IMMERSIVITY

POSITION PAPER

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1. INTRODUCTION

NEM, the New European Media initiative, is the European Technology Platform of Horizon 2020 dedicated to Content, dealing with Connected, Converging and Interactive Media & Creative Industries.

NEM focuses on an innovative mix of various media and creative content forms, delivered seamlessly over technologically transparent networks, to improve the quality, enjoyment and value of life. NEM represents the convergence of existing and new technologies, including broadband, mobile and new media, including creativity, across all sectors, to create a new and exciting era of advanced personalised services.

Following the update of the NEM Strategic Research and Innovation Agenda (SRIA) in 2016 [SRIA], it has been decided to extract the most important research domains and objectives that have to be pushed in the next WP2018-2020, completely in line with the priorities elaborated by NEM community. From these priorities, NEM have promoted the presentation of its position papers tackling the main technical and business opportunities for the sector from a holistic view.

The position paper on immersivity will tackle immersive communication enabling natural experiences and natural interactions with remote people which are very similar to real-time face-to-face experiences and interactions; and immersive content offering novel experiences aiming to improve connection, information, control, cooperation and interaction. Immersive technologies have been selected as one of the Gartner's top 10 strategic technology trends for 2018. It is expected to generate globally by the end of this year 6,350 M€ and be worth 126,950 M€ by 2020.

Virtual reality (VR) and augmented reality (AR) transform the way individuals interact with each other and with software systems creating an immersive environment. Immersive experiences with AR and VR are reaching tipping points in terms of price and capability and are expanding beyond visual immersion to include all human senses.

Integration, immersion, emotion, aesthetics, entertainment and experience have become the key words of our existence. Immersion and Interactivity with content and technology is possible by encouraging users to take a more active role, involving them in more advanced and interactive experiences, even if they have no skills or technical knowledge.

2. SCENE SETTING

Immersive Content usually refers to computer-generated simulation of reality with physical, spatial and visual dimensions. Immersive technologies and virtual reality are a set of computer applications by which humans can interface and interact with computer generated environments. Immersive systems can simulate almost everything from a walk-through of a building prior to construction to simulations of aircraft flight to the operating theatre and to new three dimensional forms of interactive entertainment.

As 3D and immersive technology becomes more integrated and accessible for a wide range of applications and audiences (professionals and the wider public), it will require well-designed user interfaces and innovative content across interoperable platforms including mobile devices, distributed web systems and desktop applications.

Immersion encompasses sensorial and interactive environments to experiment on a "sense of presence", enabling the performing of activities in the digital world (immersive capability to engage people), in artificial, interactive, virtual created scene or 'world' within which users can immerse themselves. It also raises important questions about the embodiment of the user in his/her digital representation. Many applications also expect transfer of experience or skills from virtual reality to real world.

Cognitive and emotional processes about physical content creation and choice will change as well. Virtual sets will allow a user to choose the floor tiles or a piece of furniture for their house on the basis of a virtual, immersive, location sensitive rendering that anticipates how well the tiles or the furniture fits the house. Choosing a different colour for the interior of a car will become possible while looking at the actual physical objects inside the car in the show room. In short, several consumer oriented interactive and immersive experiences will be made available as augmented reality video overlays become accepted and common.

Immersivity uses a lot of related technologies: visual rendering and capturing, gaze, gesture, physiological and psychological status tracking, auditory and immersive auditory rendering and capturing, audio/video correspondence, avatar representation and control, human computer interaction (interaction design and user-centred design), information architecture, usability - the service has to be easy to use and attractive, visual design/user interface (UI), psychophyisics and 3D modelling. In summary a very interdisciplinary approach could offer a great opportunity to improve people's lives and jobs by transforming their experiences.

3. TECHNOLOGY TRENDS

Immersive technologies have many different implementation models and applications, but their primary objective is to provide a rich audiovisual experience.

