The historical relationship between artistic activities and technology development

IN-DEPTH ANALYSIS

Panel for the Future of Science and Technology

EPRS | European Parliamentary Research Service

Scientific Foresight Unit (STOA)

PE 634.439 – May 2019

EN

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Studying the intertwining between art and technology throughout history, helps us understand that relationship today, and how it will continue in the future. Modern technology impacts significantly on art. Artists have always invented new technologies and created innovative technological applications. They tend to humanise technology by engaging with it from a human perspective.

The arts play a crucial role in the current phase of this historical cycle of intertwining of art and technology. The European Union has created Science, Technology & the Arts (STARTS); the United States of America nurtures Science & Technology, interpreted through Engineering & the Arts, all based in Mathematical elements (STEAM); and China invests heavily in creativity.

This paper aims at contributing to a better understanding of the cyclical nature of the intertwining of technology and art. It focuses on a history of that intertwining up to the transition between the 19th and 20th centuries. We seek to show that the current visibility of the intertwining of art and technology is not a new phenomenon in the policy-making world, but grounded in a long-standing historical cycle.

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ADMINISTRATOR RESPONSIBLE

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LINGUISTIC VERSION

Original: EN

Manuscript completed in May 2019.

PE 634.439
ISBN: 978-92-846-4778-1
doi: 10.2861/961315
QA-03-19-266-EN-N

http://www.europarl.europa.eu/stoa (STOA website)
http://www.eprs.ep.parl.union.eu (intranet)
http://www.europarl.europa.eu/thinktank (internet)
http://epthinktank.eu (blog)

Executive summary

Art and technology have different meaning for different people, and the ways they are perceived are determinant for their appreciation and/or utilisation. Technology design and development reflects social needs and beliefs, and, therefore, decision-makers, policy developers and innovators need to be aware of these social judgements about technology and how these might affect engagement with technology.

Increasingly the arts play, if they are permitted, a relevant role in the creation of new technologies and the generation of knowledge about it. In the United States of America (USA) the arts became an integral part of the research and education system with the creation of Science & Technology, interpreted through Engineering & the Arts, all based in Mathematical elements (STEAM) in 2017. The EU is also adopting STEAM in its skills-driven policies, as well as creating Science, Technology & the Arts (STARTS), a programme which allows artists to participate not only in research but in processes of knowledge transfer and even to contribute to innovation.

The current visibility of the intertwining of art and technology is not just another new phenomenon in the policy-making world. It is grounded in a long-standing historical cycle.

The stories from history used in this study highlight various approaches to nurturing the relationship of technology and art. These approaches are context-dependent, relevant to the stories. At any particular time in history, one approach to nurturing the relationship between art and technology worked better than another. What follows is an attempt to typify those successes, but not from an historical point of view. The historical examples have to be applicable to the complexities of our contemporary world and take account of the policy-making instruments available today.

For example, the invention of photography triggered several new dimensions in the intertwining of technology and art. As a technology, it was widely adopted by artists who, by exploring it artistically, developed photography and its range of applications immensely. As a medium for artistic expression, it allowed for unprecedented forms of realism, and techniques developed in relation to scale allowed us to see in completely new ways.

Perhaps more importantly for the artistic side of this intertwining, photography liberated painting. Painters were conditioned to the notion of portraying. They were the ones able to make things look real. With the arrival of photography that was no longer needed. Portraying with photography became a profession. Painters were now free to explore new frontiers, and movements such as Impressionism and Expressionism were born. Painting, then, allowed us to understand the world in more complex ways and possibly even made it more complex.

Photography is a great example of the intertwining of art and technology. At certain moments of its development, it supported the evolution of artistic expression. In return, artistic needs lead to the improvement of the technology of photography itself.

Each of the historical periods presented in the study could be interpreted in different ways. Different models of nurturing the relationship between art and technology can be extracted from them. We have necessarily simplified these interpretations of potential models, to make them more accessible and applicable in terms of potentially new policies in the field of art and technology.

A relevant aspect of the intertwining of the arts and technologies is that it is not challenge-based, as most innovation processes are. In those processes, a challenge is previously identified upon which action is taken. In the case of the intertwining studied, challenges are constantly recreated; problems are constantly reformulated.

The findings point to four models of promoting practices in the intertwining of the arts and technologies.

- As alternatives to an organic model of simply funding artistic practices in the referred field, it has been observed that bringing artists to reside for a period of time in companies or applied research organisations often leads to interesting outcomes.
- Allocating work time for technical personnel to resolve challenges brought up by artists is another way of nurturing developments in the field. Making real-life circumstances accessible to both artists and engineers, allowing them to figure out what might be the challenges and to find ways to overcome them also produces relevant outcomes.
- Furthermore, this study aims to reveal that artistic practices are not only relevant as cultural or creative instruments. It is urgent to put forward and strongly support artistic practices and production as a relevant generator of knowledge, technology and as drivers of innovation in general.

To achieve such an endeavour for a competitive EU, it is imperative to understand and make the non-sectoral, but immense value of the arts quantifiable. After the success of the cultural and creative industries (CCIs) spillovers discourse, followed by that of CCIs crossovers put forward by the Estonian Presidency of the EU, it is now time for action. On the ground, in close co-creation with European citizens and with the simultaneous strong support of the European institutions, it is now time to mitigate the potential danger of the European Union becoming a 'museum of the world'. It has become increasingly crucial to support the inter-relationship of art and technology in the EU.

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1. Introduction

Technology makes tools; art makes meaning. Technology is human creativity directed towards usefulness, whereas art is human creativity directed towards goodness, beauty and truth. Technology is a means to other ends; art is its own end. (Woodbridge, 2017)

Art and technology have different meaning for different people, and the ways they are perceived are determinant for their appreciation and/or utilisation. Technology design and development reflects social needs and beliefs, and, therefore, those in the areas of decision-making, policy development and innovation should be aware of how technology is judged socially and how this could affect society's engagement with it (Williamson et al., 2015).

Art and technology are now more intertwined than they have ever been. Modern technology is having a significant impact on recent art. Contemporary artists are using new materials and techniques to produce artworks. Artists today are continuously experimenting with new technologies in different forms. They find new ways to use old mediums as well as inventing new ones. Computer programs allow artists to easily manipulate media using customised tools, creating effects in a few minutes that once took months to produce. The impact that these technologies are having on contemporary art is hard to pin down, however, as they are evolving and changing so quickly.

The willingness of the art world to contribute to the debate on future technologies is reinforced by the creation of STARTS, the Science, Technology and the Arts initiative of the Digital Single Market of the European Union[1]. Besides paving the way for artists to participate in research and innovation processes in technology, STARTS engages with renowned cultural institutions such as the Venice Biennale, Centre George Pompidou in Paris and BOZAR in Brussels. Debates about technology are taking place in artistically driven institutions.

Technology has always been a fundamental force in the evolution of art, facilitating easier creative processes, and enabling new types of artistic expression and revolutionary art forms. One of the most prominent artistic *modus operandi* consists of connecting things that have not been connected before, or connecting them in unexpected ways. Whereby, new things emerge. One of the visible faces of art and technology is innovation where the domains connect and deliberately produce new ideas. It is not surprising, generally, that when informational capitalism is the basis for a society, domains should be combined in this manner (Haahr, 2004).

Nonetheless, economic success through innovation is not everlasting. World history is littered with examples of nations that rose to economic prominence by initiating one transformative innovation only to fade away at the start of another innovation from rival nations. If nations and societies want continued economic growth, then they must continue to allow new ideas to compete while sufficiently rewarding innovators.

