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Technology roadmap for the Creative Industries

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ABSTRACT

This paper discusses the findings of research conducted between 2013 and 2016, which concerned the development of technology roadmaps for the Creative Industries. The roadmap presented in this paper was built based on input from communities of creative and Information and Communication Technologies (ICT) experts collected during the consultation and validation phases of the research. It provides a synthesis of challenges and recommendations from the five creative sectors examined by the project – Architecture, Art, Design, Games, Media and e-Publishing – and proposes research directions for the development of desired future technologies, by highlighting innovative future developments in the Creative Industries, while also assessing their technology maturity in the short, medium and longer terms. By rating the desired technologies as ‘present’ (1–2 years), ‘possible’ (2–5 years), or ‘probable’ (5–10 years or beyond), the roadmap gives orientation towards the development of new technologies and related business models and skills and provides guidance for informed policy-making. The paper thus aims at enabling stakeholders – creators, professionals, SMEs, creative groups, creative communities, associations, organisations and institutions, as well as governments and policy makers – to maximise their benefit and the societal value from the new emerging technology landscape in the Creative Industries.

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KEYWORDS

ICT roadmap; technology roadmap; creative roadmapping; creative technologies of tomorrow

1. Introduction

Our experiences and understandings of the world are increasingly being filtered by multiple layers of digital environments. Digital technology, augmented reality, virtual reality and corresponding technical capabilities are continuously transforming all aspects of our lives, be it social, cultural or economic. Governments, the local, regional and national authorities, policy makers and businesses are also becoming more aware of the important role and potential of creativity and the Creative Industries to drive innovation and growth in the broader economy (European Union Open Method of Coordination Expert Group on Cultural and Creative Industries 2012).

Today’s business world is shaped and challenged by the development of highly innovative, competitive and disruptive technologies. New emerging technologies such as cloud

computing, the Internet of Things, wearables, 5G, big data analytics and three-dimensional (3D) technologies are urging all relevant stakeholders to rethink and reinvent their approach to quickly and effectively respond to these.

Technologies have become commonplace and ubiquitous in the Creative Industries, often used as means to directly enhance creativity, and in so doing, as Loveless puts it (Loveless 2006), they contribute to the life and culture of society as a whole as well to identifying ways to overcome barriers or solutions to specific problems. The increased interaction of the creative sector with technologies has led to: (a) new forms of artistic expression and entirely new genres of art (e.g. new media art, digital art, video art); (b) new understandings of creativity (e.g. in-museum, in-theatre and in-gallery apps); (c) new materials, processes and tools for creative practices; (d) new business models, digital market places, consumer groups and distribution channels, as well as entirely new ways of marketing and selling creative products, tools, apps and services; (e) new forms of user-producer interaction and collaboration; (f) new virtual communities of creators and innovators; and (g) new forms of creativity, such as human-free and computational creativity.

At the dawn of the twenty-first century the Creative Industries are considered by many policy makers across Europe to be at the heart of their national innovation and economic development agenda (Chapain and Comunian 2010; Chapain et al. 2013, 2014). Therefore, innovation and creativity have become broadly used terms in many national development strategies that can lead to growth; consequently, many countries are adopting policies to support and develop their Creative Industries and local creative production and consumption (Musterd and Kovacs 2013; Musterd and Murie 2010; Pratt 2009).

The challenge for local and international policy makers is to shift from static to dynamic approaches, able to meet the requirements of the Creative Industries sector, which is marked by considerable and rapid changes in the wake of the digital revolution. In response to these requirements, governments have identified the need for continuous assessment to ensure that their regulatory framework is properly updated and suitable, taking into account that the Creative Industries operate within complex business environments defined both by the standard regulations concerning businesses, and broader political or philosophical issues such as intellectual property rights, piracy and taxation.

Over the past few years, the evolution of digital technology, tools and applications (or apps) has allowed users to easily access a variety of new digital technologies and tools. In this new digital economy, immaterial value increasingly determines material value, as consumers are looking for new and enriching 'experiences'. The ability to create social experiences and networking are now important factors of competitiveness (Green Paper 2010). The single digital market was conceived before the arrival of the Internet, before information and communication technologies became one of the main drivers of growth and before services became such a dominant part of the European economy. The emergence of new services (such as digital media) has huge potential, but in order for European communities to fully exploit it, they would have to overcome the barriers that currently block the flow of on-line content and restrict access for consumers and companies (European Competitiveness Report 2010).

Creative Industries have been heavily influenced by the convergence of internet, computing, telecommunication and television technologies, and the opportunities they offer for digital storage, big data, linked data, manipulation, transmission and reproduction of digital media. The Internet has revolutionised the way of distributing and sharing

information and works of art, as well as how we collaborate in their co-production and co-creation. Today, bookshops or record shops are no longer limited to their premises or by the physical conditions once affecting the volume of their stock: they can have customers from anywhere and offer almost all titles (Nielsén 2008; Turning the page 2011).

Further development of more complex applications has dictated the construction of personalised and user-friendly interfaces that facilitate access and navigation through a broad and diverse multi-content environment. In addition, there has been significant development of new types of intelligent interfaces, including the use of speech, pattern and gesture recognition, as well as new touch screens and advanced micro-displays that also contribute to this aim. Moreover, improved speed and algorithms for real-time content processing have also become a priority due to the fast expansion of peer-to-peer applications, wireless networks and available bandwidth that demands integration of individual applications at higher levels.