Tele-immersion

Tele-immersion (TI) is the union of networked VR and video in the context of significant computing and data mining. Tele-immersion enables users in different locations to collaborate in a shared, virtual, or simulated environment, placing their real-time produced, digital replicas together inside a virtual world [TIT]. It promotes the synergies between networking and media technologies to enhance collaborative environments combining audio, video, virtual worlds, simulations, gesture tracking, facial expression and body position capturing, amongst others. It was one of five key technologies identified as necessary for the future use of the NGI.

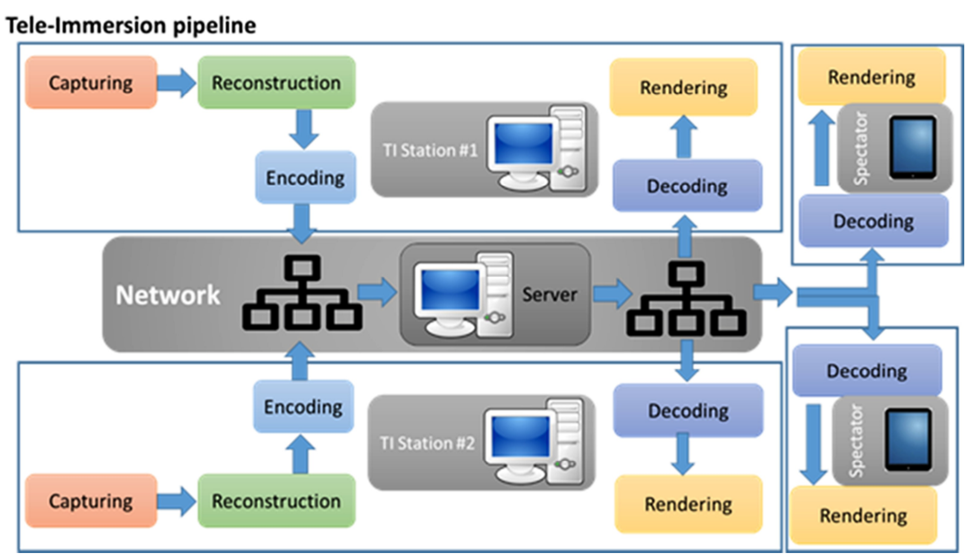


Fig. Tele-Immersion pipeline

TI imposes severe restrictions in terms of bandwidth, latency, storage and computing resources. Quality of Service (QoS) and Quality of Experience (QoE) are top priorities in immersive media, whereas availability and real-time interaction between users are considered critical challenges that need to be met as they ensure a smooth user experience. New network capabilities should provide the response to the volume of data produced by real-time TI applications, so 5G is intended as a key enabler for covering the necessities for real time TI applications. [5GENT]

Virtual Reality

Virtual reality is an artificial environment that is created with software and presented to the user "as a real environment". VR is becoming increasingly more available and commonplace. Because of this, companies are beginning to use the technology to offer consumers new ways to enjoy various forms of media.

VR evolution starts to involve wrap-around display screens, "augmented rooms" equipped with wearables, and *haptics* devices that let you feel the display images. VR evolution using wearable devices raises also the question of controlling, simulating and rendering avatars to ensure embodiment and Presence in places where users cannot directly see their body.

Recently, VR has undergone a hardware-driven revival, which has had massive effects on the ways users experience and use VR compared to a few years ago [OLSZE] [GREB] [ZHANG]. The introduction of the Oculus Rift Development Kit 1 (2013) can be considered a turning point for VR, indicating when VR became accessible, up-to-date, and relevant again [RIVA] [HILF] [KAP] [OLSZE] [BOLET]. Devices like the HTC Vive and the Sony PlayStation VR headsets followed, along with open-source software development kits, such the Open Source Virtual Reality project [KAP] [BARN] [OLSZE] [BOLET]. Low-cost VR solutions that can turn a regular smartphone to a VR headset, were also implemented, such as Google Cardboard, and Samsung Gear VR [BARN] [KESS].