'We live in a complex, interconnected, unpredictable and rapidly changing world.' (Ruche, 2017)

Change is the watchword for all technological systems. Different pressures push technology forward. 'Consumers' demand 'more, better, bigger, faster', at a pace that requires a growing number of engineers, the major technology developers. But more engineers provide more solutions faster, creating technological loops. The artist, as well as contributing to innovation, can bring some equilibrium to these feedback and feed-forward mechanisms contributing to technology humanisation. Technological changes are a major source of economic growth and social

[1] 'The (s+t)*arts = STARTS initiative merges Science, Technology, and the ARTS. It attempts to remove boundaries between art and engineering to stimulate creativity and innovation.' https://ec.europa.eu/digital-single-market/ict-art-starts-platform https://www.starts.eu/

transformation. However, these changes seldom follow the linear model: invention, innovation and diffusion of technology (basic research, for instance, spurs the development of technology, which in turn induces commercialisation and diffusion of products). The idea that research directly leads to new technology-based products does not necessarily means that these are innovative products (Williamson et al, 2015). The inverse is also true: innovation is not necessarily a direct result from research. Technologies mostly change via the means of assembling parts, in which the current technological components are innovatively recombined (Williamson et al, 2015). It is exactly here that artists make a difference for innovation in technology, due to their ability to create unexpected combinations.

Figure 1 – The ideal internet of things showroom

Source: ©So Kanno

As an example, So Kanno, a STARTS artist in residence in CRoss fErtilisation through AlignmenT, synchronisation and Exchanges for IoT (CREATE IoT),[2] created an artwork[3] in which connected objects talk to each other through Twitter (Girão et al, 2018). The artwork is a materialisation of the fact that technological change is crucially facilitated by the enhancement of interoperability of technologies. It is a fable of objects. It is a humanised application of technology.

'*We shape our tools and, thereafter, our tools shape us*.' John Culkin (1967)

Technology is central to human existence. Humanity has always pursued technological answers in its activities – in the production of food, in comfort and safety, in defence, transportation, trade and commerce, in information, media and communication, and in the areas of health and sanitation, reproduction and manufacturing, art and culture – indeed, everything (Williamson et al, 2015).

Technology and humanity create and shape each other. Most people focus on how 'we shape our tools', to make our lives easier, more pleasant or more beautiful. However, our behaviours, attitudes, and culture are also being shaped by the tools/technologies we use. People are not distinct from their technologies and there is a growing urge to try and control our technological destiny before it

[2] CREATE IoT is the coordination action overseeing the European Union Internet of Things (IoT) Large Scale Pilots. The programme is a €100 million European Commision investment in the five relevant sectors of IoT for the European Union Digital Single Market. https://european-iot-pilots.eu/

[3] The Ideal IoT Showroom is an artwork resulting from the STARTS Residencies programme. https://vertigo.starts.eu/calls/2017/residencies/the-ideal-showroom-of-iot/detail/

controls us. Therefore, understanding the past of art and technology helps us in navigating the present and future.

Economic, social and cultural activities drive technology innovation and acceptance. A good example of this is the fact that significant historical periods are named after a technology that is perceived as being the prevailing one – the Bronze Age, the Iron Age, the Industrial Revolution, the Green Revolution or the Digital Age (Williamson et al, 2015).

Technologies are tools generated under specific contexts, either historical, cultural, geographical, political or social. This specificity renders a technology popular in one place, or at one time, and not another. It will have particular impacts under specific situations. Hence the relevance of knowing the level of acceptance of a certain technology, or the balancing between technophile optimism and concerns. Cadin (2018), in a very interesting paper on 'A Digital Renaissance', maintains that this balance is rather biased towards Europe and the USA (particularly California): in Europe dystopian speech (dark projections of a jobless future, or dictatorships of algorithms, or transparency rhyming with surveillance) prevails, whereas in California people see technological utopia without any nuance.

From building Egyptian pyramids or Gothic cathedrals, to making refined pottery and glass, or providing painters with new colours through the discovery of artificial pigment, technology has always had a major role in the arts. Music history provides several very good examples of the intertwining of art and technology. The inherent properties of physics and mathematics within music were perceived and explored by Pythagoras as earlier as the 6th century BC (Leopold, 2005). He established the numerical and mathematical basis of acoustics. Much later, the concepts of hydraulics were used to develop pipe organs. In the 20th century, with the creation of electronic musical instruments, composers had to turn into sound researchers. But it was the development of a 'machine music', the record player, which changed the music industry forever.

From this point of view, it seems correct to speak of a 'technologisation' of the arts in the 20th century. A period when technologies might have had a stronger role in their relationship with the arts, as they widely experienced with other practices. However, it appears that an opportunity to give the arts a chance to strongly influence technological developments, was missed once again. Hence the significance of demonstrating at this point in time, through this study, the repetition of this constant rebalancing between art and technology.

In order to frame the discussion we have included a couple of attempts to define the relationship between technology and art. Although complexity is key in describing our world today and bipolar approaches seem less useful for understanding contemporary realities, a transitional distinction between the two components of the discussion is essential. Defining art is an impossible task and definitions of technology tend to be too strict and therefore limited. Widening an understanding of technology while narrowing a notion of what art might be is a well-intended attempt to find common ground by overlapping the two concepts.

1.1. A broad definition of technology

The terms **art** and **technology** have different meanings in different contexts and evolved over time. For the purposes of this study, we will adopt Haahr (2004) definition as: art is the result of applying creativity and thus **artworks** – the physical objects, performances or digital creations which emerge – are the result of this application of creativity. The purpose of art is to communicate, so art brings meaning to life by provoking us, and offering us insight in the way we understand the environment, the others and ourselves. Art challenges our views of the world. We will also use the term **technology**, as Haahr (2004) to refer to a body of tools available to humanity at any given point in time. Those tools are understood here as resulting from the application of scientific knowledge for practical purposes, especially in industry.

Technology based products have been assembled over millennia and are always under continuous development. Technological development refers to the expansion of these products through research and innovation. As new technologies are developed, old ones become obsolete and tend to be completely removed from the set. They can also become so prevalent in our daily life that they are no longer regarded as technology. Paper overtook papyrus as a knowledge transfer technology, and in its turn has been supplanted by digital media. The typewriter, once the leading technology for inscribing information on paper, has now been almost entirely replaced by digital word processing. The simple pen is now so common, it is not usually considered to be technology (Haahr, 2004).

'Technology alone is not enough — it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing.' (Steve Jobs)

The meaning of technology keeps generating much debate. Definitions, uses and understanding of technology also vary with time and social context. Some even define technology based on the arts (see below). Although we now try to draw distinct lines between art and technology, their radical separation can be traced back only to the 19th century. It is therefore a relatively recent historical phenomenon. The root of the word *tékhnē* , borrowed from Greek where it meant 'art' or 'skill,' refers to art, not in the modern meaning of the word, but rather with an older meaning, where art is defined as making or doing, often called 'craft' (Wilson, 2001).

Initially, technology represented the knowledge of rules for making tools. Later, it was extended to describing arts in practical, utilitarian or mechanical fields. This semantic development, which was widened to include the very means of production of arts in these fields, was a process which occurred over various centuries of social, cultural, economic and technological change. This escalation of new machinery, materials and processes of manufacture also engendered a new vocabulary, or the use of old words in new ways, to describe these new features of experience (Wilson, 2001). In 2017, La Shun L. Carroll laid out the definitive definition in three parts, in which he stated that *technology* is:

a *'something that is always inherently intelligent enough to have a function that only intelligent beings have the ability to comprehend'*;

b *'something devised, designed, or discovered that serves a particular purpose from a purely secular standpoint, without requiring mankind to be responsible for it. For example, salt doesn't inherently "elevate" or do anything deliberately. It does "elevate" the boiling point of water, in which it has been found to serve a purpose'*;

c *'a significant beneficiary of rationally-derived knowledge that is "used for" a purpose, without itself necessarily being translated into something physical or material that "does". For example, instructional methodologies in education, processes and ideas'*.

However, the society of global information which we live in tends to funnel technology towards computers and robotics. It tends to leave behind biotechnology or nanotechnology; environmental or materials technology; agricultural or production technology, to name just a few. All of them rely on other 'materials' generating products that we all use daily. Those materials are nowadays also under the scrutiny of artists to produce new artworks and art forms.