There is a clear link between the development of the Creative Industries and Information and Communication Technologies (ICT): interlinking the Creative Industries with digital technologies results in the creation of new jobs, opportunities, services and products that have a positive impact on the whole economy. The Creative Economy concept derives from the concept of innovation when this is combined with the different forms of creativity that characterises the Creative Industries. The Creative Industries concept in policy documents suggests added value, enhanced market and new jobs – the all-important foundations for a competitive and growing economy. Policy makers are stressing that innovation, creativity and independent thinking are becoming increasingly crucial for the development of the global economy (Moore 2014). The *European Competitiveness Report 2010* identified the Creative Industries as one of Europe's most dynamic sectors, with increasing growth potential as the Internet develops. They currently account for approximately 3.5% of the GNP of the EU. In 2011, the EU represented 38% of exports and 35% of imports in the international trade of cultural and creative products. A report from the McKinsey Global Institute (2013) identifies 12 technologies that could drive truly massive economic transformations and disruptions in the coming years. The report also looks at exactly how these technologies could change our world, their benefits and challenges, and offers guidelines to help leaders from businesses and other institutions to respond to these changes. It further predicts that by 2025 2–3 billion more people will have access to the Internet and estimates a potential economic impact of \$5–7 trillion from automation of knowledge work. Gartner's Hype Cycle for Emerging Technologies report (Gartner 2013) provides a cross-industry perspective on technologies and trends. These technologies would be used to augment humans (for example, an employee with a wearable computing device), replace them with machines (for example, a cognitive virtual assistant acting as an automated customer representative), improve collaboration between humans and machines (for example, a mobile robot working with a warehouse employee to move many boxes), improve the understanding between humans and machines, and, finally, make both humans and machines smarter.

According to the *ICT for the Creative Industries Background document for the Expert Group Meeting (2012)*, the Creative Industries are dominated by small or medium enterprises (SMEs), with micro-SMEs and freelancers representing 85% of all actors. These SMEs co-exist with a few 'global players', in films and publishing. Like many SMEs in other sectors, SMEs in the Creative Industries often lack good knowledge of innovation

management, eSkills and access to finance; they also show low adoption of state-of-the-art ICT and target markets, which are often fragmented and localised, thus increasing the market entry costs and reducing their international competitiveness. Furthermore, PAC (2015) reports that more than three-quarters (78%) of European businesses agree that the expansion of their digital presence will be top IT priority over the next two years. The Innovate UK's Digital Economy strategy report 2015–2018 (*Innovate UK Digital Economy Strategy Report 2015–2018*) states that 'Around 80% of smartphone users check their phone within 15 minutes of waking and they do it 150 times a day' and that 'by 2020, 30 billion devices will be wirelessly connected, supporting a global digital services market worth \$2tn IoT services as much as the entire UK economy'.

Yet, a technology-biased approach is not sufficient. The active involvement of stakeholders in the roadmap development plays a decisive role in identifying the real challenges and research directions in the planning and adoption phases (Beeton et al. 2008). This is particularly pronounced today because innovation aims at using these new emerging technologies for designing and building new tools and applications fast in order to achieve several transient advantages (easily abandoned and re-invented), rather than for long-term developments of standalone products. Günther McGrath (2013) argues that 'In a world where a competitive advantage often evaporates in less than a year, companies cannot afford to spend months at a time crafting a single long-term strategy. To stay ahead, they need to constantly start new strategic initiatives, building and exploiting many transient competitive advantages at once. Though individually temporary, these advantages, as a portfolio, can keep companies in the lead over the long run'. In addition, users' involvement in this process is becoming a complex activity. The idea of prosumers is already a reality and is pushing innovations to become more systemic in comparison to the previous supply-production chain innovations models.

Technology roadmaps are used to predict the future technology/tools/products and identify the opportunities for competitive edge and sustainability (Kappel 2001; Rinne 2004). Several technology roadmaps have been developed in the area of science, technology, engineering, ICT, the Internet, healthcare, defence, aerospace, construction, energy, manufacturing, life and social sciences, chemistry, service industry and many other areas (Daim and Oliver 2008; Suh and Park 2009; Andrade Coutinho 2010). Lee et al. (2009), conducted an analysis for technology, capacity and business planning to support the strategic decision-making.

Technology roadmapping is used to integrate 'business strategy, product development, technology and R&D activities and actions' (Kamtsiou et al. 2015). A roadmap helps develop and implement innovation plans with emphasis on adapting to changes in technology, market trends, new business opportunities, designs and processes. Hence roadmapping is a tool for collaborative strategic planning that acts as an activity with respect to future strategy in the sector, as a means of knowledge creation for all stakeholders. Therefore, crucially, roadmapping does not merely approach the interaction between technologies and the Creative Industries from a technological perspective. The needs, drivers, challenges and concerns of those working within the creative sector are essential to understanding the present and future state of this interaction. This is particularly true since the very idea of 'prosumers' – so central to the new forms of user/producer interaction here emerging – has already decisively changed the nature of innovation in the Creative Industries.

