepts such as Ubiquitous Computing, but with the intention to differentiate their approach from those concepts. They refer to AR as the visual overlay of digital information onto the real environment, and distinguish their vision by saying that they rely on physical objects as input and output sources rather than pure visual augmentation.

AR development, by imposing restrictions through hardware configurations and efforts to restrict and explain such systems, led to the emergence of a range of different philosophies about augmenting the physical world trying to secure their authority as distinct fields of research, visions that would otherwise fall under the same category or field of research.

3.5. Stumbling Blocks

Despite the multiple methodologies and approaches to the design of AR experiences, there is one feature that is inherent to all AR systems: The ability to perceive, track and respond to the environment and the actors within it. Independent of the system configuration, for the virtual artifact to be displayed in the real environment, the system needs to perceive the space and process the information to react accordingly, displaying the desirable results. This kind of interaction is deemed by the researchers themselves to be sensitive in terms of user privacy and data security. If we take into consideration the restrictive definition of augmented reality as overlaying information over the view of the physical world, i.e., the required use of head-mounted display with see-through technology, a further aspect (and hindrance) becomes visible: significant impact of wearing the device in public and social contexts, that affects personal and professional identities. It is therefore no surprise that most of the industry investment in AR projects is made to be used in contexts where the user has no choice over whether to use it or not.

Privacy, data security and ergonomics issues in AR development were already acknowledged by developers and enthusiasts in the 1990s, despite the focus on technical aspects of the technology (Mann, 1997; Starner et al., 1998). In a short paper, Feiner (1999) examines these issues in the use of wearable augmented reality systems, however, while proposing to take a human-centered stance, Feiner's analysis tackles these issues from a device standpoint, suggesting ways for systems to circumvent these issues instead of discussing changes, or even truly acknowledging their role as stumbling blocks to the use of AR systems. For instance, while recognizing that wearing a tracking device can be invasive, Feiner questions how we would perceive privacy in a world where devices with tracking technology are commonplace. He further envisions changes in social conventions and common behavior, such as "politeness" in sharing tracking data when in face-to-face conversations, or the desire to profit off such captured information. Ultimately, in Feiner's view the technology is believed to be a driving force in changing and normalizing user behavior, as the advantages offered by AR systems surpass the changes in privacy and social interactions (Feiner, 1999).

The treatment these issues receive are a reflection of the techno-centric approach that dominated (and continues to dominate) the field. An approach that prioritizes hardware development and imagined social change over current user experience. Not only that but most AR studies are conducted in controlled environments and specific contexts, such as university facilities and work spaces and often the military, where the users are not seen as (human) factors and/or also do not need to be convinced to use the device. This approach to the development of augmented reality is still visible and has contributed to the failure of AR devices to join other technologies in our everyday lives.

3.6. The Stabilization of Augmented Reality

Despite the different discussions and philosophies surrounding augmented reality development, it consolidated as virtual computer graphic enhancements to the user's perception of the physical environment, favoring the HMD format. Following the evolution and discussions in the field, Milgram and Colquhoun Jr's updated his taxonomy model following the discussions and advancements in the field (Milgram & Colquhoun Jr, 1999). In their study they identify two major different classes of definition of AR, being the dominant one referencing AR strictly as see-through HMD systems, and the second one still mentioning computer graphics augmentation of the environment, but removing the requirement of a see-through HMD. The authors also mention a third class of AR displays, being that any kind of mixture between real and virtual environment. Regardless, these three definitions further support the dominance of virtual graphics, excluding non-display focused systems. Milgram and Colquhoun Jr kept the same definitions as his original work, but added a new layer to the framework, by addressing controllers in AR systems: Control-display congruence, referring to the means by which the user controls or navigates the system; and Centricity, referring to changes in the observer's viewpoint, between egocentric and exe-centric positions (Milgram & Colquhoun Jr, 1999). It's worth noting how different sensory technologies are recognized as input/output methods for AR systems, but not as AR systems by themselves, specifically without the presence of computer graphics.

Even with friction inside the field, hardware advancements were bringing the technology closer to real world applications. As we transition to the 2000s, solutions based on AR development start to make their way to the market and general audiences.

In a complementary survey to the previous work from 1997, and with the contribution of other scholars, Azuma summarized the current state of the technology, presenting examples and possible applications, noting how its advancements are already impacting the real world (Azuma et al., 2001). Although restating the same definition from the previous survey, the author emphasizes that there is no limitation to a specific technology nor to the sense of sight. Yet, all the examples presented in the article have graphic interfaces or interactions. Interesting applications presented in the article that the common user might not relate to AR were the Television Sports Broadcast augmentation.

