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Drivers and Bottlenecks in the Adoption of Augmented Reality Applications

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Abstract- *In the last decade, Augmented Reality (AR) has been one of the emerging technologies that have been in the centre of attention among academics and business practitioners. Despite the numerous studies which have demonstrated the multitude of benefits derived from AR applications, the technology has not reached yet its full potential due to various bottlenecks which are preventing it from becoming the mainstream technology that many have anticipated. In this paper, we first present briefly the history of AR followed by the evolution of related software algorithms and hardware devices. The main contribution of this paper is the overview of the drivers and challenges related to the adoption and diffusion of AR across five major application domains; (a) industry and military, (b) training and education, (c) travel and tourism, (d) medicine and health care and (e) retail and marketing. Such overview facilitates especially a cross-domain comparison, which here enabled us to identify a list of five drivers and five bottlenecks in the adoption of the current AR technology.*

Keywords: Augmented Reality, drivers, bottlenecks, technology adoption.

1. Introduction

Augmented Reality (AR) is a concept where elements from real life are augmented by additional visual information after recognizing the environment in order to guide the augmentation (i.e. to position and orientate augmented content). In 1994, Milgram and Kishino defined a Virtuality Continuum (VC) [1]. In this continuum, the concept of Mixed Reality (MR) is set between two ends: (a) Virtual Reality (VR), an environment where the user is totally immersed in and (b) Real Environment (RE). MR refers to the combination of elements from both ends of the VC (i.e. a mixture between real and virtual worlds). One state inside the VC is AR, which refers to those cases where the RE is augmented by virtual objects. This definition explains the most common approach of AR nowadays, where images of a real environment (e.g. video feed from a camera) are augmented with elements from virtual worlds in real time (e.g. 3D model, images, videos, text, etc.).

The first known reference to AR concept was provided in 1901 in [2] where the idea of overlaying metadata on top of people (basically, information about their real character) through the use of spectacles was mentioned. Yet, it took almost a century until the AR term was first announced in 1990 by Tom Caudell [3] when he was working for Boeing and one of the first AR-relevant papers was published in 1992, presenting an AR system prototype called KARMA [4]. The same year, one of the first AR systems (Virtual Fixtures) from US Air Force was released [5]. Even though AR was introduced in early 1990s, the technology that is based on has its roots deeper embedded in history. Specifically, AR evolved from VR which in turn originated from simulators in 1920s. For instance, in 1950s, Morton Heilig introduced Sensorama (patented in 1962 [6]), the first machine with AR elements that provided sensing-related techniques utilizing 3D images, sound, wind, vibrations, and aromas; however, it never sold commercially largely due its high cost, complexity and scalability limitations. Also, in 1961 the first Head Mounted Display (HMD) was introduced [7].

AR development became easier after Hirokazu Kato from HitLAB introduced ARToolKit in 1999 [8]. This among other technological developments (namely gained by computer gaming industry) in early 2000 attracted more developers to AR. Due to the increasing interest in AR technology, researchers and experts from different fields are nowadays

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working together to develop new applications that can bring the benefits of AR technology to the respective fields. The number of different useful applications and recent developments of smartphones and AR-goggles by large companies like Google [9], indicate that AR can be one of the hyped technologies in the next years.

Despite the numerous studies demonstrating the multitude of benefits derived from AR applications, the technology has not reached yet its full potential due to various bottlenecks which are preventing it from becoming the mainstream technology that many have anticipated. While there is a large amount of studies discussing the benefits and problems encountered in the adoption and diffusion of AR technology, the majority of these focus on a single application field of AR. Motivated by this observation, in this paper, we study what drives but also what impedes the adoption of AR technology across five major domains, and taking into account both the developers' and final users' perspectives. The main goal is to provide a general overview of the current state of the art and to provide hints for future developments.

Unlike the invention of a new technology, which often appears to occur as a single event or jump, the diffusion of that technology usually appears as a continuous and rather slow process. Yet it is diffusion rather than invention or innovation that ultimately determines the pace of economic growth and the rate of change of productivity [10].

Technology acceptance models are used to explain how users come to use or accept a specific technology [11]. For instance, Louho et al. defined technology acceptance as the way people perceive, accept, and adopt technology use [12]. According to the Technology Acceptance Model (TAM), the success of a system is based on an individual's behavioral intention (i.e. attitude) to use it and this is determined by two factors: perceived usefulness and perceived ease of use [13]. Perceived usefulness is defined as the degree to which the user believes that using the system will enhance his or her performance. Perceived ease of use is defined as the degree to which the user believes that using the system will be free from effort.

According to Rogers innovation diffusion theory, five characteristics of a technology determine its acceptance [14]:

- Relative advantage (the extent to which it offers improvements over available tools),
- Compatibility (its consistency with social practices and norms among its users),
- Complexity (its ease of use or learning),
- Trialability (the opportunity to try an innovation before committing to use it),
- Observability (the extent to which the technology's gains are clear to see).