This erroneous perception is probably related to the fact that art and science, which become a fashionable subject at the turn of the 20th century, was mainly based on digital and media art. The central European scene already had several festivals and events presenting artworks that used and addressed digital media in the 1990s, as well as having established art and science education in some of the major art universities.

We must bear in mind that art and technology is a trend as old as art itself: in order to paint their caves, humans had to develop pigments that when dried kept long enough to convey the drawings' message to coming fellows, conveying formal messages, e.g. 'these are the animals that you can hunt here', or more informal ones, e.g. 'look how beautiful these animals are'.

In sum, the notion of technology adopted in this study develops around usefulness and application. It does not necessarily need to be material. It can be a process. Technology is understood here in opposition to art, which is not supposed to have a purpose of usability, although it can also serve a purpose and be applied. Common ground between the two seems to be the notion of process.

1.2. Hybrid practices of art, science and technology

'The most beautiful experience we can have is the mysterious. The fundamental emotion which stands at the cradle of true art and true science.' (Albert Einstein)

Technology is everywhere. So are creative minds. Scientists explore many different subjects producing knowledge and then transform that knowledge into something else. One of the most prominent personas associated with scientific research and artistic practices is Leonardo da Vinci (see section 3.6.). But other creative minds left their mark in the world by exploring art and technology in ways that triggered the *Art&Science* movement.

Frank Malina (1912–1981) was an American aeronautical engineer and painter. He became known for his pioneer work both in art and scientific engineering. Besides being at the origin of the famous Jet Propulsion Laboratory (JPL) at the California Institute of Technology, he founded *Leonardo*, in 1968, in Paris. *Leonardo* is an international peer-reviewed research journal which focuses on how the contemporary arts interact with new technologies and the sciences. *Leonardo* is part of the Leonardo/ISAST project (the International Society for the Arts, Sciences and Technology)[4] which focuses on interdisciplinary work, creative output and innovation.

The community behind Leonardo/ISAST had a great influence in transforming STEM into STEAM policies of education in the USA. In STEM, disciplines of Science, Technology, Engineering and Mathematics formed the core pillars of research and education in the USA. The Arts were added to those disciplines in a recent bill[5] of the US Senate and then STEAM was created. STEAM in the USA, alongside with STARTS in the EU, confirm the need to support emergent hybrid practices in science, technology and the arts.

Art and technology continuously define and reshape the world. New inventions and experiments lead the way to new perceptions for mind and body, words and world make room for fresh rules. Technology in art challenges our perceptions. However, while we grasp that creative production is a reflection of a specific time period, how can we comprehend the increasing numbers of young, current writers whose practice is based on presenting the immaterial or ephemeral? (*Widewalls Editorial*, 2017).

Artists and scientists have been exploring artistic practices emerging at the intersection of their fields. Dialogue between disciplines, in particular between the sciences and the visual arts, has been intensifying and thriving for many years. Science institutions have discovered art as a medium for both intelligibly communicating their specialised knowledge to a broader public and thus generating new knowledge. This knowledge generation in *Art&Science* revolves around two key questions: what scientific methods are used by artists, and what artistic approaches are used by

[4] *Leonardo*/The International Society for the Arts, Sciences and Technology (*Leonardo*/ISAST) is a non-profit organisation that serves the global network of distinguished scholars, artists, scientists, researchers and thinkers. https://www.leonardo.info/about

[5] The STEM to STEAM Act of 2017 amends the STEM Education Act of 2015 to include art and design in research and educational grants of the National Science Foundation. https://www.congress.gov/bill/115th-congress/house-bill/3344

scientists? Another focal point has been the ways and means to foster creativity in schools and in public spaces.

As art and technology changes the world (or our perception of it) it also changes the words. Countless new terms have emerged to describe this new field of hybrid practices: 'art/science hybridity', 'interdisciplinary', 'transdisciplinary', and even 'anti-disciplinary' (O'Brien, 2014). A wide range of unconventional platforms has been made available for both the investigation and expression of new art modes ranging from public spaces to research labs, or more traditional performance such as theatres or museums.

Art's impact on humans is transformative, although it is not easily defined and is even more difficult to prove. Nobel Prize winner Eric Kandel (Physiology or Medicine, 2000), among others, has made advances in neuroscience recently that show the brain to be constantly rewiring itself; this depends on the way in which people experience the world on a moment-by-moment basis. Our earliest memories and experiences are also being recreated each time they are summoned. They are in a constant state of being reshaped by new intellectual and emotional contexts.

Artists and scientists use parallel approaches on their quests for authenticity. The scientific method is, by definition, objective. Scientific authenticity is pursued by designing experiments that test a potential explanation, or hypothesis. Whereas, artistic method and evaluation seems more driven by intuition. Artistic authenticity is largely pursued via the creation of an art object transmitting a new perspective.

We live in an age where the technological pace is continuously changing our culture and the human condition. To name but one example, there is more data surrounding us than we could possibly process or have the wisdom to understand. It is not only possible, but may be imperative for artists and scientists to collaborate, building on each other's research and processes to enable society to grasp these changes. If we think, do and learn with and from each other, artists and scientists can potentially harness the knowledge now emerging in ways which are both meaningful and translatable (O'Brien, 2014).

1.3. The example of the music industry

Music is amongst man's first cultural expressions. It appeared before agriculture or writing and is present in every known society, present and past, on the planet, in different formats and social functions (Assis, 2005). Music was most likely present in the populations of our ancestors before humans dispersed all over the world.

The music industry is probably one of the oldest industries. For example, Johann Sebastian Bach (1685–1750) officially produced 1 126 compositions, according to the Bach-Werke-Verzeichnis (BWV).[6] Most of his compositions had a functional purpose in religious contexts, designed for religious ceremonies. Similarly to Bach, Wolfgang Amadeus Mozart (1756–1791) and The Artist Formerly Known As Prince (1958–2016), are extraordinary examples of prolific generators of content for the music industry (Assis, 2005).

Technology has always been inseparable from the development of music. From the 'monochord' (single stringed instrument) that Pythagoras used to study musical intervals in relation to the ratios of the string lengths that produced them, to the biggest pipe organs in the world, or the evolution of keyboard technology, instrument technology has also evolved with the music.

[6] The Bach-Werke-Verzeichnis (BWV; literally, Bach works catalogue) is a catalogue of compositions by Johann Sebastian Bach. It was first published in 1950, edited by Wolfgang Schmieder. https://en.wikipedia.org/wiki/Bach-Werke-Verzeichnis

Organs from the Middle Ages and the Renaissance were technological masterpieces. They used both exquisite craft and knowledge of engineering and produced a mass of pipes, stops, keys and bellows which transformed air into astonishing and breathtaking music (Assis, 2005). Four basic technological elements characterised this instrument:

1. a compressor which pressurised the air, in the form of a pump operated by levers or pulleys;
2. a vessel for storing air;
3. a mechanism for controlling air flow, usually in the form of a keyboard;
4. a progression of pipes of different sizes which produced musical tones when air was directed across them.

The earliest organ had seven notes for each octave, however new notes were added and instrument builders were faced with the problem of designing keys such that twelve could be controlled in the span of a hand. These were the first attempts to develop a keyboard. A plethora of keyboard innovations and 'adaptations' have provided classic expression and exercise for the inventive and innovative genius of the Western mind throughout the history of Western music.

In 1837, Guiseppe Ravizza adapted the musical keyboard to mechanical writing, calling this invention the *cembalo scrivano*. In 1870 came the Remington company's patent for the first commercially successful typewriter. In the 20th century, with the keyboard's application to computing – the studio tool of the medieval *musicus* – the data bank has entered into service. The keyboard is the most easily observable way in which the Western musical tradition has shifted the human psyche into a mindset in which progressive innovative technology became a dynamic of human culture (Hindley, 1997).