Figure 18 - AR in Sport Broadcast - Real time annotations, NASCAR, 2001.

Feiner also published an update on Scientific American presenting AR to the general audience and envisioning the future of the technology (Feiner, 2002). The article presents AR in a raw (and still emergent) state, describing its functionalities and limitations while also pointing requirements and giving real world examples. Feiner recognizes the multisensory capabilities of AR systems, but focuses the presentation on visual systems and interactions. While pointing out the potential of AR systems for general use, like desktop computers, Feiner argues that specific applications are the driving force in AR development, also suggesting that AR just needs a “killer app” to compel mass adoption. This indicates the author’s conviction that the technology was already mature enough to join the real world and exit contained and tight controlled environments, while also pointing this moment to an imaginary future.

While the number of studies AR increased throughout the 2000's, with AR achieving the status of emergent technology, the focus was mainly still on trends and problems in AR technologies, as well as reviewing current development and spreading the knowledge to the public (Feng Zhou et al., 2008; Haller et al., 2007; Krevelen, 2007). AR development stagnated, hindered by the need of hardware advancements: lighter, cheaper, more accurate and power efficient. Mobile phones and portable displays rose as a potential platform, with technological advancements and popularity increasing in the following years, but yet lacking the power to deliver AR experiences (Wagner et al., 2005; Wagner & Schmalstieg, 2009). With more powerful mobile phones and the arrival of smartphones, Augmented Reality regained a little momentum by the end of the decade, with studies focusing on mobile augmented reality experiences (Pence, 2010; Schmalstieg et al., 2011). At the same time people start to get upset about the changes brought by smartphones (very similar to what happened to desktop computing 20 years before), finally leading to the Google Glass Experiment in 2012, bringing back excitement to Augmented Reality.

3.7. Preliminary Conclusions

In a span of 40 years (from the 1960's to the 2000's), Augmented Reality went from concept and a small set of loose ideas to become a complex network of concepts and methods. While it is possible to identify multiple paradigms in the development of AR, the prevailing concept is that of overlaying virtual graphics in a view of the physical world, and the favored format being see-through HMD systems. The dominance is evidenced in the extensive number of studies tackling hardware issues (including other areas, such as VR and wearable computers), thus drawing attention from other issues and possibilities. Milgram and Kishino's taxonomy model in particular (Milgram & Kishino, 1994), being the most significant classification effort in the field, reinforced this dominance by classifying systems based solely on hardware characteristics. In the 1999 update (Milgram & Colquhoun Jr, 1999), there is an effort to three different definitions for AR based on computer graphic interfaces, reinforcing it as a requirement for a system to be classified as such. These boundaries impose very strict requirements for the field, what limits the problems that can be tackled and how the technology is perceived by other entities.

As Augmented Reality matured as a field of research, there was a wide variation of concepts and studies defending different points of view, what suggests friction inside the development of AR technologies. The lack of consensus in the field is related to the physical configurations of the technology, pointing to an technocentric vision driving the discussions in the field. The concern in major studies to detail and discuss the technical characteristics of the systems over user perception and experience with the technology is also an indication of technocentrism in the development of AR. While this discourse is pertinent when tackling performance and efficiency, it is contradictory to the early desire for better and more natural human-computer interactions, once it disregards most human-related themes.

The definition of AR itself poses an issue to the development of AR systems and in the general understanding of the technology. Augmented Reality is mostly defined by the system's features, as in "overlaying the user's vision with computer graphics", or "embedding technology in the material world surrounding the user", but lacking in terms of human experience. Does this mean that the use of the term "Augmented Reality" was a mistake? While it is possible to argue in favor of new terminology, more specific to each configuration of the technology, Augmented Reality is a valid expression for what the technology achieves, and also it is already established in the common vocabulary to refer to the technology. The issue is in the abrangence of the term and the attempts of different studies designing very specific systems and definitions for the concept, closing the network to other actors. Taking in consideration the dominant definition, while overlaying the user's view with virtual graphics cause a major impact on what the user perceives as reality, justifying the use of the term "Augmented Reality", reality itself is rather complex and abstract to be referred objectively as what an individual perceives mostly with their eyes. Not only all of our senses take part in the construction of reality, but there are also individual and collective experiences and contexts, events and entities that exist in the real world beyond one's individual perception.

