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How Blockchain, Virtual Reality and Augmented Reality are Converging, and Why

Alberto Cannavò, and Fabrizio Lamberti

Politecnico di Torino, Dipartimento di Automatica e Informatica, Torino, Italy

Abstract—Nowadays, breakthrough technologies such as Virtual Reality (VR), Augmented Reality (AR) and Blockchain have definitively attracted the attention of a huge number of investors worldwide. Although, at first glance, Blockchain (traditionally used for financial services) seems to have little to none to share with VR and AR (originally adopted for entertainment), in the last few years several use cases started to appear showing effective ways to integrate these technologies. In this paper, an overview of opportunities investigated by current solutions combining VR, AR and Blockchain will be discussed, showing how they allowed both companies and academic researchers cope with issues affecting traditional services and products in a rather heterogeneous set of application domains. Opportunities that could foster the convergence of these technologies and boost them further are also discussed.

I. INTRODUCTION

Blockchain, Virtual Reality (VR) and Augmented Reality (AR) are rapidly evolving technologies which largely captured the attention of industry, academia and, lately, also end-users.

Considering the widely accepted definition, a Blockchain is a distributed ledger, that can be used to handle digital transactions, i.e., peer-to-peer messages exchanged among nodes, over a decentralized network [1]. In order to add a new transaction to the Blockchain (through the process exemplified in Fig. 1), all the nodes belonging to the network must verify it by using a majority consensus mechanism that can be implemented in different ways [2]. This mechanism allows a given process or service to remove the need for relying on a *trusted third party*, like a bank or a notary [3]. Each node is in charge of storing a secured copy of all the transactions. Since altering and/or deleting stored information is extremely difficult, the Blockchain ensures that

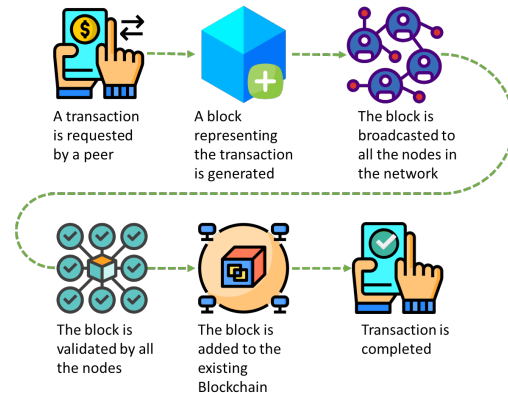


Fig. 1: How Blockchain works.

the transaction history can be obtained at any time, guaranteeing its transparency and immutability [4].

After its birth, which can be dated back to 2008 (when the use of this technology was first proposed) and 2009 (when the first implementation was actually delivered) [5], Blockchain has been longly associated with cryptocurrencies and financial services. However, in recent years, the attention started to be shifted also to other domains. More specifically, according to a report by Outlier Ventures [6], on a sample of 700 companies whose business was not centered on cryptocurrencies, 33.8% was operating in the field of Artificial Intelligence, 14.7% in Banking, 10.9% in Analytics, 10.7% in App development, 7.8% in Business-to-Business (B2B) services; the remaining 22.1% was working in areas such as Advertising, Asset management, Tourism, Education and Gaming.

Unsurprisingly, many of the companies focusing on the latter domains developed their business by combining Blockchain with other emerging technologies, including VR and AR. This choice is clearly related to the fact that, after the acquisition of Oculus by the co-founder of Facebook, Mark

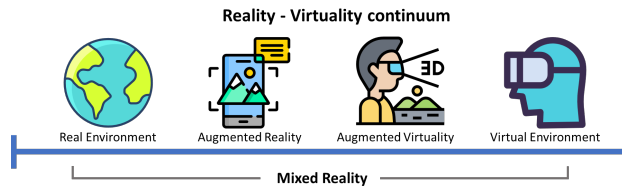


Fig. 2: Reality – Virtuality continuum [10].

Zuckerberg, in 2014 for \$2.3 billion [7], VR and AR attracted huge investments by big companies like Google, HTC, Samsung, and Sony, to name a few [8]. According to forecasts by Statista, the estimated market size for these technologies will exceed \$18 billion in 2020 [9].