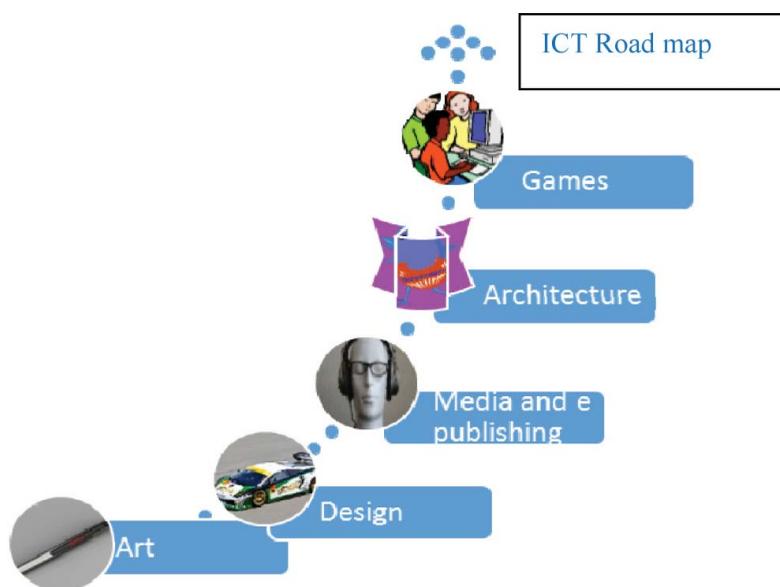


Figure 1. Creative sectors.

The Institute for the Future (ITF Technology Horizons programme), presents 20 new innovative combinatorial forecasts one can use to navigate the future as it unfolds. Each of these forecasts is built on a range of enabling technologies and newly opening possibilities. A trends and technology timeline for 2010 by Richard Watson, shows a roadmap for the exploration of current and future trends by dividing timeline into the following zones: ZONE 1: 2010–2015, ZONE 2: 2015–2020, ZONE 3: 2020–2025, ZONE 4: 2025–2035 and ZONE 5: 2035–2050.

By contrast, Ray Hammond (2013) states that humans are not designed to think about the future as ‘today the speed of human innovation is accelerating to such a pace that only words like “fear”, “scary” or “frightening” are appropriate to describe the emotions most humans experience when confronted with the implications of probable technological development in the near future’.

The data presented in this paper was collected through the CRe-AM EU funded project. The CRe-AM project aimed to bridge communities of creators with communities of technology providers and innovators, in a collective, strategic Roadmapping effort in order to streamline, coordinate and amplify collaborative work. It thereby developed a roadmap for new ICT technologies, applications and tools to address the needs of different sectors of the Creative Industries (e.g. art, architecture, design, games, media and e-Publishing) as shown in Figure 1.

2. Methodology

The data was collected in two phases, combining a bottom-up approach (followed in Phase 1) with a top-down approach (developed in Phase 2), as depicted in Figure 2. In order to ensure the effective delivery of the engagement strategy a sector facilitator was

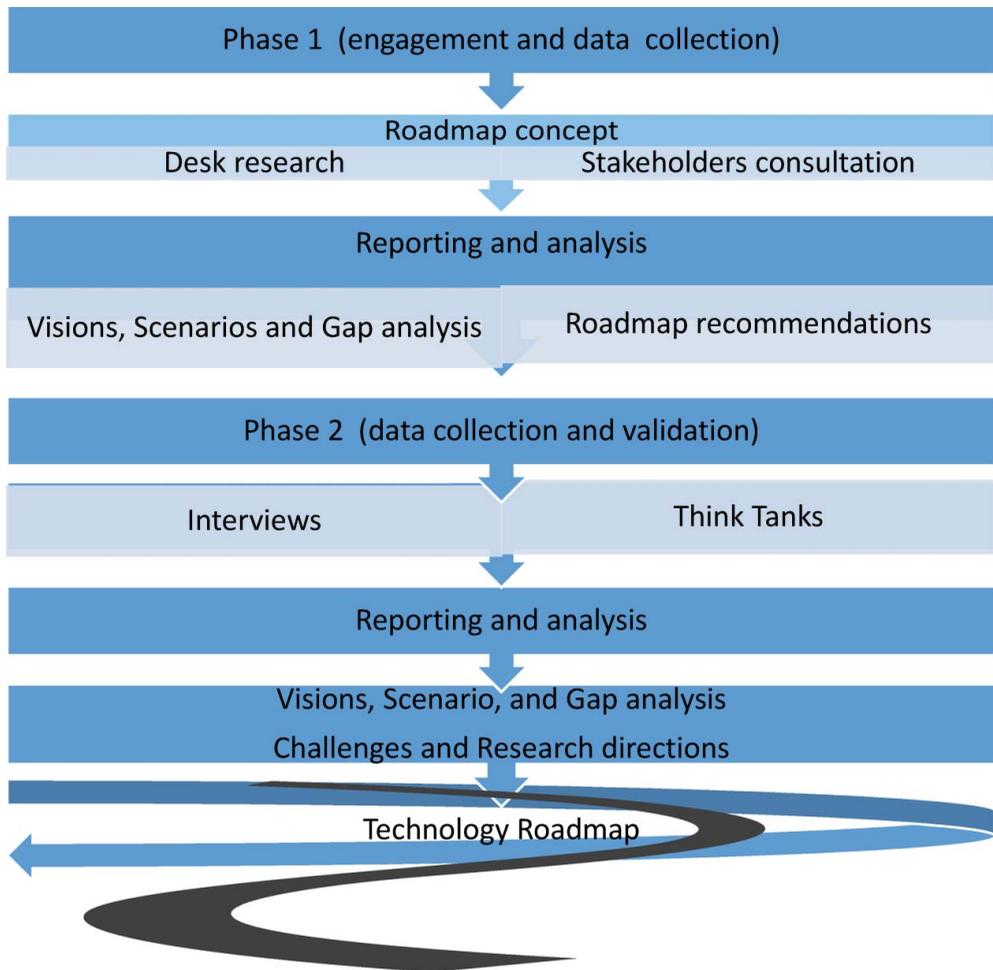


Figure 2. Road map methodology and process.