Finally, AR was not developed as a consumer product. Systems have very unique configurations designed for specific problems, despite similarities in terms of hardware layout. Most of the designs were tested in contained environments, isolated of many variables present in the open world, leaving human-centered themes untackled. Its use id for specific settings and users: factory workers and military soldiers, idealized users from the contexts where the technology is applied. Added to the techno-centric vision dominating AR development, it is not surprising that developers were always in a position of waiting for the right opportunity or a last enhancement for the technology to finally catch on to the public, but only small glimpses and experiences ever made their way to the open world.

4. The Google Glass Experiment

In order to understand how visions of AR materialize into particular artifacts, we now analyse the case of the Google Glass Experiment. We attempt to answer what were the envisioned roles for the device, how did the users utilize the device, and how was AR defined within the experiment. The goal is to examine the differences between the aforementioned visions and discourse behind AR development and particular materializations of the technology.

In 2012, Google announced "Project Glass", a streamlined wearable computer, raising excitement and interest in the field of augmented reality that had been for the consumer market mostly stale since its major advancements in the 1990s. The device, that would come to be known as Google Glass, was not the first head-worn device to be made available to the market - for instance Reflection Technology's Private Eye (1989) - but it was marketed as being different from everything seen until the moment, promising augmented reality capabilities while departing from the bulky and cumbersome format of older projects (Newman, 2012; *Project Glass*, 2012).

As we know today, the Google Glass Experiment did not turn out well, with consequences that deeply impacted the development of modern AR solutions, catching a lot of enthusiasts of the field by surprise, considering the amount of excitement supporting the arrival of AR in the mainstream of technologies. This failure is all the more important given that the project is backed up by one of today's tech giants: Google.. Because Google Glass represents many of the visions and discourses of the field, the problems experienced in its deployment in the open world suggest a conflict between developers' visions of the technology and the interests, needs and experiences of the users. Furthermore, Google Glass Experiment was a turning point in the development of AR technologies, thus analysing the experiment would provide a better understanding of the current state of AR, as well as of the process of construction of AR as technology.

4.1. Background

In the 80s, with the popularization of personal computers, many activities, in personal and professional contexts, transitioned to a desktop modality, staring at a screen and fiddling a keyboard. Researchers of mobile technologies were determined to revert this scenario and bring the user back to "the real world", with AR and wearable computing projects challenging the desktop model (Mackay, 1998; Starner et al., 1997).

Starner, the person behind Google Glass, and also a key figure in wearable computing and augmented reality research, made interesting contributions combining both fields. While a wearable device by itself would already free the user from the limits of the desk and offer computing assistance in everyday activities, Augmented Reality would provide improved interactions by overlaying context and location-sensitive content directly in the real world (Starner et al., 1997). Illustrating this approach, the Remembrance Agent (Figure 19), a text-based wearable AR system, using a see-through HMD and a search engine presented and discussed possibilities with the combined technologies.

Figure 19 - Thad Starner (far right) with the MIT WearComp group, wearing Remembrance Agent prototypes, 1997.

The system was capable of tracking user inputs, including typing and gestures, feeding those to the search engine that would return with relevant content based on the user behavior, then displaying it on their field of view. The ultimate objective of this study was to train the system to anticipate user behavior and perform interactions between real and physical worlds seamlessly. Wearable technology, and particularly HMDs, were favored as they were expected to free the user from the limits of the screen to perform other tasks, while easily displaying graphic interfaces on the real world, despite the limitations of the technology. For the developer, and Google later, this ability to be "free" from a screen was deemed crucial.

However, by 2010, smartphones had already taken the world by storm, causing major shifts in our lifestyle. People now had in their pockets a powerful and fully mobile device, capable of creating, displaying and sharing high quality media, virtual social interaction, as well as web and real world navigation. The devices were so compelling that people were hooked up, spending a lot of time looking at their screens, which deeply impacted their social and personal lives (Smith, 2011). It is interesting though how the smartphones could achieve in such a short time what AR have been trying for years, to free the user from the desk.

4.2. Launch

The first time Google officially manifested the existence of the device was with a conceptual video in April, 2012 (*Project Glass*, 2012). In this video, while it was not clear how the device properly worked, Google envisioned features of the future artifact, with a demonstration in first person view of how it would look like to use the device, the user point of view. The device performed like a smartphone, being able to take pictures, access weather information, contacts, calendar and reminders, but using voice commands. Later that year, on the Google I/O 2012 event (*Google I/O 2012 - Keynote Day 1*, 2012), the company officially revealed the product, offering a live demo and a deeper look into the device. Google Glass was presented as a smart glass, a wearable computing device with the objective of offering interactions with a virtual world without getting distracted from the real world. The wearable device is connected to the Google search engine, working as a personal assistant to the user.