With recent advancements, the hardware costs for VR systems dropped due to such systems gaining traction in the mainstream gaming community [HILF] [OLSZE] [BOLET]. The low acquisition cost of VR hardware transformed VR into a widely-accessible and popular technology over the last few years [MORE] [BOLET]. Regular users can now acquire VR systems at low cost, use them in the comfort of their home, and develop VR applications for the application domain of their choice (Boletsis et al., 2017).

Moreover, the quality of virtual environments has increased rapidly, offering realistic graphics and full immersion [ROSE] (Boletsis et al., 2017, Rosen et al., 1994). Recently introduced VR systems have taken advantage of rapid advancements in the Graphics

Processing Unit (GPU) field to produce high-quality graphics and perform high-fidelity rendering of complex scenes in fully immersive settings [REIN] [BOLET].

Finally, multi-user VR environments have become technically robust, surpassing the lack of intuitive multi-user capabilities of the past, and have begun pushing the boundaries of next-generation social platforms. Current VR systems easily connect distant users, immerse them in multi-user virtual environments, and provide them with all the communication tools (text input, audio chat, collaborative GUI, etc.) necessary for multi-user collaboration and interaction [OLSZE].

The changes mentioned above have revived the potential of VR. The interest of the public and the Human-Computer Interaction (HCI) community in the VR field has reached high levels.

Augmented Reality

Augmented Reality (AR) is a type of interactive, reality-based display environment that takes the capabilities of computer generated display, sound, text and effects to enhance the user's real-world experience by adding a virtual display on top of real images and surroundings.

AR technologies are both hardware and software intensive. Special equipment, such as head-mounted devices, wearable computing gears, global positioning systems, etc., are needed. Real-time tracking and computation is a must, since synchronization between the real and the virtual worlds must be achieved in the shortest possible time interval.

3D Modelling

3D modelling plays a fundamental role in creating objects with geometric shapes and physical behaviours in 3D spaces. Rigid or deformable geometric shapes can be typically represented by polygons (meshes) or freeform surfaces. Meshed geometry is a popular representation widely used today in animation and games. On the other hand, objects' physical behaviours should also be modelled for the purpose of illustrating their physical properties and dynamic change processes. Avatars raise special questions about capturing and faithfully rendering the interactions between the meshes attached to the body and those modelling the digital environment.

High visual quality 3D reconstructions are created in the form of time-varying meshes (TVM) [TCSVT] that produce a large volume of heterogeneous data, thus creating a challenging networking scenario. Although TVM data can be compressed via static mesh compression or techniques that exploit correlations of the data over time, existing compression schemes are not yet ready to support real-time applications.

User interfaces and user interfaces

There are several interfaces coexisting and facilitating interactions. The oldest are graphical user interfaces (GUI) used in software applications. Natural Interface (NI) is becoming more and more popular (i.e. Microsoft Kinect) for gesture-based human–computer interaction. Tactile/Haptic User Interfaces (T/HUI) emphasize the experience of touch or force feedback. Several haptic or tactile devices such as phantom and cybergloves are commercially available in the market.

The true revolution for interfaces comes from VR head-mounted displays (VR HMDs) that are attracting users with enhanced full-sensory immersion in virtual environments. A head-mounted display is simply a small monitor that is shaped like or positioned in a visor so that it takes up the entire field of view of the user or at least ensures that whatever the HMD is displaying is always in the field of view of the user. Creating the illusion of immersion on HMDs requires high framerate, low latency, and high visual quality. The Oculus Rift and Vive virtual reality headsets feature high-end performances that no HMD product has ever done before. However, Oculus Rift has a 80° horizontal FOV as Vive has a 100° FOV. This is nothing compared to the natural human FOV of 210°.