The remainder of the paper is structured as follows: section 2 describes the AR-related software and hardware and how these have evolved over time. Section 3 overviews the drives and bottlenecks in AR adoption across five of the fields where AR has been used most extensively. In section 4, a discussion about the drivers and bottlenecks is presented. Finally, section 5 presents the conclusions.

2. AR Software and Hardware

The evolution of AR has been tied to the available computational power. In particular, during many years in the past, computers were not powerful enough to process video feed, analyse it and overlay virtual content on top of it in real-time and with the necessary level of accuracy. With the increasing availability of computational power, the AR-related techniques have evolved and more complex algorithms can nowadays be supported. Moreover, the current trends show that even more advanced and complex techniques would be supported in the following years.

There are two main challenges in AR development related to software: the recognition of the environment and the rendering of virtual content. As the rendering of virtual content is a mature technology thanks to VR, AR researchers have focused mainly on the former task, i.e. the recognition of the environment. This has been performed traditionally using computer vision algorithms or positioning-based systems. Marker based algorithms have been widely used long in the past as they enable a robust and fast recognition process. ARToolKit [8] and derivative studies have diffused the use of marker-based systems and nowadays, these are still one of the most important approaches. However, this approach is limited by the requirement of attaching the markers to the real world and thus, new approaches were studied in order to overcome the above limitation. For instance, the evolution of computer processing enabled the use of image-based algorithms. The main benefit compared to marker tracking is that no additional markers need to be placed in the real world, as images that are already present in the captured video can be used.

One of the current research trends is to detect not only real objects but also humans. Specifically, point cloud based systems allow detecting real objects using their corresponding 3D models not only for the augmentation, but also for the spatial recognition and also to track movements of humans. As it can be seen, the evolution of software algorithms towards a more natural tracking system is a constant. However, it requires higher computational power and therefore, the standardized use of these tracking systems is still far in the time.

From the hardware point of view, there are three main components required in the majority of the AR applications. The first component is a camera that is used to capture the real environment (although the use of the camera can be avoided in some see-through systems that may use GPS or non 3D positioning of virtual elements). Almost any kind of off-the-shelf camera (e.g. USB cameras, built-in cameras, IP cameras, industrial cameras…) can be used for an AR application, depending on the requirements of the rest of the hardware. The video captured from the camera (or any other spatial acquired information), together with the virtual information, needs to be processed by the second component, i.e. the computing unit. The last component is a device where the final augmented information is displayed (e.g. a flat screen). Additionally to these three elements, further hardware, e.g. GPS, human motion sensors, accelerometers, gyroscope, etc., can be included into the designed system in order to serve a specific purpose.

Traditional computers with USB or built-in cameras and flat screens have been the most common setup for the early AR systems. However, with the growing computing power of handheld devices (i.e. smartphones and tablets), AR technology has started to be integrated also in these devices as they are constitute all-in-one hardware systems. In 2008-2009, the first commercial AR browsers for smartphones were introduced. These AR browsers were based on GPS tracking instead of computer vision, as the computing power was still not enough for image recognition. With the fast evolution of smartphones and the expansion of tablets, the number of computer vision based AR applications is growing rapidly. Moreover, Head Mounted Displays (HMD) have been for long in the centre of attention among researchers because they can also serve as all-in-one devices. However, so far existing prototypes have been heavy to use and the computing power has also been limited, preventing their wider adoption.

In the recent years, new lighter glass-type devices have started to appear with higher computing power which makes them particularly suitable as AR devices (e.g. Vuzix Wrap 1200DXAR [15], Google Glass [9]). The last Consumer Electronics Show (CES) has shown this trend as several AR-glasses have been presented (e.g. Epson Moverio BT-200 AR glasses [16], Lumus DK40 smartglasses [17], ORA-S AR eyewear [18], etc.). In the future, it is expected that these devices will further evolve enabling an even higher number of AR applications for these devices to be developed. Finally, cloud services are nowadays a new trend in the AR field which may lead to a new standard of AR computing. Moreover, the use of cloud services is very tempting because it enables the utilization of powerful computer vision algorithms with low requirements of hardware, as the majority of the calculations are done remotely. Therefore, if the tracking is done in the cloud, a smoother rendering can be achieved with the same hardware. However, cloud technology also presents some drawbacks, such as the need of continuous connection to internet for the cloud processing and an appropriated bandwidth for the targeted cloud service.

3. AR Applications – Drivers and Challenges

3.1. Industry and Military

Industry is one of the fields that may take more advantage of AR technology than other fields, as it can be applied to the whole life cycle pipeline, starting from the design of the product and going through the workers' training, the product manufacturing and the maintenance of the facilities. Figure 1 shows a block diagram of the current possibilities of AR in the product pipeline. These possibilities are explained in this section, except the marketing of the product that will be explained later in a separated section.