nominated for each sector of the Creative Industries examined by the project (Architecture, Art, Design, Games, Media and e-Publishing), who, with the support of an invited champion from the corresponding sector, coordinated engagement activities and mobilised the relevant communities of individual creators and professionals, SMEs, creative/ICT groups and communities and larger organisations across Europe. Phase 1 activities involved primarily consultation workshops, both small-scale standalone events as well as larger-scale events organised as part of key national and international conferences and meetings, and included a set of preliminary validation activities. Phase 2 focused more on one-to-one interviews and Think-Tank events with experts from each creative sector and ICT, with more emphasis being placed on validation activities.

In Phase 1, Tech Futures (Visioning and Scenarios) and Delphi Game methodologies (Chia-Chien 2007; Gene and George 1999; Riggs 1983; Ricard and Kristian 2011) were combined in a series of events that ranged from local to small-scale international, following a bottom-up approach (Abbasi et al. 2015). These were enhanced by a set of online desk research materials, resources, surveys and tools, and were also supported by social media. Tech Futures consultation activities aimed at capturing and articulating Visions and

Scenarios for the future, while the Delphi Game aimed at identifying and exploring Trends & Weak Signals (Abbasi et al. 2015). The consultation events were structured around questions that enquired envisaged future technological developments and their impact on creative practices, user needs, challenges, barriers, strengths, weaknesses, opportunities and threats, which were then used for the development of sector-specific roadmaps. During the events, participants were split into groups of 5–8, the discussion was guided by a facilitator who ensured that all participants had the opportunity to voice their views and develop them in dialogue with each other, and a scribe ensured that the discussion was thoroughly documented. Participants were introduced to each other and briefed on the aims, objectives and parts of the consultation process at the beginning of each session. Participants were also provided with a hard copy of the consultation questionnaire and project details and were invited to hand over their notes at the end of the session, thus ensuring that no view was missed, even if there had not been a chance to articulate it during the group discussion. The consultation events were divided into four parts, and this process was also followed during the validation events with the difference that during the latter, experts were asked to comment and validate participants' responses to the relevant questions that had been collated through the consultation events. Although some validation activities were organised during the first phase of the project, validation was more fully conducted in the second phase of the project. Also, in Phase 2 of the project, the bottom-up approach was complemented by a top-down approach, which involved an extended process of targeted small-scale Think-Tank validation events and one-to-one interviews with distinguished and highly influential experts in each of the creative sectors examined by the project, as well as ICT experts. The underlying research materials for this article (research data from multiple sources, including interviews, expert consultations, and workshops) can be accessed through the CRE-AM project website: www.cre-am.eu.

3. ICT roadmap challenges, research directions and recommendations

Prediction is very difficult, especially about the future.

Niels Bohr

The ICT roadmap for the Creative Industry sectors (Architecture, Art, Design, Games, Media and e-Publishing) is based on the results identified by the gap analysis for each sector. The technology recommendations cover a broad range of the Creative Industries, delivered into distinct roadmaps corresponding to each creative sector (Smith, Rasool and Almond 2016; Wortley et al. 2016; Stergioulas, Lane, and Kondakova 2016; Stergioulas et al. 2016; Vassilopoulou et al. 2016; Bernheimer, Rasool, and Stergioulas 2016). Although previous roadmap papers, reports and initiatives have been studied, our roadmap recommendations are based on original primary-source data, and the gap analysis performed was based on primary research conducted with various stakeholders and validated through the sector experts.

The roadmap recommendations offer research directions for the development of desired future technologies in the Creative Industries at large. In order to assess the likely timescales of technology maturation in the sector roadmaps, we have adopted the 'Timeline of Emerging Science and Tech' created by Richard Watson (Now and Next) and Alex Ayad (Imperial College) in 2014, which uses the following three timescales: 'Present' (1 year), 'Probable' (next 5–10 years) and 'Possible' (10 years and beyond) (Watson 2010; Watson and Ayad 2014).



Figure 3. Challenges.

Even after the completion of broad surveys of the general direction of technological trends and desires, determining when a desired technology will move from the ‘possible’ to the ‘probable’ may be quite difficult. However, once a technology achieves a ‘probable’ status, it is feasible to consider the various factors affecting its route to market and user/consumer adoption in order to suggest plausible timeframes in which it may reach a ‘present’ status. In grading the ICT roadmap recommendations we have used the same categories of timescales as Watson and Ayad, ‘**Present**’, ‘**Probable**’ and ‘**Possible**’, but we deem ‘Present’ technologies to be viable within a window of 1–2 years (2016–2017); ‘Probable’ technologies to be viable within 2–5 years (2017–2020); and ‘Possible’ technologies to be viable in 5–10 years or beyond (2020–2025) as depicted in Figure 3. In addition, the roadmap timescale methodology takes into account research indicating that the few early innovation adopters have different characteristics from the large group of people/users who adopt the innovation at a later stage (Rogers 2003). When promoting an innovation to a target population, it is important to understand the characteristics of the target users, industries or population that will facilitate or hinder the adoption of the innovation.