Initially, hearing music required the presence of musicians. But by the end of the 19th century some rudimentary audio recording technologies became available; Thomas Edison introduced the phonograph in 1877. At the turn of the 20th century, new electricity-based technology again changed the way in which we access music. Developing the technology of microphones and discovering electromagnetic waves enabled radio to gain popularity as a system of broadcasting news and music in the 1920s. Anyone with a receiver at home could listen to radio, which, as a point of interest, still relied on broadcasting real-time performances from the studio. Live transmissions enabled much higher sound quality than that possible with recording equipment at the time, and this helped produce an entire generation of radio musicians (Assis, 2005).

The first magnetic tape recorder was released in 1948, expanding the possibilities for broadcasting – live musicians were thus no longer needed, and the birth of the recording studio arrived. Vinyl records reached the market in 1948 and rapidly became the medium of choice for sound reproduction. Vinyl records of various sizes and speeds were made; they changed and evolved in line with technology and the demands of commerce. Vinyl grooves, for example, placed significant restrictions on the volume of bass frequencies, as high bass volume made the needle jump. These limitations were a strong influence on the very nature of pop and rock music as we know it (Assis, 2005).

Listening to music on records became so popular that it sprouted a new branch of the musical industry: the record company. The important tools for this emerging industry were the recording studios, with each studio having its own approaches and equipment, which thus created a sound with its own personality. Producers ingeniously overcame the limitations of the technology and by finding solutions for problems that occurred with each new project, they produced new techniques which broadened the scope of recorded music, and spurred other producers on in their search for better solutions (Assis, 2005).

Perhaps the music industry is the most tangible example of art-technology intertwining and its influence on the world economy.

2. Artistic practices and knowledge generation

Knowledge is fundamental to human development due to its key role on driving economic growth, social development and cultural enrichment. We will elaborate further on human development in section 5.2.2. UNESCO proposes a concept of knowledge societies; which includes notions of inclusiveness, pluralism, equity, openness and public participation, making it distinct from the 'information society'. In this we can see UNESCO's belief that not only science and technology but also societal choices should shape and drive knowledge societies. Systems involving science, technology and innovation should provide knowledge which can enable contemporary society to confront the uncertainty and complexity of the present day. The challenge is for societies to integrate new approaches to thinking via the creation and promotion of quality education (UNESCO, 2012).

The notion that art practice can be a knowledge generator – and therefore qualify as a research method – was introduced to research in art and education by E. Eisner in the 1970s (Marshall and D'Adamo, 2011). A substantial amount of theory and experience in support of and expanding upon Eisner's ideas has been generated since then by theorists, researchers and artists. Currently major universities worldwide offer PhD programmes on Arts (not about Arts) and the body of knowledge produced is the foundation on which models for art-based research can be built in the social sciences, healthcare, and education.

2.1. The practice of art as a thinking process

The Practice as Research (PaR), in any disciplinary area, implies action/experimentation as an imperative method. It is a recognised methodology in medicine, design, and engineering. In engineering it is often called action research, to accommodate field-based research and participatory experiments as opposed to laboratory tests (Skains, 2018). In the arts, PaR implies exploration, tests and extension of a wide range of creative methodologies by artists and researchers working across multiple contexts, thus making possible an exploration of how creative interventions are related to not only understanding but also changing the world (Sjoberg, 2014).

PaR initiative in the arts has a history spanning more than three decades. PaR originated in Finland and the UK at about the same time (mid 1980s). Australia is now significantly developing PaR and there are strong spots of activity in Nordic countries, South Africa, France and Canada. However, in some parts of Europe, PaR has been met with resistance whereas in the US development has been much stronger in the visual arts than in the performing arts (Nelson, 2013).

Policy reforms towards the creation of PhD programs in the creative and performing arts prompted the artistic research debate trying to clarify three major issues: a bureaucratic one, *how can we get art recognised and funded as research?* A philosophical one, *do the arts produce knowledge, and how?* And the artistic one, *what should it be like and where are we going?* (Solleved, 2012).

H. Borgdorff has been leading this debate, particularly after his 2004 article *The Debate on Research in the Arts* (Borgdorff, 2004). Despite years of discussion a satisfactory answer as to what artistic research is remains elusive. But still, there are currently thousands of artists pursuing a PhD, and as a consequence we are getting a huge surge in artistic research in art academies and universities across Europe; there is, however, a long way to go to make the public fully aware of this. Artistic research, which is supposed to make an important leap forward, seems mostly to be a by-product of the UK university reform and the Bologna Process from 1992 (Borgdorff, 2004).

What has definitively changed is the number of performances and exhibitions presented under an academic format, in symposia and publications. The Journal for Artistic Research (JAR) is a good example. JAR is an international, online, Open Access and peer-reviewed journal that publishes artistic research from all disciplines.

2.2. The debate on research in the arts

As discussed, Borgdorff (2004) shows that the policy shift was not the only reason for *research in the arts* to be the focus of public and academic discussion; changing practices in art also had a role. It has been common for a considerable time now to speak of contemporary art under the umbrella of reflection and research. Although these practices have always been linked to the tradition of modernism, they also mesh with the late modern or postmodern practice of art. This thus involves both creators' and performer's self-perceptions and is also increasingly common in institutional contexts, from regulations for funding to programme content in art academies and laboratories. After a period of the mantra being *cultural diversity* and *new media,* in the last decade especially, research and reflection have been common parlance for both the practice and criticism of art in public and professional arts fora.

Research & Innovation are no longer confined to universities, businesses, independent research centres and consultancy agencies. Increasingly numbers of artists and art institutions are also now calling their activities *research*. The granting of master's or PhD degrees to artists (composers, architects, designers, performers, …) on the basis of their art work is now spreading through the world, and it has been possible for decades in the US (Borgdorff, 2004).

The global discussion on *practice-based research* has benefitted from the inclusion of research in professional European art schools. There has also been a significant contribution to this debate from the 1990s university reforms in the UK and Scandinavia. In the UK, these reforms meant that polytechnics (higher professional schools) were officially assigned a standing equal to that of universities, and thus art schools were able to gain direct and indirect public research funding. Australia and Scandinavia underwent reforms along similar lines, and this allowed current research programmes in professional arts schools to obtain structural funding. The EU has no rules and or directives on this debate, with each country having the right to make independent decisions. Obviously, not all governments are willing to undertake this type of reform, and there are various countries which still maintain a strict divide between, on the one hand, academic education *with* research and on the other, professional training *without* it.

It is clear that the arts increasingly play, or want to play if allowed, a relevant role in the generation of knowledge. As previously stated, in the US, the arts have been an integral part of the research and education system since 2017, with the creation of STEAM. The EU is also adopting STEAM in its skills-driven policies. Furthermore, the EU created STARTS, which allows artists to participate not only in research but in processes of knowledge transfer as well and even to contribute to innovation.

The current visibility of the intertwining of art and technology is not another instance of hype in the policy-making world. It is grounded in a long-standing historical cycle, like threads of a rope that has constantly been braided.

3. Historical episodes – stories in the history of the intertwining of art and technology

Each technology started as state-of-the art. An artist needs not only vision but also the courage to start working with new techniques and the tools and concepts from an area of technology which is still nascent and has not yet been accepted as valid for the arts. Working with a new medium before it has been defined as a medium is a challenge. The accelerated pace at which technological innovation is progressing means that new technologies quickly become institutionalised. Computer graphics and animation, digital video, 3D modelling, Web art interactive multimedia, seen as revolutionary a short time ago, are now mainstream (Wilson, 2001).

Seen through the lens of the history of art, artistic works have a pedigree as long as that of humankind, all the way from pre-historic to contemporary art. Through the ages the artist has played a changing role in changing times. There was the artist as craftsman and creator of useful objects during the early stages of civilisation. The artist was shaman and magician, decorator and storyteller and illustrator in the service of church and state during the Middle Ages. The Renaissance artist was also a scientist and the inventor of a mathematical system to represent deep space on a flat picture surface. In more recent times, as technology has taken charge of our life, the artist responded to the challenge by using the tools of technology to investigate new art forms (Brendel, 1993).