HCI puts strong emphasis on the construction and presention of new interaction metaphors and systems [OULA]. However, the VR-related empirical and conceptual work around UX - over the last few years - may not have been powerful enough to drive the field [BOLET]. We recommend putting more effort into investigating the immersive User Experience, i.e. examining empirical problems and formulating more conceptual work to address the recent developments, improve HCI's problem-solving capacity in VR, and advance the field. HCI practitioners can carry out more new designs based on the updated VR technology. However, without grounding the contributions in empirical and conceptual work, the results will have low impact and problem-solving capacity. Empirical work should be done in such a way that its hypotheses inform design. Designs (constructive work) should embody and be driven by empirically validated hypotheses. Integrative concepts, theories, methods, and models should act as the connecting link between constructive solutions and empirical work [OULA] [BOLET].

Another suggestion to address the need for more UX-related empirical and conceptual work and to plan the future of HCI in VR is to visit its past. Even though the VR field has a long HCI research history, some research questions of the past may need to be re-examined under the new prism. The hardware-driven revival of VR has produced new and updated metaphors, which can strongly affect and alter the User Experience of VR [BOLET]. Several VR-related topics, e.g. text input and locomotion in VR, should be re-examined from empirical and conceptual perspectives, focusing on the User Experience they offer. Even though most of these HCI aspects have been presented and covered in the past [ARNS] [BOW], recent VR developments have generated interest in new designs and constructive work [PICK] [BOZ]. Nevertheless, HCI work should also empirically evaluate these metaphors and "build" concepts and models that would facilitate communication between hypotheses and designs [BOLET].

Naturally, there are steps taken in the right direction (such as the empirical works of [PORT] [KIT] for text input and locomotion, respectively), but more effort is needed to cover the rapidly changing field of VR.

Holography

The definition of holography is reflection of light projecting an object that is not physically there. A hologram is a photographic recording of a light field used to display a fully three-dimensional (3-D) image of the holographed subject, which is seen without the aid of intermediate optics. At research level, the main goal is to widen the viewing angle and size of 3D images today.

Real-time holography of a live scene, object, or person requires considerable computing resources, including high-resolution cameras, calculation of depth perception using sensors, and accurate and high-rate rendering of the live video. [KIM]

The current major driver for the holographic and volumetric display technology is for entertainment applications, such as 3-D TV and movies, gaming, and mobile devices. [TSAN] But beyond entertainment, there are various fields including arts, biomedical imaging, scientific visualization, engineering design and more that are beginning to incorporate hologram usage, and the technology seems to be making access easier. Industry, marketing and advertising, and training, especially when haptic feedback is incorporated into the interaction with the projected image, are gaining momentum.

There is significant growth in the research and development of holographic (and 3-D volumetric) display technology. In fact, a market research report published in 2015 by Markets and Markets on the holographic display market, estimates that the holographic technology market will grow to an estimated $3.57 billion by 2020 and grow at a compound annual growth rate of 30.23% from 2014 to 2020. [M&M]

4. MAIN AREAS OF APPLICATION

Immersivity through virtual, augmented and mixed reality technologies have been evolving for many years and are already demonstrating how they can shake up entire industries. They provide the opportunity to solve real challenges when they are well focused to specific industry needs. NEM has identified several industry sectors that are well positioned to take advantage of immersive innovation. Although currently mainly known for consumer applications in the entertainment industry, there is real potential in fields as medicine, science, engineering, data visualization and the military to name just a few.

Improved hardware will pave the way for a larger consumer adoption. Immersive leisure content (immersive concerts, immersive movies) will likely follow the gaming lead, but afterwards, hopefully shortly afterwards, many more sectors will benefit from effective, open, immersive technologies and content.

Design and engineering in manufacturing, maintenance of complex artefacts by remote maintenance crews, remote health care assistance, virtual immersive enhancement of tourist attractions and cultural heritage sites are just the first examples that come to mind... but, in truth, the possibilities are endless.

4.1 Gaming

The games industry in general has been a massive driver for technological innovation. There has been a significant improvement in games development and presentation tools across multiple technology platforms, with special importance of virtual world applications which link real-world environmental data to 3D visualisations in virtual world environments.

The technologies of video games, virtual worlds and social networks have become collectively known as immersive technologies. Their ability to engage people is driving massive investment into these kind of technologies.