We are presenting the six challenges shown in Figure 3, which were identified through research following the relevant directions and recommendations (Smith, Rasool and Almond 2016; Wortley et al. 2016; Stergioulas, Lane, and Kondakova 2016; Stergioulas et al. 2016; Vassilopoulou et al. 2016; Bernheimer, Rasool, and Stergioulas 2016).

3.1. Challenge 1: bespoke technology development

Lightweight, adaptable and flexible bespoke digital technologies and tools for easy acquisition and creation (including 3D) with an emphasis on creating bespoke and more personalised experiences adaptive to user needs and desires.

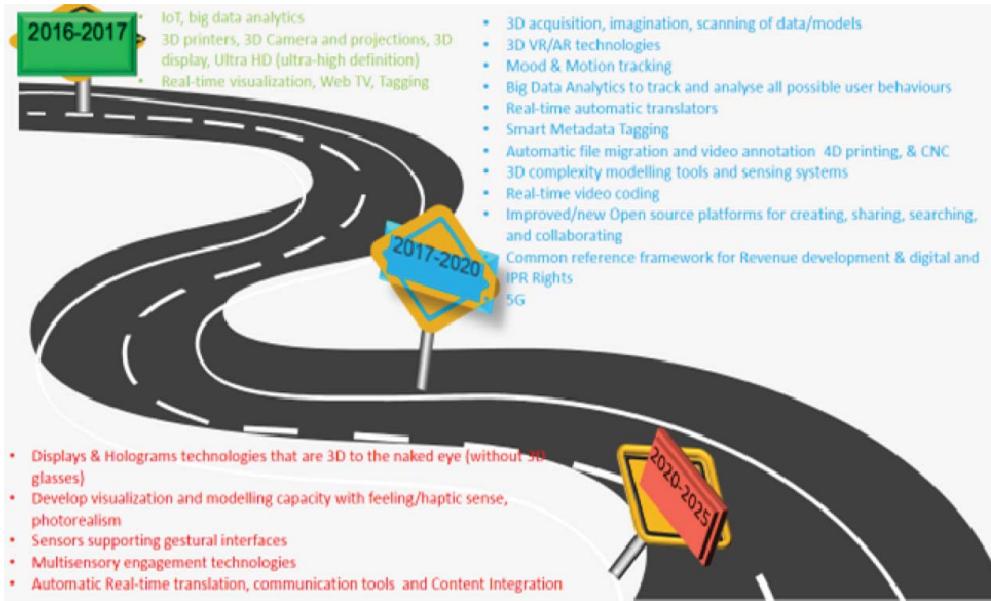


Figure 4. Technology road map for Creative Industries.

An overall Technology roadmap for the Creative Industries is shown in Figure 4. The descriptions are presented in the following sub-sections.

3.1.1. Research directions and recommendations

3D acquisition (or scanning) of data/models and multispectral colour and materials analysis combined with 3D scanning: New technologies need to be developed to facilitate 3D model/data acquisition (or scanning), as well as multispectral colour and materials analysis combined with 3D scanning, using new materials that allow a direct engagement of the users, perhaps through 3D reproductions of artefacts. Multispectral colour and materials analysis combined with 3D scanning can enable complex spectral and geometrical calibrations. **Timescale: Probable.**

3D VR/AR technologies: New 3D VR/AR technologies to address the inadequate capacity of current modelling applications to approximate the sense impressions generated by objects, e.g. with regard to their texture or the diffusion of light on their surface. Instead of using off-the-shelf products, usually conceptualised and developed for other applications, new modelling and management software tools for non-programmers (curators, librarians, artists, etc.) are needed in order to help manipulate and use rich, multi-layered structured data files (i.e. ones which include data generated by 3D scans, 3D cameras, 3D projectors, 3D imagination, colour measurements, material descriptions and other metadata) as they become standard and replace flat files (two-dimensional [2D] images, text files, etc.); these new tools should provide to their users the capacity to rapidly generate alternatives, explore their implications, or revert to earlier stages when needed. In addition to these technologies, there is great potential in the application of 3D readers and the use of holograms, as well as in the introduction of gamified ebooks and content to which a social element has been incorporated. This can link with the

development of wearable technology and the internet of things (for instance, in-car readers). There is also interest in applying VR & AR to visualisation, modelling, and user testing with enhanced approximation for haptic sense, photorealism of actual material, and diffusion of light. Senses like smell and touch in VR are still at the prototypal level, and should be developed further. Research should also address using Augmented Reality for the physicalisation of textual narratives into the real world using AR glasses, VR, experimental body technologies, cyborg implants and wearable technologies for performers and audience. New multisensory engagement technologies for interaction and interface may include gesture recognition, eye-tracking, biometrics, robotic automation, as well as technologies that work directly on optical perception to produce images, getting thus technology 'out of the way' in AR and VR. For Virtual Reality, more processing power is needed in order to make the synchronisation between the movement of the head of the user and the adjustment of the picture as near-simultaneous as possible. There is also a need to develop a symbiotic relationship between content and technology in order to overcome problems like the nausea induced by the use of VR for even a few minutes. The lack of broadcast grade or even hobbyist cameras capable of capturing VR content (hence, the existence of very little VR content) is a fundamental constraint and key reason for VR's minimal impact on TV and movies to date. Hence, VR camera development is also needed to support this pathway. **Timescale: Possible/Probable.**