Figure 20 - Google Glass Explorer Edition, 2013.

In the keynote, Google Glass designer Olsson stated that the device was designed to be close to your senses but not blocking them, hence the asymmetrical design and the display offset to the corner of the field of view, with a minimalistic approach to seamless use and avoid conflicts with the user individuality (Google I/O 2012 - Keynote Day 1, 2012). The main concept behind the project was to make it possible for users to communicate through images and rapid access to information without disengaging the real world. The device features tools for the quick sharing of videos and photos, while the first person point of view helped convey new meaning to the images on an emotional level. The voice and touch interfaces, together with the head-mounted display were supposed to help the user to quickly access information without taking away focus from the activity or task at hand (which remained free to use). Based on personal experience from the team with the device for months prior the event (Google I/O 2012 - Keynote Day 1, 2012; Starner, 2013), Sergey Brin, one of Google's founders, also shared three reasons for why Google was trying the experiment:

(...)There are basically three reasons. First because we just found it incredibly compelling, since we made these and started using out and about (...) The second is that it's actually one of the things we can show you, because you all can't experience what is like to have all this information available right here (...) And third, you know, we are a pretty small team,

and we've had only so much time to try various kinds of functionality. And in fact everyday We've been getting great ideas, from inside, from outside, from all around the world, and that's why we really want to involve all of you. This development community will be key to us. (Google I/O 2012 - Keynote Day 1, 2012).

Brin's discourse is directly related to the visions from early AR development, suggesting that the technology itself is compelling enough for its acceptance, based on the experience of a very particular set of users then extrapolated as normal users. Brin also stated that it was not going to be a consumer device, "rough around the edges", needing commitment, passion and forward thinking from the interested developers. Pre-ordering was available for US citizens attending the launch event for U$1.500, with release scheduled for early 2013, thought as a closed beta program, focused on developers to bring the technology to its feet.

It is important to note that "augmented reality" was never mentioned during the launch event of Google Glass, as well as developers clearly saying in interviews that they are moving away from immersive AR models (Levy, 2012). The device configuration did not suggest it was AR capable, since its display size and position would not be fully capable to display 3D images as if they were placed in the physical world, nor change the user's perception of their surroundings, as dominant AR definitions indicate. However, features such as image recognition would be possible through the built-in camera with simple software updates, thus the device would be able display information related to objects, places and people it could perceive. Furthermore, even before the device launch, some media channels perceived Google Glass as an augmented reality device, some pointing it explicitly as AR glasses (*Google Glasses Sound As Crazy As Smartphones And Tablets Once Did*, 2012; McGee, 2012; Newman, 2012), while others used the term in the keywords to classify news articles about the artifact (Levy, 2012). It puts to evidence that there was already an inconsistency between what the public and the developers considered to be augmented reality.

In the months following the launch, there was intense coverage from the media, with tech insiders registering their impressions and opinions on Google Glass (see for instance Stern, 2013; Topolsky, 2013). The overall impact was positive, with a lot of excitement around the new technology, but at the same time some already show concern about this vision of the future and speculate about possible failure. There were some extreme points of view, speculating about different scenarios where technology like Google Glass strips society from any level of privacy, with the company profiting from personal information and constant surveillance (Sullivan, 2012). On the other side, TIME magazine for instance, named Google Glass the "best invention" of 2012 (McGee, 2012). With AR in the spotlight and the momentum brought by Google Glass, other companies, projects and alternatives started to appear (e.g. TTP Prototype) (Cardinal, 2012).

Google Glass was released in February of 2013 for the first developers enrolled on the program. Together with the device, Google released a manual that not only included instructions for software development, but also guidelines for the design of interfaces and experiences. Among the principles listed: Design for the google glass, resisting the temptation to replicate phone or computer interactions; Design with care to not draw attention from the real world; Deliver information at the right place and time, avoiding unwanted or unexpected content; Design for people, with focus in more natural and seamless interactions (*Principles | Glass Explorer Edition*, n.d.). In addition, Brin was adamant in its "boundary work" (Gieryn, 1983) working hard to distinguish Google Glass from smartphones. At one point, he stated "We often question if this is the way you want to connect with the people in your life. (...) I feel it's kind of emasculating. You're just rubbing this featureless piece of glass." (Brandom, 2013). Google Glass then carried the promise of reconnecting users with others and the world and breaking the constricting relationship people have with their phones. Ironically enough, this first version of Google Glass needed to connect to the user's smartphone to make possible the use of all the features it offered.