VR and AR belong to what is commonly referred to as the *Reality – Virtuality continuum* (Fig. 2), i.e., the various ways in which virtual and real objects can be visualized through a display [10]. On the one side, according to the definition in [11], the goal of the AR is to let users visualize the real world “augmented” with digital contents superimposed on or composited with the real-world objects; ideally, AR should allow the users to see the real and the virtual objects coexist in the same space. On the other side, with VR users are immersed in a fully synthetic environment; they cannot see the real world around them, which is totally replaced (rather than supplemented) by virtual contents.

After a long history of niche applications in laboratory settings, advancements in graphics hardware and software finally enabled the development of high performance, cost-effective solutions covering the whole continuum [12], [13]. Market products range from dedicated systems like the all-in-one Quest kit for VR by Oculus [14] or the HoloLens AR glasses by Microsoft [15] to very cheap accessories like the Google Cardboard [16] that let any user access VR and AR experiences using his or her own portable device at roughly no extra cost.

Although the use of VR and AR technologies is often associated with entertainment and, since few years, industrial applications, recently the availability of a wide spectrum of consumer devices stimulated the exploration of many other domains [17], with a number of successful use cases in the fields of training, healthcare, architecture, etc. [18].

While the widespread diffusion of Blockchain as

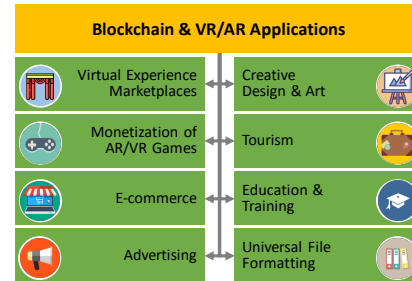


Fig. 3: Domains in which the combination of Blockchain and VR/AR has been experimented yet.

well as of VR and AR are there for all the see, considering their different goals one may ask why they have been used together? What are the advantages possibly coming from their integration? Since there are already some concrete examples, what are the application domains in which integration has been/could be more promising? This paper tries to provide some answers to the above questions, by discussing selected use cases that have been developed so far in a set of representative domains.

II. BLOCKCHAIN FOR VR AND AR: USE CASES

By analyzing systems that have been either presented in literature works or are available as commercial products, a number of use cases that combine Blockchain with VR or AR and encompass a set of application domains ranging from video-games to education have been identified (Fig. 3).

A. Virtual Experience Marketplaces

A first use case where a combined use of the said technologies has been explored concerns the possibility to let users access virtual experiences after paying a fee/ticket. By leveraging VR, users can attend live and/or on-demand events, such as concerts, sport matches, conferences, etc., by wearing a Head Mounted Display. Most of the profitable events worldwide could be easily tailored to VR/AR technologies, allowing a wider number of people to attend (or better, participate in) the events. This alternative way of enjoying events would be more realistic than watching them on television and less expensive than attending in person. The affordability of VR/AR compared to the high costs for tickets of events like, e.g., the Super Bowl, the Final of

the UEFA Champions League, a Cirque du Soleil performance, etc. could represent a key aspect for the widespread adoption of these solutions.

If in these solutions VR/AR could be used to bring users to their favorite events, the Blockchain may be exploited as a payment method for buying tickets or reserving seats. For instance, the company named Ceek [19] offers its users the possibility to participate in immersive music and entertainment experiences. Past events like the U2's concert at the Rose Bowl Stadium in Pasadena [20] or the Katy Perry's Live at Rock in Rio [21] can be accessed on-demand. Ceek supports various content formats, from 180°/360° videos to full 3D experiences.

Another example of a Blockchain-based platform for virtual events is RevolutionVR [22]. This platform allows users create and visualize high-fidelity VR environments where the RVR token (an ad-hoc cryptocurrency) can be used for purchasing games and other interactive experiences, as well as digital assets such as 3D models, animations, sounds, etc.