Mood and Motion tracking, including wearable tracking: Motion sensors are currently limited in their capacity to recognise more complex emotional states that might also be culturally dependent, such as confusion, interest and concentration. New gesture recognition technologies, with wearable or wireless sensors, are needed that would allow for crowds or groups of people to collectively modulate experiences in communal settings. This could open up the potential for a more 'socially inclusive' experience. Furthermore, faster motion tracking is desirable. Currently, motion tracking cannot keep up with fast movements, and available hardware is not powerful enough to eliminate the latency that would occur in a projection mapping system used in real time for the identification of facial expressions beyond the eight core emotional states. Such capability will require technologies and tools that can recognise more complex emotional states (emotion sensors, emotion wearables, gesture recognition) and social value. **Timescale: Probable.**

Users' behaviour modelling and personalisation technologies, including cognitive analytics (Big Data and Data Mining): The resources to track and analyse the possible behaviour of the user and to perform face detection, recognition, and image classification are rarely available, which means designers have to develop new approaches to analytics that take into account cost-benefit/risk relationships between the resources required for tracking, storing and analysing user telemetry/metrics on the one hand, and the value of the insights obtained on the other. The collection of behavioural data, placed in the context of more traditional asset based data, such as plays and subscribers, unlocks new insights by capturing the 'who, what and when' of the viewer. Large amounts of behavioural and asset-based data become valuable only through intelligent transformation and interpretation, which leads to a better understanding of the audience and emerging trends. The advent of cognitive analytics entails the possibility to automate analytical thinking through machine learning. **Timescale: Probable.**

Real-time automatic translators: There is a need for real-time translation tools overcoming linguistic, cultural and disciplinary barriers. Current machine translators work

adequately only when the text to be translated operates within a controlled linguistic context, e.g. by following standardised style guides or term glossaries. **Timescale: Probable.**

3.2. Challenge 2: archiving and digital preservation

New archiving solutions, both in terms of media and forms of collecting and conserving digital content, are required to ensure access to reformatted and 'born-digital' content in spite of the challenges posed by media failure and technological change (Jenkins 2004). Content production, consumption/delivery, storage and infrastructure need to be streamlined. There is also a need to develop or refine software and tools for providing more effective forms of socialware in which content can be stored, conserved, archived and shared.

3.2.1. Research directions and recommendations

Tagging: 'Smart Metadata', new tools and methods for creating and working with metadata to facilitate better use of digital media in the Creative Industries: There is a strong desire for new kinds of comprehensive content and metadata management systems to enable multichannel publishing and to create 'content eco-systems' that extend beyond the traditional media. Content will need to become scalable across media and devices. For example, in e-Publishing, readership is moving from interacting with a single paper book towards multimedia e-publications accessed across a variety of devices in different contexts and situations. New technologies are needed to ensure that in the future content will render with the right resolution and quality, independently of the specific device it is being accessed from. This interoperability will be key for innovation. **Timescale: Probable.**

Robust and future-proof file formats – Automatic file migration technologies to ensure preservation of digital content: Significant investment and innovation is needed in key digital infrastructure areas, such as data capturing, data processing, and storage, especially with regard to the storing, editing and transmitting/distributing the high resolution large image files captured with 4K–8K cameras. One production-level camera features 42 cameras capable of 4K resolution; it captures a gigapixel image (about 500 times the size of a standard smartphone image) and shoots at 30 frames per second. The storage of such large image files already presents a challenge; their subsequent editing and transmission processes pose further challenges. There is also a need to develop or refine software and tools that can provide new and improved forms of socialware to store, conserve, archive, and share content. Finally, there is a need for automatic file migration technologies to ensure preservation of digital heritage. **Timescale: Probable**

AI (Artificial Intelligence) for automatic annotation: The current approach to automatic annotation consists in linking a bag-of-words of low-level visual features to each of the identified concepts. Clearly, there is a gap between human perception and the low-level visual features, referred to as the 'semantic gap'. The current automatic annotation process often results in a disconnected graph that represents an incomplete annotation or may contain errors. Therefore, a validating and correcting step is often required, and new tools should be developed to achieve this. New intelligent tools and methods for automatic annotation of digital content will enhance the use of digital media in the Creative Industries. **Timescale: Probable.**

3.3. Challenge 3: displaying and presenting

Technologies for presenting and engaging people with cultural artefacts.