What follows are descriptions of episodes in history illustrating the various roles artists have had in their relationship with technology. Reversely, the influence that technology had in artistic expression will also be taken into account. The aim is to understand the possibility of typifying some of those episodes in conceptual models that can become useful for policy making in the field of art and technology.

3.1. Cave painting, images and communication

Cave art is a term referring to the decoration of the walls of rock shelters and caves throughout the world and also to carved figurines (mainly of animals of animals). The best-known sites are in Upper Palaeolithic Europe. Multi-coloured paintings made of charcoal and ochre, and other natural pigments, were used to illustrate animals, humans and geometric shapes. Although the purpose of cave art is still widely debated, it shows that humans always had a drive to communicate their experience of the world. There is a close association of cave art with shamanistic activity: it may have been the work of religious specialists, painting on walls to show memories of hunting trips in the past or to help further trips in the future (Hirst, 2018).

Humans were thought to have arrived in Europe from Africa around 40,000-45,000 years ago. However, recent paleoanthropological studies place that migration out of Africa as early as 120,000 years ago (Hershkovitz et al., 2018). The results of new dating techniques have called into question the received wisdom that a vital episode in the development of modern intelligence and culture in humans took place in Western Europe; this was formerly based on the figurative or representational art which emerged about 40,000 years ago in cave paintings and sculptures. The dating data obtained from hand stencils and other paintings of animals found in caves in the Maros karst in Sulawesi, Indonesia raise the possibility that figurative art made a more or less simultaneous appearance in completely different corners of the world (Aubert et al., 2014).

The Indonesian images and the European ones have certain similarities. The animals depicted are different, however, showing indigenous animals as opposed to the European mammoths and are done in a different style. The images in Indonesia have a resemblance to brush strokes, as opposed to the apparent finger daubing of early European images. Two theories have been put forward for such artwork developing, positing that it may have arisen independently in Indonesia, or alternatively that when early humans left Africa, they were already capable of making art, and they took it with them to diverse areas (Aubert et al., 2014).

Recent results for three sites in Spain, La Pasiega (Cantabria), Maltravieso (Extremadura) and Ardales (Andalucía) place cave art in Iberia at 65,000 years ago. This date is generating much debate because the researchers interpreted these results as an evidence for Neanderthal authorship. However, little is known of the extent or nature of symbolic Neanderthal behaviour, and while there it has been propounded that Neanderthals used body ornamentation, modern humans are presumed to be responsible for all cave paintings (Hoffmann et al., 2018).

Figure 2 – Bushmen San Rock Paintings

Source: © EcoPrint / Shutterstock.com

However, even newer results (from September 2018) demonstrate the ability of early *Homo sapiens* in southern Africa to produce graphic designs on various media using different techniques. Henshilwood et al, in 2018, reported cross-hatching in ochre crayon on a silcrete flake found at levels of Blombos Cave, South Africa dating from approximately 73 000 years ago, in the Middle Stone Age. The hypothesis of early humans coming out of Africa already bringing art with them has, at the moment, more scientific support.

Richard Coss, a psychologist from the University of California, Davis, is an expert on art and human evolution. Recently, he suggested that it was partly due to the creation of art that prehistoric humans developed into the world's dominant species (Coss, 2017). The hand-eye coordination along with the visualisation skills which were needed to create prehistoric cave drawings were active in developing basic hunting skills in *Homo sapiens* and this benefited humans over the Neanderthals, cousins of the humans, but lacking art. It is Coss' argument that Neanderthals made use of thrusting spears in order to hunt tamer prey in Eurasia, while *Homo sapiens* were used throwing spears for more dangerous and wary game in Africa. He posits that, as a result, a larger parietal cortex developed in *Homo sapiens;* this is the region of the brain that processes visual images and motor coordination. Drawing also improved skills of observation; these drawings may have been used to conceptualise hunts, to evaluate the attentiveness of the prey, to make targets of vulnerable body areas and to enhance group cohesion through spiritual ceremonies. Intuition does not immediately lead us to link hunting techniques and prowess in drawing, but Coss' reasoning gives one credible link between these skills and why *Homo sapiens* flourished but the Neanderthals disappeared.

'The ability to produce art was an indication that humans had begun to think in more abstract terms. It's a thought process that enabled us to come up with the science and technology that enabled our species to become so successful.' (Ghosh, 2014).

Figure 3 – Cave paintings in Patagonia

Source: © Buteo / Shutterstock.com

The intertwining of art and technology is as ancient as cave paintings. It seems indeed that it was the capability of producing art that allowed *Homo sapiens* to survive and overcome direct competitors. Artistic practices were already integrated as a practice of research in the context of the technologies of hunting. Artistic practices were nurtured naturally without a specific purpose but also had a relevant role in the creation and communication of images.

3.2. The Egyptian world

The ancient Egyptians had an extraordinary command of science and technology.

The size and scope of pyramids naturally encourages questions regarding how they were built. While some important questions are still to be answered, ancient Egyptian inscriptions and texts, wall paintings and tomb inscriptions, art and artefacts provide simple answers to many of them. Ancient Egyptian technology went further than just buildings. The Egyptians were responsible for the invention of various items we use in the present day, for instance cosmetics, paper and ink, toothbrushes and toothpaste, even the precursor of the breath mint. Furthermore, they advanced knowledge in practically every area, including the manufacturing of household goods, brewing of beer, civil engineering, agriculture, architecture, astronomy, medicine, art and literature (Mark, 2016).

Technology was also an influence on Egyptian art and literature, both in its production and also its content and form. An example of this is the Poem of Pentaur, which tells the story of Ramses the Great's victory over the Hittites at Kadesh. It was not simply written on a papyrus sheet, but inscribed for all to see on temple walls in Abydos, Karnak, Abu Simbel, and the Ramesseum. The medium which the artist used for this work, the temple's stone walls, is emblematic of the poem's content: the great victory of Ramesses when faced with a near impossible task. The medium used for the telling of the story makes it all the more impressive (Mark, 2016).

The Egyptians asked questions and gave answers in their literature and art to the questions posed by all societies. What happens after we die? How did the world come to be? Where happens to the sun after nightfall? In the absence of true scientific knowledge, they used legends and myths to answer these questions, providing explanations for what would otherwise be a mystery. These myths were passed on to the Romans, and their effect on the way in which religious beliefs in modern time developed is clear. By reading and following ancient stories, we can let go of modern preconceptions, leave the arena of our particular cultural experience and be part of a world which is not only very different, but which also enhances our lives (Mark, 2016).

Figure 4 – Luxor Temple

Source: © Jakub Kyncl / Shutterstock.com

For the Egyptians, mathematics was in daily use but for reasons more banal than providing answers to the ultimate questions. It was used to keep records, for designing machines like water pumps, for calculating rates of taxes, and making architectural designs and deciding on the locations for new buildings. The Egyptians' skill in maths can be seen in the pyramids, and Greek mathematicians, Pythagoras among them, were motivated by this example to perfect their own mathematical work. The Great Pyramid, built in 2550 BC by Khufu (Cheops), is an astonishing 46 metres high, with a slope of 51 degrees. The length of its sides, averaging 230 m, has a variance of less than 5 centimetres. It is taller than St Paul's Cathedral, and was erected with amazing accuracy to align nearly exactly with true north (Mark, 2016).

But beyond their status as mathematical puzzles, the pyramids led the way to comprehension of Egyptian society and its structure. Up to 5 000 employees worked on a permanent basis on the pyramids, and up to 20 000 others worked on a temporary basis for three or four months to erect the pyramid before leaving the work. A bewildering amount of bureaucracy supported this work: first the labour had to be brought, accommodated and fed, and then the massive amounts of stone, ropes, fuel and wood which were necessary to complete the project had to be supplied. Studies carried out on the pyramids support the theory that, even in a pre-mechanical society, great feats can be performed if the resources are available and the will is strong. If there had not been an efficient administration and a strong government, it would have been impossible to build the pyramids. This has led many archaeologists to argue that, while the Egyptians undoubtedly made the pyramids, the pyramids were also the making of Egypt (Tyldesley, 2011).