4.3. Issues and Limitations

In 2013, Stern published a summary discussing the possibilities and the issues with the device. She described Google Glass a smart glass, sleek and minimalistic in design, with built-in smartphone components, like a computer processor, bluetooth, wi-fi, accelerometer, gyroscope and compass, as well as a speaker, a microphone, a camera and a small display, rendering it capable of offering Augmented Reality experiences. According to her, the system came with a set of default features, being the ability to take photos and videos, share them in Google's social media, use google apps like maps and search, and get notifications from the smartphone. However, she described difficulties with connection, as it was needed to pair the device with a smartphone and connect to a wireless network to have full access to all the basic features of the system. The device could not connect with networks that require sign in via browser and phones need to support 4G or LTE to share data, a relatively new technology at the time. Another negative point in the reviews were the appearance of the device, or rather the user when wearing it, labeled as funny or dorky, drawing a lot of attention on public situations. In addition, reviewers also included the Google Glass' price, even though it was not yet the final product nor the final retail price. Baldwin detailed in his review the experiment term of use that prevented users from selling or forwarding their device (Baldwin, 2013), making people more frustrated with the product.

Technical issues aside, there were also concerns with privacy around the experiment even before its release. The photo and video capabilities were almost immediately deemed invasive, but an expected feature in the system that brewed both torment and anticipation was the possibility of scanning and detecting the environment for objects or people, and then using the Google engine to search for information on them (Sullivan, 2012). But contrary to public expectations this feature was neither present nor supported at launch . However, video tracking could be implemented through software, so the device featuring a camera already made it possible for it to run tracking applications. In addition, in May of 2013, Google had a keynote event where they taught users how to hack the device, showing possible exploits for the development of applications (Song & Laligand, 2013).

What happened then was a race to develop and upload applications that make use of tracking for various purposes, but the most sought after was for facial recognition (Livingstone, 2013). While Google had enough control to force updates and block undesired applications, any measures taken against tracking software were merely symbolic, as there was no way to stop the development and deployment of homebrew applications, and the situation got to the point of legal regulators demanding direct action from the company (Arthur, 2013; Livingstone, 2013). And although Google ended up updating the terms of use of the explorer program to effectively ban tracking applications, developers and enthusiasts were confident that tracking solutions were inevitable, pointing as a core feature of the technology (Arthur, 2013). If this was not enough to hinder the development of the Google Glass Experiment, user behavior further worsened the situation.

4.4. Glasshole

Noun. A person who wears Google Glass and refuses to remove it when directly interacting with other people, private gatherings, or public events. The general belief is that these people are photographing, recording, Googling, and Facebooking the people they're interacting with instead of focusing on the conversation or acting like a human being. In extreme cases this word is directly synonymous with stalker or creeper. (Nix Nightbird, 2013)

Google relied on the developers' community for the development of Glass, not only for designing applications, but also for collecting and testing in the real world. After the release of the prototype in the beginning of 2013, Google opened another round of recruitment to accelerate development, with a total of 8000 "Glass Explorers".

Being part of the program meant not only having access to an exclusive kind of experience, but also expected to grant social status, as users were easily spotted among the crowd in public spaces and, so the thinking went, they would be treated with some level of admiration. This turned out to not be true, many non-users were very disturbed by having a person wearing a "smartphone" at eye level while interacting with them, without them knowing how the device was being used during the interaction (Chen, 2013; Hruska, 2014). At the same time, the omnipresence of smartphones and existing surveillance in public environments never generated the same commotion on the privacy topic, leading to discussions about individual levels of privacy and challenging current social interaction paradigm (Hruska, 2014).

Figure 21 - Cartoon strip satirizing Google Glass use. Mike Krahulik and Jerry Holkins, 2013.