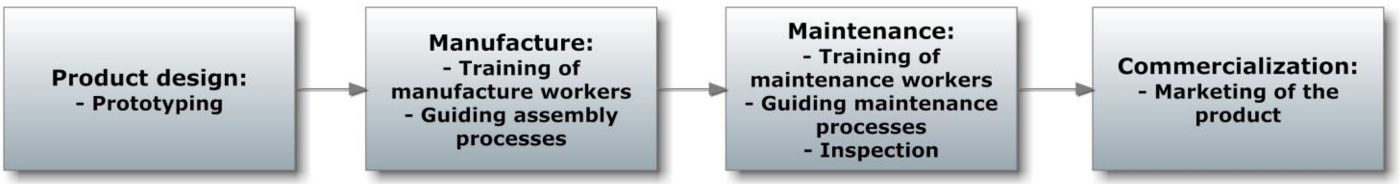

Figure 1. Product pipeline and the uses of AR.

Product design is usually an expensive process for the majority of companies, as either a physical prototype (in fact, several iterations of prototypes) or a Virtual Reality model displayed in a Cave Automatic Virtual Environment (CAVE) like system is needed. The use of AR technology allows designers to create real scale virtual prototypes that would be very expensive to build (e.g. cars, heavy machines, etc.) and analyse and present them augmented in a real scenario with a low cost solution. Thus, AR can be used at an early stage prototype design phase to reduce costs and provide means of design interaction either in a real size or in a desk size environment [19]. Designers may get interested in AR not only for saving costs, but also for some additional features like tangible interaction [20], [21], the easiness of visualizing changing variables like size, colour or textures [21] or the possibilities of usability evaluation [22].

Although the use of AR for training purposes is discussed later in this paper, it is worth to mention that AR may bring standardization of the manufacturing training which in the end would reduce costs and training time and allow workers to learn at their own pace [23]. During the training phase, the real devices can be augmented to guide the trainee through the different steps to follow, highlight some specific parts of the devices or point out dangerous parts and/or procedures that need to be avoided, for citing some examples. Several studies have already shown positive results when using AR for guiding the assembly process (e.g. [24], [25], [26]). The results from [27] show that the use of AR for assembly provides faster and more accurate performance for psychomotor phase activities. Although these studies have been carried out for small size prototypes, benefits like higher accuracy with fewer errors and shorter assembly times depict a promising future for larger scale projects. For example, [28] presents a first phase to create a large scale AR assembly process in the aerospace industry. Moreover, AR can be also used for final inspection of the manufactured products [29].

Maintenance is probably the most active research field in AR for industry and there is a large number of studies that have described the benefits of using AR for maintenance (e.g. [30], [31], [32]). Some of the benefits are faster maintenance interventions with fewer errors and more efficient and safer procedures. Furthermore, remote guidance and supervision from an expert is also possible by means of AR [33]. Several AR prototypes have been already implemented for maintenance in different sectors, such as aerospace industry [31], remote handling [34], photovoltaic pumping systems [35] or acid treatment industry [36] for citing some recent examples.

The great majority of research studies are prototypes aimed to solve a specific problem. However, the use of AR in industrial environments requires flexibility [37]. This flexibility means that the AR tools should be easily reusable to adapt to different devices and procedures with little effort. The solution to this issue could be the standardization of the patterns to be recognized by the system, like the unique identifiers proposed in [38], and the implementation of authoring tools that allow facilities to create their own AR applications without the need of dealing with low-level AR programming.

Military field has also started to research actively the use of AR technology not only for training (e.g. [39]) and maintenance (e.g. [40]) but also for simulation of actual military operations, like the prototypes presented in [41] and [42].

One of the main drawbacks of utilizing AR in industry and military fields is the accuracy of the virtual elements positioning. For instance, when using AR for the product design, the accurate placing of the prototype models is difficult to achieve [19]. Sometimes the low accuracy comes from the tracking algorithm itself which sometimes relies on environmental variables such as light conditions. Another important drawback of AR is that the recognition and tracking can be time consuming processes which complicate the direct use of the in-place objects for tracking in real time. Although some studies have shown good results in this direction (e.g. [31], [34]), a standardized method for markerless-based AR systems for large facilities is still far from the status of current technologies. Due to this fact, it is common to use marker-based AR systems which can provide a robust real time performance for large projects. However, this approach is not always convenient as the placing of markers in the facilities may not be possible or desired [31].

Despite the advantages mentioned through this section, it is still not clear for the industry whether the use of AR technology would return the investments made in the implementation of the system [23], which may be the major impediment in the generalization of AR applications in industry environments.

3.2. Training and Education

According to [43], AR is one of the ten most important emerging technologies for humanity, especially when it is used in educational environments. The reasons of this asseveration usually rely on the inherent characteristic features of the technology, i.e. immersive environments and interactivity.