The Egyptians were a highly technological society. They brought to light a practice of art that was focused on producing technologically advanced forms such as printing and carving of their texts, their symbols and high-precision architectures. In the intertwining of art and technology in ancient Egypt, artists were designing technological change that was further developed by engineers and put in place by masses of workers.

3.3. Ancient technology

Ancient technology usually refers to Greek and Roman technologies as a whole with little formal distinction between the two. But their technological histories are different as their social, political and environment contexts were also different (Flohr, 2016).

Greeks skilfully processed raw materials like stone, clay or wood. They developed or improved tools such as poetry wheels, furnaces or the wood lathe which boost production. Mining and metallurgic techniques allowed them to use several metals and contributed for a huge progress in engineering. Technology was such a hype that Greek mythology has the God of technology: Hephaestus.

Figure 5 – Roman Glass Bottles

Source: © Everett Historical / Shutterstock.com

Romans had access to a wider variety of materials which allied to improved production technologies made the end products better, cheaper, and available to more people. Blown glass was an important Roman innovation that changed both the culture of drinking and the culture of storage (Flohr, 2016).

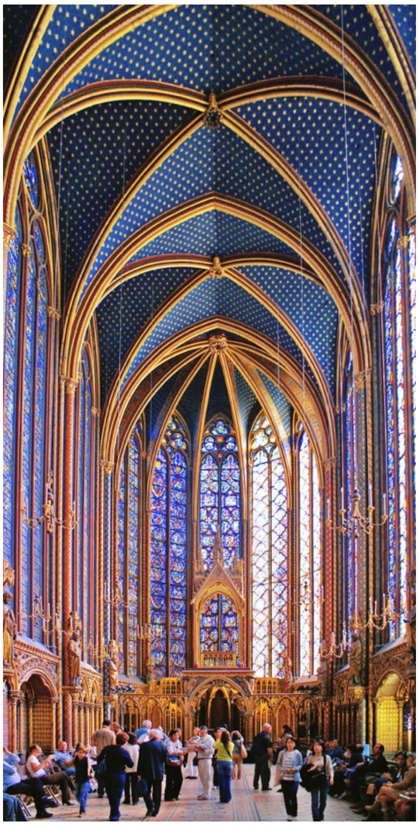
But in ancient Rome innovation and technological changes were not always related to consumer goods. By inventing concrete, introducing the arch and vault and developing new techniques for construction, great public projects could be carried out. Roads, bridges, aqueducts, amphitheatres left a deep impact on Roman social, economic and cultural history (Flohr, 2016).

3.4. Medieval projections

The medieval period of art history spans from the fall of the Roman Empire, 300 AD, to the beginning of the Renaissance, 1400 AD. It is one of the least progressive eras mankind has ever endured. With no economic growth for over a millennium, poverty and political instability lead the way to a huge social and technological regression. Most people could not read or write and this lack of skills meant that all classical knowledge was lost. Science and philosophy were replaced by spirits and superstition. During this period religion played a central role, which explains the fact that early Middle Age artists were mostly priests and monks living in monasteries. Through the art they produced, biblical narratives were passed on to the people. They also had an important role on keeping (and copying) some manuscripts from the classical period. Generally, we can divide the art of the Middle Ages into three main periods and styles: Byzantine Art, Romanesque Art, and Gothic Art. Medieval artists, sculptors and painters moved towards greater realism in their works, culminating in the style which predominated in Renaissance art.

During the Early Middle Ages, the Catholic Church financed many projects, mainly churches and cathedrals. Churches and other works for appreciation by the public were decorated with classical themes. The start of the eleventh century brought Romanesque architecture, which was indicative of the ever greater wealth of the cities of Europe and the power of the monasteries. Gothic style, named after the rulers of France, the Goths, emerged in the mid twelfth century. Figures such as gargoyles were criticised as grotesque by some of their contemporaries, but the cathedrals built by the Goths are among the most stunning and lasting achievements of the time. Notre Dame Cathedral in Paris has undergone many subsequent renovation works since its construction in the twelfth century, but the important Gothic features are still in evidence, with gargoyles and flying buttresses (Murray, 1998).

Figure 6 – The Sainte-Chapelle, Paris



Source: © Wikimedia Commons

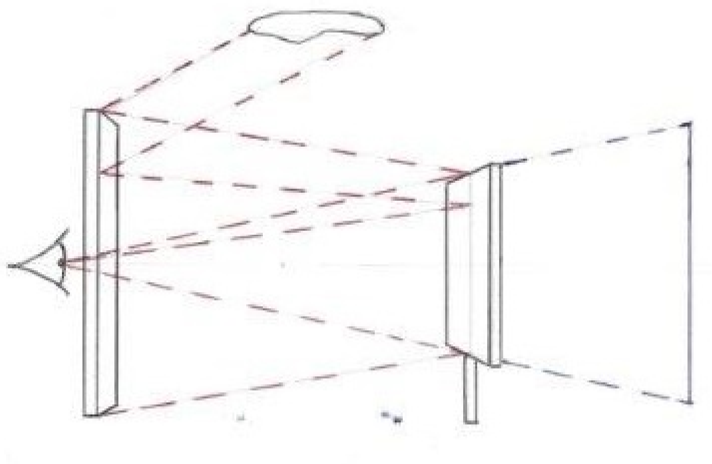
This medieval period is often referred to as the 'dark ages', however its true colours only survive in two places: the stained-glass windows, of places such as the Sainte-Chapelle in Paris, and in the pages of illuminated manuscripts, in which the decoration of the text was in gold and silver and other brilliant colours, or used intricate designs or miniaturised pictures. This art was also practised by Islamic societies, but it was in Europe that the longest and most developed tradition could be found of illuminated manuscripts (Encyclopaedia Britannica, *Illuminated Manuscript*). This art of *illumination* had an important role in way in which art developed. The fact that the manuscript was portable meant that it was simple to transmit ideas from region to region, or even from period to period.

After the development of printing in Europe, in the second half of the 15th century, illumination was superseded by printed illustrations. A fine example showing that the intertwining of art and technology has not always a happy ending. The technology of stained-glass gave the prominence to allow artistic realisation to take the front lead. However, while products of artistic expression, the glass windows served a clear purpose. In this case, the intertwining of technology and art was serving to tell narratives and convey moral values. Artistic practices were nurtured in general to illustrate narratives and eventually they triggered the improvement of a mass media technology: the stained-glass window.

3.5. The Bruneleschi experiment

Classical culture grasped the importance of spatial depth in art. They were able to make images which had convincing depth and the paintings or sculptures gave the feeling of 3-dimensional space. In the Middle Ages, however, this artistic capacity was lost; artists working in Florence were well aware 1 000 years later that they did not have the capacity to paint images with convincing depth, and were focused on working out a new system of art with perspective. This is evident in the work of painters in the late medieval and early Renaissance period. Their pictures look flat and this remained an insurmountable problem until Filippo Brunelleschi (1387-1446) arrived at an understanding of the problem (maltaly, 2011).

Figure 7 – Brunelleschi experiment



Source: © Wikimedia Commons

The Brunelleschi experiment is mentioned here in order to establish the assumption that one of the fundamental characteristics of art is to impact the consciousness of those interacting with its forms. Brunelleschi was an Italian artist and architect, and is considered to be a founder of the Renaissance. His technique for linear perspective and the building of the dome of Florence Cathedral made him famous. The system of linear perspective which he formulated was the principal influence on depicting space up to the late 19th century.