B. Monetization of AR/VR Games

Another chance for leveraging the combination of the technologies considered in this paper lies in the monetization of AR/VR games. In fact, by analyzing the money spent by gamers in the most commons platforms/online stores, it appears that they are willing to pay not only for purchasing the games themselves, but also for buying the assets to be used within those games. The case of Fortnite [23], a popular game available also in VR, is emblematic. According to the report by Lendedu [24], on a sample of 1,000 Fortnite video-gamers 68.80% spent, on average, \$84.67 for in-game purchases. Considering the huge number of gamers (more than 80 million according to the statistics by [25]), it appears that a game that, technically, is free to play may generate incomes for more than \$6.7 billion. Another interesting example of the potential market for VR/AR games is represented by Pokémon Go, a mobile AR game which was downloaded more than 500 million times in the two months following the launch and generated revenues for \$470 million in just 82 days [26].

Companies started to explore the integration of Blockchain in games to let gamers create, sell, and purchase digital assets by using a single currency.

The fact that video-games tend ever more to be distributed worldwide could represent a push towards the selection of the Blockchain to support these trading activities; the "global market" that could be created this way would make it possible for users to sell and purchase both real and digital assets without caring, e.g., about currency exchange. One of the companies that grounded its business on the above idea is Vibe [27], which created an AR/VR Blockchain-based gaming framework. The framework includes a first-person shooter VR game named "Vibe or Die" in which users can earn crypto-tokens by performing actions like, e.g., killing other players, and an AR game that lets them create and visualize holographic performances encompassing a wide range of entertainment possibilities, such as singing, dancing, and acting.

Another Blockchain-based game that is under development is CryptoCarz [28]. The game relies on the Blockchain to let the users purchase, customize, and finally race with virtual sports cars. Within the game, users can buy specific kits and mods that make each car a "non-fungible token", i.e., a digital asset that is unique, indivisible, and valuable. Thus, the car becomes not only a means to increase the probability to win the races, but also a collectible item. The game exploits VR to let the users compete against other players and explore their cars within an immersive virtual environment.

C. E-commerce

Although consumers may have a number of concerns with e-commerce pertaining, e.g., to the difficulty in estimating the way a dress actually fits or the size of a piece of furniture to buy, it has become very common purchase option for several product categories. According to Statista, in 2019, e-commerce sales worldwide were estimated in \$3.53 trillion and by 2022 they are expected to grow up to \$4.93 trillion [29]. It is well-known that the attention of possible buyers can be captured by adding images or videos to product descriptions. However, the impact of VR and AR can be much higher, since it could allow customers to have a clearer idea of how the product match their expectations, without having to travel to a physical store. Moreover, these technologies have proven to be capable of generating greater sense of immersion,

novelty, and enjoyment with respect to pure web-based presentations, leading to an increased attitude towards purchase intention [30]. Unsurprisingly, the list of product makers and retailers that started to look at VR and AR as tools for improving their business is growing every day.

In this context, the Blockchain has been exploited as a tool for selling and purchasing any type of products (cars, clothes, accessories, etc.). An example of combined use of the considered technologies is reported in [31]; here, a so-called CryptoAR Wallett is proposed, which leverages AR for visualizing products and a cryptocurrency for managing product sales. A preliminary study showed that, compared to a common wallet interface based on a 2D graphics user interface, CryptoAR Wallett enabled a higher level of interaction and the possibility to visualize richer information. The improved experience increased the users' level of trust and satisfaction, making them more willing to use both e-wallets and e-commerce services.

Another example is represented by Cappasity [32], a platform that allows users to create 3D/360° product photos that can be easily embedded into websites, mobile apps, and AR/VR applications of online retailers. The platform includes a 3D scanner app enabling the creation of 3D images of the products, which can be used to provide customers with interactive in-store browsing-like experiences. Generated images can be traded using Blockchain-based tokens. Moreover, Cappasity makes use of the Blockchain also to store product information and authorship so that to protect customers against copyright infringements and illegal redistribution.

D. Advertising

The presence of ads in many applications and games has become very common, especially on mobile devices. This phenomenon is due to the fact that more and more companies are considering advertisement as their main source of revenue. Users and gamers, in general, accept the presence of ads, considering it as the normality now. The diffusion of virtual environments as spaces alternative to social media where users can meet opened the way to new forms of VR/AR-based advertisement, as well as to the implementation of strategies for monitoring the users' behavior in such

environments, especially regarding how well money for advertisement has been spent. For instance, platforms based on Blockchain have been developed to track the movement of a user's eyes as he or she navigates an immersive environment including a number of ads. At the end of the experience, the user can receive a compensation in cryptocurrency depending on the number of interactions with ads he or she actually had. A platform based on such a usage-based paradigm is, e.g., GazeCoin [33], in which users actually pay only for the amount of time they have been engaged with a given content.