3.3.1. Research directions and recommendations

Displays and Holograms technologies: Development of more immersive, 3D and high fidelity display formats and media is strongly recommended for visualisation across the creative sectors. This direction includes advances in hologram technology that would lead to bigger, less expensive and higher fidelity holograms, as well as research in more interactive, touchable holograms (e.g. software based on ultrasonic waves that creates a sense of pressure upon contact with a hologram). This development path may also need to be supported by more mobile and affordable holographic projectors and 3D camera technology advancement. There is also significant interest in 3D screens enabling users to view high-quality 3D images by the naked eye (without the use of glasses), including laser-generated images. The development of screen and hologram technology that could better approximate the final look and form of the created objects is recommended. There is a need for further development of true holographic displays, as no technology is currently capable of achieving liquid crystal pixels with the pitches (pixel-to-pixel distance, including the unused areas, also known as dead space) and densities (pixels per area) required for 3D holography. **Timescale: Possible.**

3D/4D printing and CNC: A variety of advancements in 3D printing are needed, such as improvements in speed, surface accuracy and scale; the development of multi-material printers; the design of 3D printers of higher quality and larger variety that combine durability or resilience with intelligence; and, generally, improvements in terms of the cost, access and openness of 3D printing. These advancements entail the development of open source versions of 3D/4D complexity modelling tools and sensing systems. Especially groups of each creative sector with limited financial means need better access to tools allowing them to manipulate and use rich, multi-layered structured data files (i.e. ones which include 3D scans, colour measurements, material descriptions and other meta-data) as they become standard and replace flat files (2D images, text files etc.). Creators with fewer resources use off-the-shelf products that are not well suited to their needs, whereas open-source development would support wider access and greater specification. **Timescale: Probable.**

3.4. Challenge 4: interaction and engagement

New interfaces for creation: Immersive and Interactive User Interfaces.

3.4.1. Research directions and recommendations

Interaction technologies: There is an identifiable need for interaction technologies that move beyond verbal communication, such as sensors supporting gestural interfaces (for individuals and groups of people), or tools smart enough to reliably recognise non-verbal cues from humans in real time. In the context of the new media consumption paradigm, a desire for seamless communication between mobile devices and sensors (e.g. in the environment) both in order to handle interactive content and in order to dynamically deliver the most appropriate media type or format for the users' location has been registered.

There were also strong views in favour of the ability to use hands in order to create and edit, as part of a general shift from the mouse to haptics and sensors. There is an interest in intuitive haptic and mind-controlled tools, informed by the sentiment that simplicity is key to success in this area. **Timescale: Possible.**

Multisensory engagement technologies: Interactive art installations are generally computer-based and frequently rely on sensors, which gauge things such as temperature, motion and proximity that the artist has programmed in order to elicit responses based on the actions of the participants. In interactive artworks, the audience and the technology work together in order to produce a completely unique artwork to be experienced by each member of the audience/participant. However, apart from research in visual technology, which has now reached the ability to recognise some emotional states through facial expression, the multisensory technologies that allow the transfer of smell, taste, touch, sound or capture moods via brain waves, are still in their infancy. Nevertheless, there is a strong interest for such technologies that could result in more immersive VR (and AR) experiences and screen-less interactions. New technologies are also needed for the real-time recognition of non-verbal cues from humans in a natural and intuitive way, taking into account the appropriate semantics for natural gestures and their role in communicating moods. Recommendations in this area include research in input sensory technologies for creation, improved sketching inputs, and gestural and mind-controlled interfaces; the integration of these inputs with software and fabrication technologies has been also suggested. These developments may involve technologies such as sensors, wearables, photogrammetry, 3D scan capture, electroencephalography (EEG), brain-computer interface (BCI) and human-machine interface (HMI). **Timescale: Possible.**

Innovative 3D screens or another medium better approximating final look and form: Advancing 3D modelling to improve the 3D presentation of design ideas – with additional sensory properties such as haptic and material qualities – is recommended. This may include innovations such as a more advanced 3D interface for the design of 3D-printed objects or improved representation technologies – 3D ‘screens’ or alternative representation media are still underdeveloped. There is also interest in applying Augmented Reality and Virtual Reality technologies to present and test products for clients and customers in user research. At the digitisation stage, technology should be able to incorporate physical artefacts into the design space (at least partially), so that designers can exploit their natural and experiential qualities. The research needs to focus beyond the mere digitisation of physical objects. Sensor based input devices that facilitate the deployment of more immersive, enriched representations of real-world features in architectural model environments (such as cameras, 3D scanners, 360 and 3D systems, as well as tools that capture material properties of texture) are needed, in tandem with the emergence of 3D design that leads into Augmented and Virtual Reality editing where a more realistic multisensory feedback will inform presentation of designs. **Timescale: Present.**

3.5. Challenge 5: IP, security and data protection

Developments required: new infrastructure and common reference framework for Revenue Development and Digital and IPR Rights management (protecting the rights of authors, sharing, policies for online trading, global taxation and piracy); detection of

copyright violations and alerts to copyright owners; prevention of data piracy and data security against hacking and theft; DRM standards, including unique identifiers and an allied metadata standard. **Timescale: Possible.**

3.5.1. Research directions and recommendations

Common reference framework for Revenue Development and Digital IPR: More effective watermarking techniques need to be developed in order to protect digital or IP rights. Additionally, there was a requirement for new infrastructure with common reference framework for Revenue Development and Digital and IPR Rights (protecting the rights of authors, sharing, policies for online trading, taxation and piracy). Within e-Publishing, publishers are likely to adopt a more balanced view of Digital Rights Management (DRM) that recognises the importance of both enhancing the consumer experience and providing adequate technical and legal protection to the intellectual property rights of authors and publishers. Linguistic barriers also inhibit progress in this domain; there is a need both to create a standard specification vocabulary to describe DRM and related issues, and to standardise the corresponding practices. **Timescale: Probable.**