Gaming is a very powerful market, joining game consoles and mobiles, as there's a high demand for VR on-the-go. Last year, mobile gaming dominated the marketplace by bringing in a whopping $41 billion dollars in revenue by the end of 2016 [SDATA]. With several announcements being made in regards to mobile VR last year, we can expect to see an increased emphasis on mobile VR integration.

Besides console games, serious games aim to provide alternatives focused on areas where the cost–benefit ratio of games methodologies was most easily justified and understood, namely in areas of high training costs and/or risks and/or practicality. Development of these is still an issue today. [YOUNG]

Serious Games today apply traditional role playing techniques in innovative ways, made possible by immersive technologies and 3D visualisation. As the technologies for 3D visualisation and online multi-player interaction have developed over recent years, there has been a massive increase in the use of associated applications such as virtual worlds and social networks.

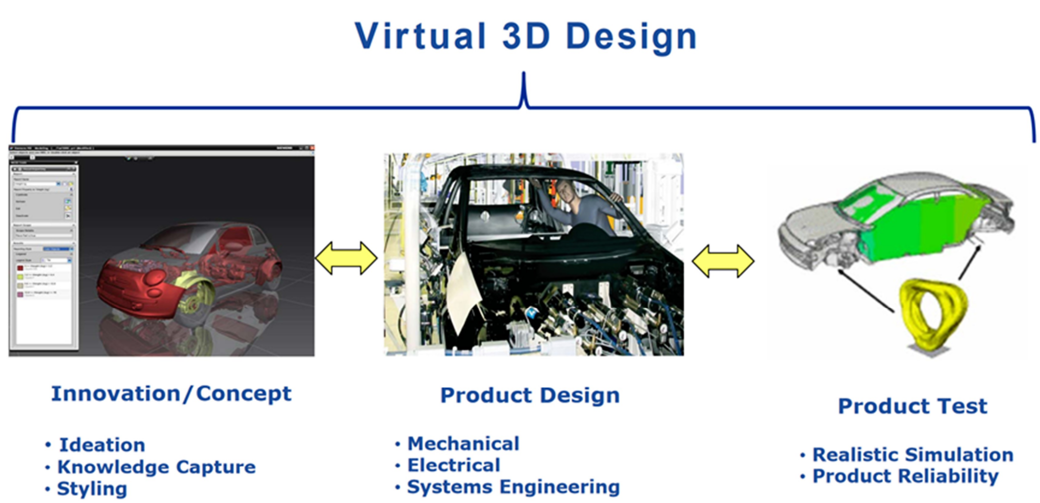
4.2 Manufacturing

Manufacturing industry is facing a complex and highly competitive environment. Industrial processes are evolving and aim to respond to a more global market where customization is a non-stoppable trend.

An innovative and effective solution to aid competitiveness is the application of virtual reality and augmented reality technologies to simulate and improve these manufacturing processes before they are carried out.

The application of immersive solutions for manufacturing applications is a strong and growing area. The challenge is to design and implement integrated immersive manufacturing systems that could enhance industrial processes, both for products and processes, leading to shorter lead-times, reduced cost and improved quality, and thus to an improvement in productivity. [ONG]

VR applications in mechanical-related areas are quite well established, e.g., design, setup planning, production scheduling, machining, assembly, etc. Many manufacturing tasks have been carried out as information processing within computers, typically prototyping by means of CAD tools. These models aim at representing the precise structures of manufacturing systems and simulate their physical and informational behaviour in real operation. Taking human factors into account at the very early stage of the design process is a challenge with digital mockups, involving plausible and transferrable interactions with the future users in the CAD models.



Manufacturing has two critical phases, product design and planning how to manufacture a product. Leading manufacturers are applying immersive virtual realiity technologies at both points. Immersive technologies are supporting the improvement of both by identifying early errors in the design process that leads to the elimination of a lot of expensive takes. And by examining 3D models at life-size scale, problems in the product design and its related manufacturing processes can be spotted more readily.

Immersive interactive design software will probably emerge and this together with the almost mainstream adoption of 3D printing hardware would allow for virtual creative crafting of objects, such as small gifts.