Unthoughtful or uncooperative behavior by Glass users when confronting opposition to the technology led to the emergence of the term "Glasshole" (Chen, 2013; Greenfield, 2013; Nix Nightbird, 2013), and to generalizations and contempt towards the device. Glass users started being harassed in public, with some commercial establishments banning the device on its premises (*No Joke*, 2013). Other examples include an artist creating a script that searched for and kicked Glass devices from a particular network, after a fellow artist had an unpleasant and undesired interaction with a Glass user (Oliver, 2014). This situation permeated the experiment during its whole duration, drawing even more attention after Google announced the beginning of the "open beta" stage in May of 2014, when the device became available to anyone interested.

While cases of misuse are anecdotal evidence, they also point to significant misunderstandings in the use and purpose of the device. Google either made poor work of explaining the technology, or it was inadequate for the context it was applied. That google, with its means and related abilities was not able to recognize and address these concerns and resentments is surprising in itself, and points to a real disconnect between the company and the public at large, as well as a disconnect between its visions of the device and that of the publics. The company seemed to hope that social behavior would adapt by itself, but the end result was that instead of approaching the user to the real world, Glass made them more isolated.

4.5. Preliminary Conclusions

Seeing the similarities with earlier prototypes of wearable computing, Bergstein foretold Glass would fail anywhere outside of professional environments (Bergstein, 2013). The device came from research that was done in contained environments and for specific tasks, as well as known privacy issues. In terms of hardware, Google Glass works exactly like systems already designed in the 1990s, except for making use of advanced hardware, more streamlined and stripped from unnecessary features to fit in an attractive package to the end user. The Glass system mirrors projects that were designed for contained environments and the execution of specific tasks, then applies to general context and everyday life. Those projects were designed with performance and efficiency in mind, which is also a part of the Google Glass discourse, the Rapid Data Access. The second part of the concept was based on prolonged personal experience of a small group of users with the device in the new context, attaching emotional experience to the system. Despite gradually opening the experiment for more users along the time, Glass was never pitched as a consumer ready product (even at its final stages it denominated 'open beta'), as it was indeed an experiment. Google Glass was not designed for social environments, It was a high effort in terms of hardware design, but low effort in terms of interaction design, to see if the already thoroughly tested model would fit a new context.

Google had hopes for the device to fit in the real world and for behavior to adapt around the device though, making efforts to contain the backlash against the privacy issues, which means that Google had a plan in case the product succeeded. For the device failed to compel the user, and consequently to sell, many deemed Project Glass as a huge failure, but considering its experimental nature it can be seen as a success, for the purpose of an experiment is to collect information.

5. Conclusions: Old Ideas Never Die

Identifying the major visions and discourses through the development of augmented reality showed us that the technology was created and surrounded by discussions about a need for natural interactions, as well as the need to connect virtual worlds to the physical world. However, what is “natural” or “needed” was always a technical, engineering vision, one that remains embedded and engraved in AR, defining the technology and its role.

In AR development, experiments were done in contained contexts, with controlled conditions for the execution of specific tasks, helping achieve specific results, the purpose always being of more efficiency and performance, whereas better user experience was often a side effect. Developers stuck with the belief that advantages offered by AR would overcome its issues, the technology itself eventually driving a change in social behavior for its own acceptance. Head-mounted displays were made a symbol, an essential part of augmented reality systems. The Google Glass Experiment came up as a materialization of this discourse, streamlined and deemed ready for open world use by its developers, but requiring acceptance and support from the community for it to actually work. What we could see from the experiment’s result was that there was a gap between what consumers expect AR to be and how developers envision the technology. The experiment not only put the device in check, but questions the whole HMD model, as the solution seems unfitting for our reality.

AR at this point is a case of an old idea not dying, and of “high-tech” practices and visions whose users are idealized in their own image, while actual users (and society) are at large less open to the technology. Looking again at the prevailing definition of augmented reality, superimposing computer graphics on the view of the physical world is an oversimplification of what is actually possible to enhance in environments, objects, our senses and bodies, and connect it all to the digital universe. AR was never truly tested to its premise to bring the user back to the physical world, but rather to take the information away from the boundaries of a screen, an exercise of stretching hardware capabilities instead of the actual dialogue between humans and machines.

For augmented reality to achieve anything more than floating interfaces, users need to be more than a component to systems, and human-centered discussions should be a priority in the development of AR technology. A possible way to start such change in the discourse of augmented reality is to develop a proper definition that goes beyond hardware capabilities, englobing human experience and perception of our reality. While it is no simple task, such effort would address the need to make the user a center piece in the configuration and construction of AR technology. It would also tackle the stagnation in AR development, as a more human concept would walk side by side with the changes in our society instead of being stuck in time.

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