The combination of real environments with virtual objects creates an immersive feeling for the user. As stated in [44], immersion in a digital environment enhances education in terms of multiple perspectives (i.e. changing frame of reference), situated learning (i.e. learning in the same context where the knowledge is applied) and transfer (i.e. the application of the acquired knowledge). AR is also a highly interactive technology which makes it suitable for the concept of "learning by doing" [45]. The interaction possibilities range from the basic interaction with virtual objects (e.g. moving 3D models, playing videos, scaling objects, etc.) to complex interactive features, like an embedded intelligent virtual tutor [46] or interaction between physical and virtual objects (i.e. tangible interfaces) [47], [48].

Moreover, AR brings further features to education and training. Collaborative applications have shown to be of great interest in this field and several studies have already shown the benefits of creating collaborative AR environments (e.g. [49], [50], [51]). AR is not only a means to educate and train people, but also to entertain while acquiring new knowledge. Students usually find concept acquisition more interesting when using this kind of systems [52]. Last but not least, AR technology has a fast learning curve, which means that users are able to start utilizing the applications with very little prior information [53], [54].

AR can be used in almost any educational subject, as it has been demonstrated in the large variety of examples that can be found in the literature, such as mathematics [55], [56], physics [57], [58], chemistry [47], [50], languages [59], medicine [60], Earth and environment learning [51], [61], natural sciences [54] or music [62], [62]. The applications can be targeted to a wide range of ages, from preschool students [54] to University students [49]. AR can be also used for training professional workers in several fields, such as training on clinical breast exam [64], planning brain surgery [65], [66], bread production in a bakery [46], full-body movement [67], myoelectric prosthesis [68] or escape guidelines for nuclear accidents [69].

There is no common standard on how to deploy AR applications for education and training. However, there are some common approaches that are followed by a large number of studies. One of the most common approaches is to use AR to augment the content of books where traditional educational or training material is explained in the form of text and images. The content used for the augmentation may cover a wide range of multimedia elements (3D models, animations, videos, webpages, etc.) and also several means of interaction that provide an added value to the books. Starting from one of the first AR books, the widely known MagicBook [70], where users could immerse themselves in a virtual world, researchers have been augmenting books for different subjects with all kind of educational material to enhance the learning process (e.g. [71], [72], [73]). The inherent interactivity of AR technology leads to a common and widely used approach where hand-sized markers are handled by students in order to analyse complex 3D representations that are not easy to understand when seen as printed images or to interact with the learning content in educational games. Another common approach is to introduce virtual characters in the AR scene to act as teachers, tutors or training guiding characters (e.g. [46], [74], [75]).

As it can be seen from the previous considerations, there is no unified procedure for the development of AR applications, as the variability of needs is large in the educational and training fields. Moreover, there is a gap between application developers, mainly from programming and IT fields, and educators and trainers who provide the educational value. Several approaches have tried to fill this gap by providing authoring tools to educators and trainers (e.g. [76], [77], [78]). Another approach is the one proposed in STEDUS [79] where a common platform provides access to educational AR applications that have been developed by programmers from the specifications designed by educators.

Despite the large number of research studies in this field, the level of acceptance is still limited. Some reasons may be that as an emerging technology, people are not used to utilize the technology or they even do not know what AR is. This applies not only to educators, but also to students who, as reported in [80], may feel overwhelmed with the large amount of information and the complexity of the educational tasks. In that paper, the authors also point out that some educators are unwilling to let the students experiment with the AR applications by themselves fearing that they may get lost in the process. Another problem may be, as stated before, that the majority of the applications are developed by programmers without the appropriate pedagogical point of view which may lead educators to ignore the potential capabilities of the technology.

3.3. Travel and Tourism

The travel and tourism industry is one of the fastest gowning industries across the world. For instance in Europe, it comprises 1.8 million enterprises, many of these being SMEs, and contributes to more than 5% of European GDP [81]. Tourism includes the activities of persons travelling to places outside their usual environment for recreation, leisure, business and other purposes. The tourism market relies heavily on information and technology plays an increasingly pivotal role not only in the delivery of it but also in the overall enhancement of tourists' and travellers' experience.

Among the various technologies employed in this heterogeneous industry (which includes tourist attractions, accommodation, bars and restaurants, transports, tourist offices, etc.), AR can be used across the value chain. In particular, AR can be used to access information about physical objects "on-the-go" via mobile AR browsers which deliver information through spatially registered virtual annotations and can function as an interface to (geo)spatial and attribute data [82]. For example, one can browse the history of Greece, see the Berlin Wall and other historic sites as well as see information about nearby business, e.g. the today's menu of the restaurants nearby. AR browsers have achieved more than 20 million downloads from mobile app stores [83] and some of the most common examples are Wikitude (launched in 2008) [84], Layar (launched in 2009 by SPRXmobile) [85] and Junaio (launched in 2009 by Metaio) [86]. Other, less popular, AR browsers are Sekai Camera (launched in 2009 by Tonchidot) [87], Tagwhat (launched in 2010) [88] and Argon (launched in 2011 by Georgia Tech) [89].