4.3 Education and learning

Education has traditionally been one of the first areas to use immersive technologies. The use of the technology enables the learner to be immersed in an environment that allows for learning through an increased range of sensory experience, which can potentially deepen understanding.

Ensuring the correct balance between real and virtual objects is essential to encourage connections between the learner and content. [YIYU]

Different educational paradigms as Visual Learning, Simulation-based Learning, Constructivist Learning, and Engaged Learning are currently enhanced by applying immersive and interactive 3D technology,

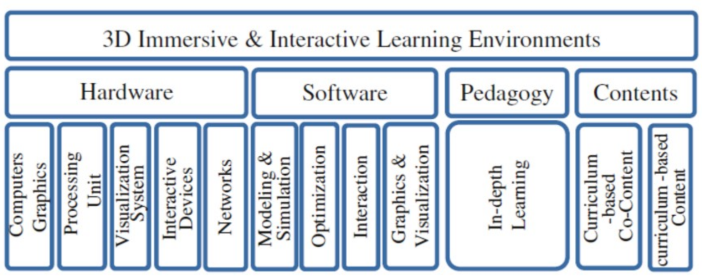


Fig. 3D Immersive and Interactive learning environments

Opportunities for AR in educational settings are rapidly emerging as technology becomes more accessible. Recent developments in mobile technology provide educators with powerful AR hardware platforms. Furthermore, the use of handheld devices increases experiential authenticity within the classroom environment as they are less intrusive than head-mounted devices. [LEE] [WU]

Beyond class education, the learning of motor skills and procedures relies on multidisciplinary developments, to associate human and social sciences with technology development. The aim is to propose immersive environments where users can train and learn specific skills with an efficient transfer to real world: learn new profession or procedures, train in sports…

4.4 Health care

Telehealth has become an accepted and validated method for the treatment of many different health care concerns. From the introduction of the Web 2.0 which has facilitated the development of new forms of collaborative interaction between multiple users, immersive applications have been progressively developed. The interaction between real and 3-D virtual worlds may convey greater feelings of presence, facilitate the clinical communication process, positively influence group processes and cohesiveness in group-based therapies, and foster higher levels of interpersonal trust between therapists and patients. With healthcare moving towards more innovative self-monitoring and data-driven models, the opportunities that immersive technologies provide are huge.

Immersive environments are revolutionizing training for healthcare professionals, enabling medical students to practice surgical procedures. Image analysis and reconstruction can improve diagnosis and injury treatment. For stroke rehabilitation, for example, VR technology has the potential to 'trick' stroke victims into regaining control of limbs they thought had become powerless, and accelerate rehabilitation times significantly. [DCAT]

4.5 Creative industries

Immersive technologies are already transforming the way that content is created and experienced by the viewer. New immersive-based storytelling is allowing them to feel, act and live the story in a radical new way and astonish detail. For example, AR technologies are building enhanced experiences for tourists around the world by providing an overlay of the important historical or cultural information relevant to the places.