E. Creative Design and Arts

Among the new application domains for VR and AR, creative design and arts are two fields that are receiving lot of attention given the new interaction possibilities offered to both professionals, artists and customers/end-users. For instance, in the last few years, a number of digital artworks started to be created by various artists, including both VR experiences like, e.g., "La Apparizione" by Christian Lemmerz (available at \$100,000) and the "C.S.S.C. Coach Stage Stage Coach Experiment Mary and Eve" by Paul McCarthy (priced around \$300,000), as well as AR content such as Marina Abramovic's "The Life" sculpture (estimated around \$775,000).

As these works started to be exhibited in museums and art galleries, it became essential to develop mechanisms able to protect them against legitimate concerns such as hack or theft, the creation and diffusion of copies, copyright infringement, etc. Blockchain technology immediately appeared to be a possible answer to the above needs, as it ensures hack-proof protection (not only for VR/AR contents). With Blockchain it is also possible to verify if the artwork is unique or it has been duplicated, thus removing the possibility to trade stolen digital artworks. Ownership can also be easily managed.

A working solution in this domain is represented by Decentraland [34], a platform that allows users to create and sell different types of digital items, such as avatars, wearable assets, and artworks by leveraging a Blockchain-based infrastructure.

F. Tourism

According to [35], tourism is one of the most growing industries of the last years, and is among

the domains that are benefiting more from technological advancements.

As easily predictable, VR and AR rapidly became the technologies having the greatest impact on this industry. These technologies can be used, for instance, to promote travels by showing a preview of the destination through 360° videos and VR experiences, as well as to provide users with in-travel AR-based entertainment experiences (e.g., enhancing museum visits and city tours by overlapping additional cues about specific points of interest, breaking the communication barriers through systems offering instant translations, etc.).

For what it concerns the Blockchain, the benefits deriving from its application to tourism are manifold; Blockchain can be used, for instance, to make secure, reliable and traceable payments, to develop automatic identification services (reducing the check-in time at the hotel or at the airport), to design customer loyalty schemes (e.g., awarding tokens that can be exchanged for additional services), to implement baggage tracking systems (which can share this information among the various parties involved in airport handling), etc.

An example of a combined use of the technologies studied in this paper is offered by SpaceTravel [36], a startup focused on making global tourism seamless and cost-effective. SpaceTravel offers a dedicated app that allows customers to navigate, search for nearby stores, book accommodations and transport means, and look for possible discount offers. The app uses AR to let travelers begin their journey or relive past travel experiences from their home; Blockchain allows travelers to make pre-purchases for the trip, automatically amending them in case of changes to the itinerary. Besides commercial solutions, other examples are offered by the scientific literature. For instance, the authors of [37] proposed to integrate Blockchain and VR to develop virtual wildlife tourism experiences that leverage non-fungible tokens as collectible items for boosting parks' revenues. Collectable items are visualized as real-life objects or pets, like the feedable, virtual creatures named CryptoKitties [38].

G. Education and Training

A number of studies already proved the advantages of using VR [39] and AR [40] for educational

or training purposes, since they provide learners with the possibility to immerse themselves in interactive experiences designed to ease the visualization and understanding of difficult concepts, thus making learning more engaging and effective. VR and AR also offer educators new tools for monitoring learners' advancements and quantitatively evaluate their results, since virtual learning experiences make the (continuous) collection of performance data easier than in traditional settings.

With respect to Blockchain and its application to the considered field, it is worth observing that a number of education institutions already started to experiment with this technology. For instance, the National University of La Plata (UNLP) used Blockchain for verification of academic achievements [41], the Holberton School in San Francisco tested it as a means for helping employers to check academic credentials, whereas at MIT it was exploited to deliver diplomas on mobile devices.