Exploring new places is the most common motivation in tourism and therefore navigation is very important. AR technology can also be used to facilitate access for visitors to and within a destination by overlaying virtual arrows on the live view in real time that indicate the direction the user should follow. Currently, there are many mobile applications available that utilize AR; few focus exclusively on pedestrians (e.g. [90]) or drivers (e.g. [91]), while a larger number focus on several modes of commuting or travelling (e.g. [92], [93], [94]). Moreover, the automotive industry is also interested in in-car AR as a means of enhancing drivers' safety. For instance, Mercedes-Benz is developing an In-Vehicle Infotainment System based on AR for its in-car navigation system which would have a split-view display in order to minimize distraction for the driver. Apart from navigation, the translation of information (e.g. menus and signs) is also very important in the tourist sector and AR can be utilized to instantly translate foreign text by pointing the mobile device's camera at the text (e.g. [95], [96], [97]).

AR can be used in cultural institutions for engaging visitors and enhancing their experience through interactivity. For example, the Digital Binocular Station (DBS) used in Canterbury Museum is based on a traditional binocular station, but adds a layer of interactive, 3D stereoscopic digital content between the user and their view [98]. Stedelijk Museum in Amsterdam used AR to install artworks in a local park [99], the Royal Ontario Museum used AR to add flesh to the bones of dinosaurs [100] while the Asian Art Museum recently unveiled a new AR application for its Terracotta Warriors exhibit [101]. AR applications have been also developed for further promoting tourism in particular regions. For instance, Tuscany+ [102] and DiscoverHongKong-City Walks [103] applications offer visitors in Tuscany and Hong Kong, respectively, an interactive, real-time AR-based guide for experiencing city's vibrant living culture while AR city tours are offered in Seville [104]. There are also mobile tourist guides which utilize AR but are not limited to a single region such as GuidePal [105], mTrip [106], and GeoTravel [107].

Despite the increasing use of AR in tourist-related mobile applications, there are several obstacles reported in the literature which prevent the wider adoption of this technology. One such problem is the lack of interoperability across mobile platforms which affects both application developers and content aggregators [108]. Moreover, many apps often require Internet connection which can limit greatly their use considering the high cost of data roaming [109] (although the effect of this is likely to decrease in EU when data roaming charges may get unified across Europe). Other major factors hindering the adoption of AR applications for tourism are the scarcity of available content, the poor quality of the user interface and user experience, as well as issues with battery life likely caused by the variety of sensors involved [110]. For example, many of the existing marker-less smartphone AR applications do not support extensively value-adding functionalities for mobile tourism such as Context-aware push of information, m-Commerce, Feedback and Routing [111]. In addition to technical limitations, aspects such as information abuse or oversaturation for marketing reasons and data privacy could also affect negatively the adoption of these in applications in the tourism sector [112].

In order to facilitate the adoption of AR in tourism, a number of critical design issues have to be addressed. For instance, according to [109], the criteria that need to be taken into account when developing an AR application specifically for tourism are (a) efficacy (e.g. does the system work as it was planned for and does it provide the required information to the right users?), (b) efficiency (e.g. are the AR application functions fully exploitable?), and (c) effectiveness (e.g. does the new AR system provide better tourist support?). AR app developers focusing on tourism also need to take into account future trends in this sector such the shift of demand from mass tourism to more tailor-made customized tourism for individual travellers [113]. All in all, innovative AR solutions can become the key to the promotion of tourism or tourist regional development therefore. However, it also important for relevant stakeholders to come along on this move toward innovative strategies, knowing that it will cost money, require a lot of training, and take time [114].

3.4. Medicine and Healthcare

Medicine is one of the most important industries for human well-being and health. The technological development has enhanced the quality and possibilities of medicine. Many illnesses and abnormal conditions that earlier caused constant pain or death, such as cardiovascular diseases or many cancers, can now be cured by modern technologies, pharmaceuticals and surgery.

The possibility of using AR and VR in medicine was recognized already in the late 1990s [115]. Benefits of using AR in medicine include a possibility to increase the (virtual) transparency of the patient, higher accuracy and precision with fewer risks, possibility of diagnosing the patient's condition during surgery and guided surgery within less time [116]. AR is especially useful in surgery. Together with 3D visualization and modeling, AR can be used to provide a virtual transparency of a patient and thus, help surgeons to conduct minimally invasive surgery that provide greater benefits to patients [117]. AR supports Minimum Invasive Surgery (MIS) approach, aiming at the least possible inconvenience for the patient. AR may also prevent patient and operator from other risks such as exposure to radiation in some procedures [118]. In orthopedics, VR training applications for shoulder and knee operations have been used with good results [119], [120], [121].