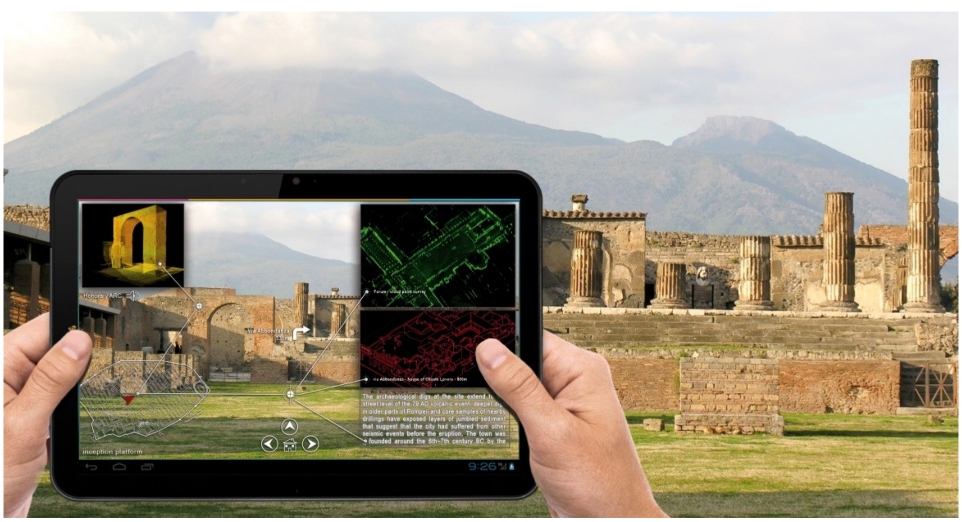


Fig. AR application for tourists. INCEPTION project [INCEP]

Marketing or entertainment are other industries taking a clear advantage of immersivity. New products can be tried through VR creating a higher impact in the final consumers; the experiences on offer can be simulated and thus, get the final product or service tailored to be closer to the user. Music or theatre can be experienced from home by virtually attending a concert or play, providing an alternative experience.

Museums are renewing their offer by showing virtual recreations of the original context of the art work. Therefore, immersivity will impact the way of creating content for gaming, entertainment and the arts as long as creators dedicate time and resource to develop content for immersive technologies.

Fig. Smithsonian Western Cultures Virtual Tour

5. BUSINESS AND ECONOMIC IMPACT

Immersive content has enormous potential, in disparate sectors of modern economies. Albeit the immersive technologies are still in infancy, think tanks plan uses for immersive technologies, ranging from the more conventional fields of application, like video games and entertainment, to newer concepts.

We have already witnessed an explosion of user generated content, with selfies being perhaps the most evident manifestation of this ever increasing trend. In the near-future, however, people will be doing more than creating media at an increasing pace; they will be creating media passively.

Such an enormous production of content needs new ways of being analysed and harnessed for useful purposes, and immersive technologies (together with big data techniques) are one of the main tools by using which people will be allowed to extract value from data & media.

A wide range of options are foreseeable, but not yet present in the market. For example, smart glasses could quite easily enable the storage of every word read. This capacity, in turn, would change how users consume text. While reading, images of people, entities, and places could be associated in background with the text and summoned with a touch. This will also affect how text is written and produced. Future media will merge text and images in new and surprising ways.

In order for VR to continue to grow, the price point needs to drop to a level where a large consumer base can get their hands on it. As with the dawn of all technologies, the price starts high, and eventually reduces.

Consumer interest in immersive content is increasing. Hardware sales alone are expected to reach $2.4 billion in 2017, according to virtual reality consulting firm KZero. For software, which is mostly video games right now, KZero estimates sales of $2.8 billion by 2018.

Facebook paid $2 billion for Oculus VR -- mostly known for applying virtual reality to gaming -- opening up the possibilities of what virtual reality's role will be in social media and beyond. Google has already delivered the specs of a simple but functional cardboard headset (Google Cardboard).

But even with all these new uses popping up, the immersive content and technologies can be a difficult thing to explain, and for some aspects, difficult to accept.

There is little or no doubt that immersive gaming will lead widespread consumer adoption, and competition in gaming sector will bring about new/refined hardware, rapidly improving the value/cost proposition for the final user.

Today, , Vive, Samsung gear, the Oculus Rift and Sony's project Morpheus are very promising.

Immersive and Interactive content and technology will enable growth and deployment in different sectors of the EU industry thanks to :

- Opening new markets for ICT stakeholders: a pan European open secured Immersive environment offering third party developers the possibility of developing a wide range of innovative applications.
- Quick response to new and sustainable market opportunities based on converged business models between content, telecom, broadcast and consumer electronics industries.
- Increasing business opportunities for creative SMEs. The Small and Medium Enterprises represent almost the 95% of businesses in the creative sector in terms of employment while they account around the 70% in term of turnover showing a competitive advantage over big companies in terms of efficiency, productivity and competitiveness. SMEs often also a lack of capacity to access to risk capital or public subsidisation in order to improve their productive capacity.