Brunelleschi developed a mathematical system which enabled him to represent the 3-dimensional world on a two-dimensional surface, via an experiment with a mirror and a hole. The basis of linear perspective is in the notion that similar sized objects appear to be smaller as distance increases between object and observer. It came into broad use in the Renaissance period, and was employed by artists of renown such as Leonardo, Michelangelo, Raphael and Botticelli (maltaly, 2011).

Brunelleschi's intention was to test this new 'realism' of perspective not via comparison of the painted image with the Baptistery in Florence, but instead with a reflection created in a mirror in accordance with Euclidean geometric optics. That 'realism' was achieved by changing the point of view of the original painting through a mirror. Linear perspective would adopt the conditions of monocular vision.

The great potential of monocular vision was recently demonstrated by the Flemish artist Eric Joris (1955-). His work, Collateral Rooms, an immersive live-art installation developed for the Frankfurter Buchmesse 2016, allows people to experience 3D vision through a single eye and the movement of the participant's body. The 3D effect is not conveyed by stereoscopic glasses or 3D projections, but only by a single naked eye, in movement. In Joris' words: 'That is sufficient to recreate the world as we know it'.

Joris, similar to Brunelleschi, invites the participant in his installation to wear a position-tracking device and close one eye to make sense of two planar video projections in the corner of a wall. While Brunelleschi used a very simple system, Joris employs more sophisticated technology developed by himself and his team especially for the installation. Many centuries after Brunelleschi, and in a time where digital technologies of immersion are in fashion, such as virtual reality, Joris makes the medieval notion of perspective current again, pointing out the uselessness of apparently sophisticated emerging technologies.

The case of Brunelleschi seems to transmit a perfect balance of the intertwining of art and technology. However, it can be argued that it was the artistic drive that led to the invention of the technique of perspective. The artistic need to impact and transform consciousness in such strong ways led to scientific/technological research.

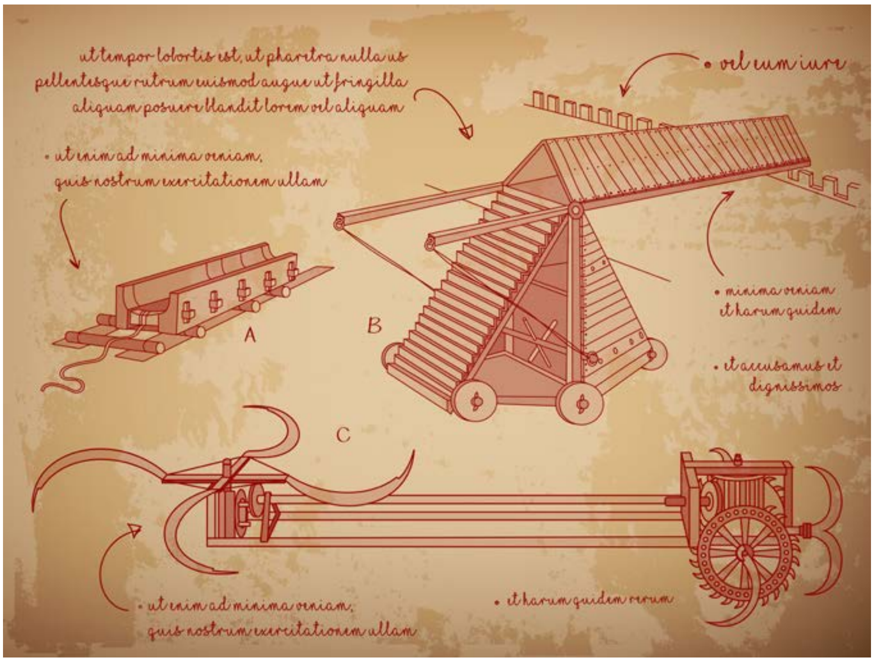
3.6. Leonardo da Vinci

Some 500 years after Leonardo da Vinci's death (2 May 1519), his genius will be celebrated in dozens of exhibitions around the world.

A recent biography of Da Vinci (Isaacson, 2017) shows Leonardo's genius was based on being passionately curious, carefully observant and so playfully imaginative that he bordered on the fantastical. He was always making plans and to-do lists. He wanted to know more just for the sake of knowing, as when he set out to describe the tang of a wood-pecker. He created what are possibly the two most famous paintings in the history of art, *The Last Supper* and the *Mona Lisa*, but regarded his roots as being in science and technology. His studies of anatomy, birds, botany, the heart, fossils, geology, flying machines and weaponry were innovative; he it was who showed the workings of the aortic valve, something backed up only recently by scientific research. His ability to place himself at the meeting point of sciences and the humanities, as conveyed in his iconic drawing of *Vitruvian Man*, has bestowed on him the title of history's greatest creative genius. Like other innovators, his greatness as an innovator was aided by his having extensive passions and extended working hours. In order to draw the muscles responsible for moving the lips, he peeled back the flesh off cadavers' faces, and went on to paint the most famous smile in history. With his explorations in optics and its mathematics, he demonstrated how light enters the cornea, among other in-depth knowledge of how the eye works, and was able to create the illusion of shifting perspectives in *The Last Supper*. Isaacson (2017) gives a description of the influence which Leonardo's enthusiasm for theatrical productions had on his inventions and paintings, and how his flying machines often made their way into settings on stage. His evident pleasure in being able to combine varied and deep interests is still the best formula for creativity today. It also helped that he seemed not to mind that he was a misfit: an illegitimate child, a vegetarian, left-handed, very easily distracted, and often regarded as heretical.

Leonardo is possibly the most well-known historical personification of the intertwining of technology and art. In him, everything was the same thing: art is science, science is art, technology is science, technology is art… he made no distinctions. He was constantly braiding art-and-technology, sometimes for no purpose at all, sometimes for a very specific purpose, sometimes even for purposes of war.

Figure 8 – Sketches of a Siege Machine by Leonardo da Vinci



Source: © Kwirry / Shutterstock.com

A very important aspect of Leonardo is that he almost always managed to be paid a monthly salary. He did not always work towards an objective. Relying on wealthy patrons, such as the Pope Leo X and Francis I, the King of France, he managed to prolong his commissions as much as possible, with delay after delay, which allowed him to explore whatever idea came to mind. This points towards the notion that nurturing the arts freely might eventually lead to innovative applications.

3.7. The invention of photography

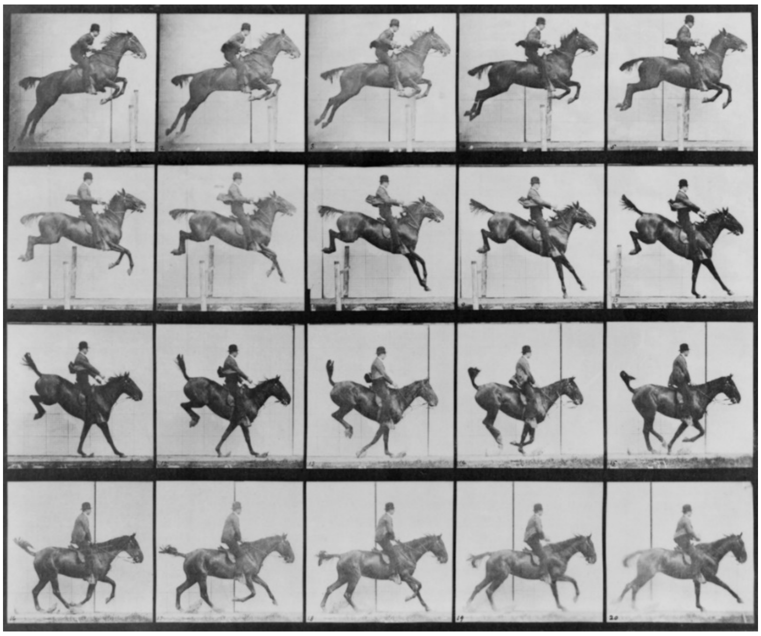
The invention of photography (in the early nineteenth century) represents a technological breakthrough that revolutionised culture and communication with an impact comparable to those of the printing press (fifteen century), or the microscope (seventeenth century). It begun with the human desire to capture reality and created a new medium for communication: an image can speak a thousand words. Photography provides a new way of recording and interpreting the world (Garfield, 1989).