Augmented reality has proven to be useful in after-stroke re-education (e.g. [122], [123], [124], [125], [126]). Luo et al. [125], [126] got promising results by creating an AR training environment for rehabilitation of hand opening in stroke survivors. They used mechanical devices to assist finger extension. However, the patient required a therapist to assist wearing the equipment. A musical AR game has been created to develop patients' motor coordination, providing a natural fingertip/toe tipbased interaction [127], [128]. An AR-based rehabilitation system for daily practice, using a 2-D web camera and fiducial markers was proposed by Alamri et al. [129]. A table-top home-based system proposed by Mousavi Hondori et al. [123] rehabilitates wrist, elbow and shoulder by tracking the patient's hand and creating a virtual audio-visual interface for performing rehabilitation-related tasks that involve wrist, elbow, and shoulder movements. The system can be used by the patient and a therapist may follow and modify the exercise as the system sends the real-time photos and data to the clinic for further assessment.

Presurgical cranial implant design technique that develops custom fit cranial implants prior to surgery using the patient's computed tomography (CT) data was pioneered in 1996 [130]. In 2004, it was shown that virtual 3D cranial models based on patient CT data can be created in a haptic AR environment, thus, using force feedback to simulate a sense of touch, which is essential while creating realistic and reliable models [131].

Despite the numerous benefits of AR in the medical field, some issues have arisen, including, for example, incorrect visualization of interposition between real and virtual objects [132], [133]. A challenge in surgery is that the position of organs and tissues cannot be estimated but the surgeon must know them exactly. AR projections do not always correspond the reality because of the structure of tissues in human body and patient's subtle movements, such as aspiration and other tissue function [115], [134]. An attempt to provide more realistic real-time data was made by Konishia and al. by integrating laparoscopy and 3D-ultrasound images, i.e. combining images inside and outside a body, provided by two different imaging methods [134].

As described earlier, AR is beneficial also in training doctors, as well as in medical education and while explaining patients their condition and treatments. AR provides a realistic method to train medical skills, as well as objective feedback, without a presence of an expert supervising the exercise [136]. AR aids medical trainees to acquire proficiency in required procedures [137]. The enhanced reality compared to traditional learning methods enhances memorability of the procedures and thus, the efficiency of training and the speed of learning [138], [139].

3.5. Retail and Marketing

The retail industry involves the sale of products and merchandise online or from a static location, such as a physical store. It is also coupled with marketing activities undertaken by a retailer with the purpose of promoting awareness of the company's products and increasing sales. While e-commerce has improved dramatically over the last 20 years since Amazon was founded, still a large percent of all retail commerce is being done in the brick-and-mortar world. As an attempt to bridge this gap, many retailers, small and large, have increased their investment in their e-commerce divisions but one of the biggest challenges they face when entering the online shopping space is the lack of interaction with physical products. Moreover, retailers have traditionally relied on print advertising campaigns or other media to promote products. With the increasing use of tablets and smartphones, the use of augmented reality technology could completely transform the way traditional retail and marketing activities are done [140].

In the retail industry, AR can bring major benefits both in the online and brick-and-mortar sectors by enabling the interaction with virtual objects and enhancing the shopping experience with capabilities offered by the Internet, respectively. Specifically, there are many advantages in using AR in the retail industry [141]: It can improve the conversion rates and reduces returns for clothing stores via the use of virtual fitting rooms. Such rooms allow customers to sample products online as clothes are automatically overlaid on the consumer`s real-time video image through their webcam. For example, both Bloomingdale and J.C. Penney have tested the use of virtual dressing rooms, which let customers "try on" outfits that appear when they are looking at themselves on a large screen. In addition, the clothing retailer, American Apparel, is also adopting AR technology with the aim of bringing the online experience offline. By using a particular application, in-store patrons can scan the item to see the product in different colours and read reviews by other customers who have bought that item [142].

Besides clothing, AR allows customers to try a product before they buy it with the use of a 3D preview, as in the case of Lego. Major beauty retailers also plan to offering customer a new way to try out new makeup with the help of 3D AR Makeup and Anti-Aging Mirror which was unveiled at the 2014 CES conference by ModiFace. Moreover, the assembly of models can be digitally displayed on products, such as furniture, that require at-home assembling. This increases convenience and perceived flexibility to the online shopping experience. For instance, IKEA has utilized AR for visualizing the 2014 product catalogue and providing a virtual preview of furniture in a room. In 2014, Matterport, along with a growing and diverse list of companies, will start selling software to the public that can create a 3-D rendering of indoor spaces such as the inside of a house. People can view the rendering on a computer screen, explore the house as though taking a video tour and add objects to rooms. Such application could be also be utilized in construction, home improvement and insurance industries. Furthermore, AR can be used to optimize the warehouse space resulting in the reduction of time needed to process orders. For instance, Vuzix and SAP have created a partnership with the aim of developing AR applications for data collection and warehousing.