The Immersive open environment will enable the creation of creative ecosystems on which SMEs heavily relies, in which the quality and diversity of partnerships across different sectors and types of actors is decisive. The most obvious example is the wider use of design in car industries, adding value to products, services, processes and market structures.

The relevance of a new aggregation paradigm, organisational processes and business models is then a key issue for a strong economic impact of immersive content and technologies.

6. CONCLUSION

Immersive technologies are consolidating as one of the most intriguing topics in the content sector. Advances in the generation of 3D Virtual/augmented reality services and the gradual appearance of a variety of devices (glasses, 3D Screen, windscreen display, ...) opening the opportunity for holographic content, i.e. true 3D volumetric media, give an idea of how fast immersivity is emerging.

Improved VR headsets, which currently are positioned for VR gaming and 360-degree video, are evolving towards consumption of Free Viewpoint video. Content is being created for many genres, currently using 360-degree video: (live) sports, musical performances, virtual tourism, educational content, adult content, fiction, news and documentaries, eSports video streams. User generated content (UGC) is expected to constitute the second wave of content, in the form of short video clips in a social media context of messaging and sharing and live streams shared on social media platforms. Handhelds (smartphones and tablets) with auto-stereoscopic multi-view capabilities will allow users to enjoy the cases described above when they are not in a position to put on a VR/AR headset.

We consider that the road to VR's social impact as an enabling, fully-immersive technology for education, health, training etc. goes through its problem-solving capacity and its ability to offer regular users a smooth, robust, and seamless User Experience, while addressing their interaction problems and needs.

Even though problem-solving may not apply to all HCI, it provides some great first questions for any HCI paper or research programme: "Which problems does it tackle, and how does it increase our capacity to solve them?" [OULA]. After the revival of VR technology, a discussion of the problem-solving capacity and social impact of HCI in VR is important [BOLET]. The direction of future HCI work in VR will define the degree to which expert and non-expert users understand and utilise VR for the greater good [BOLET]. We consider that HCI in VR can benefit from conducting more UX-focused empirical and conceptual work, examining past, related research questions in a new light.

Immersivity challenges include :

- Robust algorithms to create volumetric media from multiple cameras, stereo cameras, smartphones with multiple cameras and/or depth cameras, multiple robotics cameras (e.g. follow-me drones); hybrid approaches combining local preprocessing and cloud-based synthesis; calibration-free set-ups.
- Novel volumetric media representation formats, balancing compression processing requirements, compression efficiency, bandwidth and manipulation capabilities. (UGC holographic communication will require manipulation capabilities similar to current

visual messaging like beautification, stickers and comments, backdrop changes, fun masks and transformations etc)

- Bandwidth efficient delivery of volumetric video. Streaming of the complete holographic video is bound to pose substantial bandwidth challenges. Research into novel networking solutions that stream personalized perception-based holographic video to users from CDN's, taking into account bandwidth, latency and cloud/local processing loads.
- Human-machine interaction. Many types of human-machine interaction will be developed in the near future, allowing consumers a wider range of activities and a broader spectrum of experiences that can be gained from their engagement with media, their embodiment with their digital representation, and transfer of experience between virtual and real world. New developments are expected for avatars and robots, haptic sensors, Brain Computer Interfaces (BCI), Enhanced Sense of Presence (ESP), sensing and monitoring, Quality of Experience (QoE), audience monitoring and analysis.
- Usage of multiple audio-visual capturing sensors for creation of multi-angle content for creation of free-viewpoint video for consumption with VR and AR HMDs. Capturing modalities include visual, audio and depth (radar, sonar, lidar, time of light), and could incorporate ground-based tele-operated and autonomous vehicles and airborne drones and balloons and definition and implementation of capturing strategies for robotic camera teams.
- Media orchestration tools for managing multiple, heterogeneous devices over multiple, heterogeneous networks, to create interactive and immersive experiences.

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