3.6. Challenge 6: better digital content, production, collaboration, delivery/ broadcasting and connection tools

3.6.1. Research directions and recommendations

Improved/new open source platforms for creating, sharing, searching and collaborating: These are tools that enable creative professionals to combine live performances, video and computer-generated imagery in real time. This research direction brings together a variety of suggestions for open platforms, tools and formats to advance future creative production. The primary requirement concerns creative and collaborative real-time production platforms, technologies and tools that enable creative professionals to combine live performances and computer-generated imagery in real time in order to create imaginative entertainment, experiences and social value. There is a widespread expression of interest for a much closer collaboration between content creators (including editorial) and technical developers in the design and development of tools and technologies for the media industry. There is an emphasis on the need for technologies to be developed hand in hand with their users, so that innovations in creative production tools would be driven by needs and affordances derived from working practices, sector-based knowledge and insight. There is also a strong desire for open formats to become standard across the industry, streamlining many processes from content creation, editorial and post-production, through to broadcast, delivery and distribution.

In terms of the way in which the content will reach these delivery platforms, 5G is cited as having massive potential for the sector in aiding innovation. When 5G coverage becomes available, it is believed that the way we consume content, and the amount of content we consume, will change profoundly. An equally significant change is predicted for the moment in which all our screens will have an IP connection and can thus communicate with one another. Cloud computing, extended with new 'fog'/ 'mist' infrastructures, can contribute to this vision. In order to take this trend further, interactive, unobtrusive real-time collaboration, story mapping, editing and communication tools are needed to support the creative process. Tools that enable creative professionals to combine live

performances, video and computer-generated imagery in real time and collaborate to create imaginative entertainment and experiences are still at the prototypal stage. The gaps between the envisaged technologies and current solutions and trends are attributed to the current predominantly engineer-led approach to collaborative design. Remote collaborative story-mapping platforms are not yet developed enough in order to replace face-to-face collaboration, presenting a major obstacle for creators increasingly working in virtual teams or partnerships. Specific issues with current virtual platforms that must be addressed include non-verbal communication deficits (i.e. eye contact), scalability for larger teams and reliability in low bandwidth regions. Enhanced connectivity may also involve advances in cloud/fog/mist-based storage access, in hardware such as a cloud/fog-connected digital whiteboard, in storing and transmitting data between distributed teams, or in personal, cloud-based servers connected to a wearable device. These advances are likely to require greater collaboration between application and technology vendors as a condition for the development of more integrated features, greater interoperability and user-focused interfaces. **Timescale: Probable.**

Automated Content Integration – and Automated Post-Production for improved discovery: Data sources and services specifically designed to support machine-to-machine access to contents, APIs using the standardised format for indexing and retrieving contents, including a comprehensive suite of APIs and content syndication services. There is a strong desire for a range of new technologies and standards to tackle the complex processes and differences in skills in the post-production phase. The automation of logging, in a way that would incorporate automated interpretation of content, was considered to be highly desirable, as well as systems that could perform automated content curation and integration. Creating tools with which directors and producers can generate automated timelines from logged media before handing over to editors was seen as having huge potential. The enhancement of tools facilitating transmedia storytelling and the development of a new model that includes many-to-many, multi-dimension, multi-authoring and relevant material were also suggested. **Timescale: Probable.**

Automatic real-time translation and communication tools overcoming linguistic, cultural and disciplinary barriers. There is particular interest in automatic real-time translation and communication tools to facilitate the dialogue between creators and collaborators within teams, making possible a quicker and more efficient integration of one's personal 'work algorithm' into a team. There is also a related desire for technological help in the communication between collaborators in real time: translating between actual linguistic barriers or the language silos of different disciplines and cultures. Interaction and industrial design experts also expressed a pointed need for better communication amongst designers, engineers and production experts. **Timescale: Probable.**

4. Conclusions

This paper presented the roadmap for the technology future of the Creative Industries, which was created through the collection, analysis and validation of input from communities of creative and ICT experts under the EU CRe-AM project. The paper discussed the current situation in the Creative Industries, which is marked by considerable and rapid changes in the wake of the digital revolution, and the benefits of roadmapping as a means for the Creative Industries, as well as the economy more generally, to respond effectively

to these changes. After briefly outlining the roadmapping methodology deployed in the project, the paper discussed in detail the challenges that creative sectors are facing and proposed research directions and recommendations for actions in order to successfully overcome them. To maximise the use and value of technology in the Creative Industries, according to these research findings, the focus of future research should be on technologies that facilitate greater personalisation, enhanced user interaction and user engagement and immersion, creative online (co)working, collaborative content production and automated (online) production, new streamlined ways of content production, consumption, storage and infrastructure, archiving and digital preservation, content delivery / broadcasting, collaborative and personalised forms of gaming, new forms of media, such as Visual interfaces, holograms, 3D vision, 3D-physical, VR/AR, as well as new, more effective tools for Digital Rights Management. The proposed innovative technological developments in the Creative Industries were assessed in terms of their technology maturity in the short, medium and longer terms, and were rated as either 'present' (1–2 years), or 'possible' (2–5 years), or 'probable' (5–10 years or beyond). Therefore, the paper gives orientation towards the development of new technologies and related business models and skills, and provides guidance for informed policy-making in this respect.

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