With the help of AR technology, additional information can be displayed about products in order to enrich the shopping experience, enable customers to search for nearby deals and attract them inside a store. Yihaodian, China's largest food e-commerce retailer launched in 2012 a chain of 1000 "virtual stores" with an AR mobile app that allows customers to shop in public places across the country. Glashion, a fashion app recently released for Google Glass allows users to purchase fashion items online as soon as they spot someone else wearing it. Pocket BargainFinder, a handheld device for augmented commerce allows customers to physically inspect products while simultaneously perform a price comparison online [143]. Another AR application, called TrackMyMacca, was lunched in Australia with which customers of McDonald's could see what their meal is made of [144].

AR technology can also be regarded as an effective marketing to enable a new form of visualization and interaction. In particular, AR can enhance brand recognition and empowers advertising campaigns. For example, Accenture has developed an app for Google Glass that allows customers to explore Toyota showrooms and check out new cars. Another example is Unilever, a global hygiene and personal care brand, launched in Buenos Aires an interactive AR campaign to promote one of their products [145]. AR, which has been used in marketing campaigns, can be seen as a form of experiential marketing because it focuses not only on a product/service, but also on an entire experience created for the customers [146], [147].

While the use of AR in retail and marketing is increasing, there are still several obstacles preventing its mass adoption. Specifically, only a fraction of consumers with Internet access have a webcam and the majority of mobile handsets are unable to support AR activities or have a limited computational power. Also, awareness is low and not every product is outfitted with the ability to display the interactions [148]. Therefore, relevancy of idea with the product should be taken into consideration when designing AR applications for the retail and marketing sectors.

4. Analysis of Drivers and Bottlenecks

AR has been an active research topic during the last decade and its importance will likely increase in the future as technological advancements (e.g. new hardware devices, more computational power, etc.) could fuel further the development of AR technology as well as help overcome existing bottlenecks. Several benefits and bottlenecks regarding the use of AR in five different domains have been discussed in this paper. Such approach enables us not only to identify the domain-specific benefits/bottlenecks but also to expose potential commonalities. One of the most commonly encountered benefits of AR across the examined domains is the reduction of various types of costs. For instance, as a tool for learning and guiding (e.g. in maintenance tasks, in medical procedures, etc.), AR helps to learn faster and reduce errors which leads to increased time savings, safer procedures and less operational costs. Furthermore, AR can also reduce fixed costs such as those related to the purchase of various items as virtual objects can replace physical ones (e.g. using virtual robots instead of real ones for the path planning phase). Moreover, the use of virtual objects is also beneficial in terms of reduced damage costs (i.e. virtual items cannot be damaged by misuse) as well as development costs (e.g. in product development, the use of virtual prototypes can be employed in the design phase to fine-tune the development of the final physical prototype).

AR is still an unknown technology for many people. Although this is still a problem for the expansion of the technology, its fast learning curve and the curiosity make it already suitable for many contexts, like education, training, or leisure activities (e.g. tourism). Moreover, the use of AR also allows users to visualize content that cannot be easily viewed otherwise. For example, it is possible to see the 3D disposition of the planets in a desk-size environment, recreate in-place 3D environments of historical moments, view the interior of the human body or understand 3D objects that are usually printed as images in books. Although the visualization of 3D content has been done for several years in VR field, the possibilities of tangible interaction and in-place visualization (mixing reality and virtuality) that AR provides, together with the fun side of its use, make AR a solid alternative that can overcome traditional VR applications in several fields. However, as it has been explained in this paper, there are also some common problems that still prevent AR from being a mainstream technology.

Nowadays, there is no standard for the use of AR technology. Although the creation of an all-purpose standard would be a very challenging task, defining several standards for different purposes would be a more realistic approach to follow. For example, the standardization of AR use in the tourism field has already shown some progress when considering the related AR browsers. However, the content of these browsers is still not common as it could be, for instance, in traditional web browsers. For this reason, the majority of existing applications are still of prototype level with the lack of flexibility being often a common denominator. Nonetheless, several tools have been already developed to help overcome the flexibility problem, but the efforts need to be still increased.

From the technological point of view, there are two main problems nowadays which hinder the adoption and diffusion of AR; these are the lack of accuracy (e.g. light conditions affect to the right alignment of virtual objects) and the time consuming algorithms (which may be an important bottleneck in some devices with limited computational power). While both of these problems have been tackled during the last years and some progress has been made towards achieving higher alignment accuracy and reducing the algorithms' complexity, the demand for more robust AR applications is yet to be met.

In the recent months, a new bottleneck has arisen as a major issue: the compatibility with social practices. As we have described before, there is a current trend on new devices in form of glasses or HMDs. Although the majority of these devices are used in specific environments (e.g. training rooms, maintenance facilities, etc.), some of these devices are beginning to appear as common accessories in everyday life (e.g. Google Glass). The possibilities of these devices in their daily use are unlimited and their use could boost the development of AR technology. However, the use of these devices is still far from being socially accepted. Apart from the inherent problem of getting distracted by the virtual content displayed on the glasses while establishing social relationships, one crucial problem is the privacy issues that may appear, as stated in [149]. In that paper, they explain that a new technology may create privacy concerns at the beginning but this may change when we get familiar with the devices and with the real value of using them. Despite this fact, the problem of social practices may become so important in the early stages of the product commercialization that even Google has release a list of "do's and don'ts"

[150] targeted to the users that are currently testing the device.