Pairing VR/AR education-oriented solutions with Blockchain may open up to a number of new applications. As a matter of example, entire curricula' and/or courses' material could be made available as immersive experiences or digital assets for augmented lectures through Blockchain-based databases, which would be able to protect users' identity while providing access only to authorized users and securely tracing learners' activity. For instance, the work in [42] presents an educational platform, named VoRtex, which relies on Blockchain and VR to support secure learning into virtual environments. The prototype implementation uses VR to create immersive experiences where the users are free to move and interact with other users or learning material. The experiences are designed to present gamification features (such as role-playing) and promote teamwork. The Blockchain is used to protect data ownership and integrity. More specifically, data such as educational material or user-generated content are synchronized among all the connected users over the Blockchain. Moreover, the identification of the users' role through the Blockchain makes it possible to define access control rules and allow, e.g., only the teacher to manipulate the lesson contents or only the students attending the lesson to visualize the learning material.

H. Universal File Formatting

The wide adoption of VR/AR technologies as well as the growing diffusion of new applications in heterogeneous domains ask for ways to limit as much as possible issues concerning file formatting. Errors due to the use of wrong or unsupported file formats are very common in applications that, e.g., request users to download files from the Web, publish and share generated content online, etc. Making the file formatting totally transparent to the final users that consume it is one of the most important goals for companies that leverage digital technologies, including VR and AR.

The Blockchain could help in the standardization of file formats since it is able to create a single technological platform and a standard way for transmitting and sharing data. Besides fostering interoperability, Blockchain would also allow applications to benefit from security properties that characterize this technology.

A domain in which VR/AR and Blockchain have been experimented together and the above issues had to be firstly addressed is represented by scientific research. In particular, the decentralized platform named Matryx [43] provides an ecosystem built on VR and Blockchain to facilitate collaboration among researchers working on cutting edge areas like, e.g., medicine and health, using 3D data. The platform offers the possibility to reward collaborators working on the same project depending on the actual contribution they made to the research by using Blockchain's smart contracts technology.

Another system designed to support collaboration via telepresence is reported in [44], where a Blockchain-based peer-to-peer distribution model is proposed to let users collaborate by sharing the same virtual spaces through AR applications. Each space is uniquely identified by a code stored in the Blockchain. Users sharing the same virtual space can collaborate securely by exchanging audio and video streams, as well as 3D annotations.

III. CONCLUSIONS

The use cases reviewed in this paper suggest that combining VR/AR and Blockchain technologies is feasible and, in some domains, their integration also opened interesting opportunities for companies and academic researchers. By summarizing the

advantages that emerged from the analysis of the considered use cases, it can be observed that VR and AR are generally added to Blockchain-based solutions as enabling technologies able to improve the way users interact with digital content (using gaze, gestures and other natural interfaces), e.g., to create new or enrich existing experiences (virtual stores, immersive events, etc.). In many cases, psychological effects related to how users engage with such content in interactive, 3D environments (e.g., for education and training purposes) are leveraged to improve the effectiveness of the experience.

Conversely, the potential benefits deriving from the integration of Blockchain into VR/AR solutions lie in the possibility to integrate, within unified platforms, digitized economies where assets and payment methods can be managed in a unique and seamless way. In this way, it becomes possible to sell/purchase assets which have not been previously exchanged digitally, and even transform virtual content into valuable (e.g., collectible and tradable) items. In fact, many of the analyzed solutions use Blockchain to protect content and access to them, leveraging security mechanisms offered by this technology to verify products' authenticity and ownership, validate users' identity, etc.

Although the number of integrated use cases is still somewhat limited, there are clear evidences that, in some fields, the considered technologies are converging. Given the growth estimates and the clear benefits outlined by the above review, it is not difficult to imagine that many other applications will be developed in the near future both in the considered as well as in other domains.

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Alberto Cannavò is a Post-doctoral Researcher at the Dipartimento di Automatica e Informatica of Politecnico di Torino, Italy. Contact him at alberto.cannavo@polito.it

Fabrizio Lamberti is a Full Professor at the Dipartimento di Automatica e Informatica of Politecnico di Torino, Italy. Contact him at fabrizio.lamberti@polito.it