Last but not least, there is a risk to overwhelm users by a large amount of information. Therefore, it is crucial, to carefully analyse the information before presenting it to the users (e.g. shops in an AR city application or instructions for maintenance) in order to ensure that the amount of information conveyed is sufficient for the application's purpose, but not too much or more than needed as it may distract the user and limit the outcome of the application use.

If we analyse the drivers and bottlenecks presented here with Rogers' innovation diffusion theory (mentioned in the introduction), we can conclude that three out of the five characteristics are already fulfilled by AR, as it is shown in Table **1**. AR shows advantages over VR and other multimedia technologies, it implies low complexity in its usage and it is relatively easy to try nowadays (although not all devices are prepared for AR technology). However, there are still two aspects that are not met yet. Although technically AR can be used nowadays, there are still some compatibility issues in terms of social practices for some devices (e.g. AR glasses). On the other hand, the observability of the benefits of the technology is not clear for all potential users.

Table 1. Roger's theory applied to AR

Roger's theory applied to AR	
Relative advantage (the extent to which it offers improvements over available tools).	Compared to VR, AR offers new advantages (e.g. Visualization of virtual worlds mixed with real environments)
Compatibility (its consistency with social practices and norms among its users).	Some devices are not socially accepted yet due to privacy issues.
Complexity (its ease of use or learning).	AR is easy to learn and to use.
Trialability (the opportunity to try an innovation before committing to use it).	AR is easy to try nowadays as many applications are freely available (especially for smartphones, tablets and consoles). However many users do not have the required devices to test the applications.
Observability (the extent to which the technology's gains are clear to see).	The benefits are not clearly seen from the consumers' point of view. Some users are not aware of the benefits of the technology while others need more information to know if AR would return the investments made in the implementation of the system (e.g. investment in AR maintenance systems, investment in marketing and retail solutions, etc.).

In today's economy, network effects due to technology standards are very important because there is a high degree of interrelation among technologies [10]. A technology has a network effect when the value of the technology to a user increases with the number of total users in the network. Network effects in adoption can arise from two different but related reasons, often characterized as direct and indirect. Direct network effects are present when a user's utility from using a technology directly increases with the total size of the network. Specifically, in AR direct network effects are relevant when considering e.g. the user-generated content in AR browsers where the higher the amount of content is available, the more probable it is to attract new users or in the case proposed in [79], where a larger number of users implies a larger number of available applications. Indirect network effects also arise from increased utility due to larger network size, but in this case the increase in utility comes from the wider availability of a complementary good [10] such as smartphones, tablets, head mounted displays and AR glasses.

5. Conclusions

As a conclusion, this paper has presented an overview of AR and related technologies and has introduced the benefits and most common problems of its use in different fields. Table 2 presents a summary of the drivers and bottlenecks analysed in this paper.

Table 2. Summary of drivers and bottlenecks in the adoption of AR

Drivers		Bottlenecks	
Reduction of costs	Costs can be reduced by using AR in several manners (e.g. reducing costs in manufacturing processes, reducing errors, safer procedures, etc.)	**No standard and little flexibility**	There is no current standard for AR applications. The majority of applications do not allow their use in other domains and thus, the creation of new applications is usually required with the additional effort and time that it entails.
Fast learning curve	The technology is intuitive and easy to use. Therefore, the adoption from newcomers is easier than in other technologies.	**Limited computational power**	Many AR applications require complex computer vision algorithms to work. These algorithms tend to be time consuming for current devices (especially for mobile devices).
Curiosity	The idea of "expanding" the real environment with virtual content usually catches the attention of users that feel tempted to use the applications.	**Inaccuracy**	Some of the techniques are still not accurate enough to provide a robust localization of the virtual content to be displayed in the augmented view.
Tangible 3D visualization	Visualization of 3D content in real life and the possibilities of interaction offer an added value.	**Social acceptance**	New devices (especially glasses) are in their first years of existence and they have not been fully accepted in social practices.
Fun	The technology offers a component of fun in many cases that can be useful in several fields (especially in education and tourism).	**Amount of information**	The amount of information to be displayed in the augmented view may exceed the needs of the user. This problem may become critical when advertising becomes popular in AR applications.

From the aforementioned considerations, it can be concluded that AR technology is not mature enough to be mainstream (at least not as mature as VR is nowadays), but the steps followed by developers are pointing in the right direction. Also, changes in the perception of the technology from the users in terms of social practices and the perception of the benefits from its usage are needed to enhance the acceptation of the technology. Finally, an increase of the number of users and devices may create a network effect that can boost the implantation of AR as an everyday life technology.

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