The history of photography is another example of how technological change is not always immediately welcome, similar to what happened earlier with the printing press. But, despite some reaction against it, certain artists were inspired by the realism which the camera gave them. In the space of just a few years, photography came to change the viewpoint of artists in ways both technical and philosophical. The artist was encouraged to be a recorder of nature, and art started to be judged on how close it came to the exactitude of photographs (Garfield, 1989).

Muybridge (1830-1904), a photographer whose work is still highly regarded on both scientific and artistic grounds, is known for his motion studies. In 1872 he was commissioned to take photographs of a galloping horse to find out if the four horse's hooves ever left the ground all at the same time. Not only did Muybridge prove that all four hooves of the horse did in fact leave the ground at the same time, but for the first time the world had a better understanding of the true nature of movement. An artwork had added a new insight into the physical world, extending our understanding of animal physiology and behaviour (Garfield, 1989).

Muybridge than set to work delving into more studies of motion capturing the movements of everything from pigeons, to lions, to humans carrying out their daily tasks. His motion pictures greatly influenced Thomas Edison who introduced the use of high speed shutters into movie making technology (Johnson, 2009).

Figure 9 – Muybridge – Consecutive mages of Man Riding a Horse



Source: © Everett Historical / Shutterstock.com

Later progress in photographic technology enabled an understanding of events and processes in the physical world that before had been beyond human capacity to perceive. Harold E. Edgerton's invention of the strobe light around 1930, for example, in the Massachusetts Institute of Technology (MIT) CA, allowed cameras to capture momentary, almost ephemeral events – an apple being pierced by a bullet or a hummingbird's wings in motion (Garfield, 1989).

The invention of photography triggered several new dimensions in the intertwining of technology and art. As a technology, it was widely adopted by artists who, by exploring it, artistically developed it and its range of applications immensely. As a medium for artistic expression, it allowed for unprecedented forms of realism and further in history, with, for instance, techniques related to scale, allowed us to see in ways we have never seen, and to see things we have never seen before.

Perhaps more importantly for the artistic side of the intertwining, photography liberated painting. Painters were conditioned to the notion of portraying. They were the ones able make things look real. With the arrival of photography that was no longer needed. Portraying with photography became a profession. Painters were now free to explore new frontiers and movements such as Impressionism and Expressionism were born. Painting, then, allowed us to understand the world in more complex ways and possibly even made it more complex. But that would possibly be enough of a theme for another full study.

Concerning the present study, photography is another great example of the intertwining of art and technology. In certain moments of its development, it supported the evolution of artistic expression. In return, artistic needs lead to new improvement of the technology.

The stories in history, presented above, point to various ways in which the relationship of technology and art can be nurtured. These ways are context-dependent as can be observed in those stories. At certain moments of history, one way of nurturing the intertwining of art and technology seems to have worked better than another. What follows is an attempt to typify those ways but not from an historical point of view. The historical examples need to be adapted to the complexities of our contemporary world and in keeping with the possibilities of the actual policy-making instruments available.

4. Models of art and technology collaborations

Each of the historical episodes presented might be interpreted in different ways. Different models of nurturing the relationship between art and technology can be extracted from them. In some of them, those different models overlap and coexist. We have simplified the interpretation of those potential models in order for them to become useful in terms of potential new policies in the field of art and technology.

A relevant aspect of the intertwining of the arts and technologies is that it is not challenge-based as the majority of innovation processes are. In those, a challenge is previously identified upon which action is taken. In the case of the intertwining studied, challenges are constantly recreated; problems are constantly reformulated.

To illustrate this distinction let us look at the difference between art and design. Practices of design, even if art-inspired, are problem-driven. A specific problem is addressed and a design methodology is developed and applied to tackle that same problem in an objective way. This is what became known as *design thinking*.

Facing the same challenge, an artistic practice would focus on the constant reformulation of the problem allowing itself the freedom to probably even shift its point of action to a matter adjacent to the problem. This freedom of action allows for, and results from, the integration of subjective aspects into the process of technological development. Furthermore, artistic practices tend to be action-based. Problem and solution evolve simultaneously as an emergence of the concrete practice. In other words, acting first in a subjective matter to objectify in a second step. This process could be denominated as *artistic thinking*.

Of course boundaries between *artistic thinking* and *design thinking* are blurred. For example, even if a technological development is artistically driven, a design methodology has always necessarily to be in place. The process of artistic reformulation of a problem will ultimately lead to a process of implementation in order to materialise ideas and produce results.

4.1. Artists working independently

In this model, artistic practices are simply nurtured without concrete expectations of results, outcomes or processes. Allowing and promoting freedom of expression without a purpose beyond itself might eventually lead artists to address aspects of technology and therefore get in touch with those developing them, sometimes even becoming the first ones to do it themselves.

This is of course the ideal model from the artistic perspective. It fully allows for artistic freedom and therefore can lead to more unexpected results. For example, the case of Leonardo is exemplar. By managing to be constantly financed, he allowed himself to explore things that he was not being directly financed to do. In a way, he financed his own research, be it of artistic, scientific or technological nature. The cases of the cave paintings and of the medieval storytelling or projections can be interpreted in a similar way. The activity of artists was not nurtured for artistic purposes. In the case of cave paintings, artistic practices were part of a survival mechanism. Medieval artists were employed to produce religious storytelling. These contexts allowed them to improve the technologies they used not for the purpose of making better technologies but because they had the freedom to experiment in order to express themselves better. Eventually, technological development happened during artistic exploration.

4.2. Artists in residency in technological research centres (universities and companies)

Integrating artists in research and innovation processes by nurturing their practices in very specific and clearly identified technological contexts is at the core of this model. Here, the research and innovation processes are clearly defined, and the artistic contribution is a temporary addition to the ongoing activities. The aim in this model is to hopefully impact perspectives of people addressing problems and challenges by shifting their points of view over specific matters under study. This is an organic model of healthy interference. It could be also referred to as disruptive but that could attach a more negative connotation to this model: destruct to rebuild – a process some believe is the nature of innovation.

Leonardo, by allowing himself the freedom to explore new areas of knowledge, became a sort of artist in residence in places dedicated to anatomy or to the construction of weapons. He shared common places with others interested in the field for scientific reasons, while he had as well the need to better understand the human body to be able to better represent it. Brunelleschi and the case of photography can also be interpreted to fit into this category. In them, the artistic practice was complementary and contributed directly to the development of a specific technology.

4.3. Engineers developing solutions for artistic challenges

Making expertise available to artists at the edge of current technological developments is a model that became particularly famous in the last century. The aim of this model is for artists to create new pieces employing recently developed technologies. Results are usually bifold in this process. On the one hand, artists tend to push the technologies in question into previously unforeseen developments. On the other, they promote those technologies in contexts and for audiences to which technologists would not naturally have access. From the latter point of view, this model is also about integrating engineers into artistic contexts.

The case of photography fits perfectly into this model. By utilising a new technology in an artistic way, the boundaries of new developments are pushed further. It happened similarly with architects in ancient Egypt who had access to building techniques and resources that allowed them to create previously unforeseen architectures. Although on a smaller scale, Brunelleschi could also fit into this category as his artistic side pushed him to develop his scientific and technological side.

4.4. Artists and engineers in real-life circumstances

In this model, both artists and engineers operate outside their comfort zones. In the last couple of models presented above, artists are permitted to enter engineers' comfort zone – their daily life work context – and vice-versa. Here, by being integrated into a real-life context for a certain period of time, both artists and engineers face new contexts for their practices. The organicity of this model allows for more or less clearly defined contextual boundaries for action, while giving space and time for what in technology is denominated the identification phase: the period within which the specification of the technological needs are created.

This model is historically less present and it is nowadays made possible due to the ubiquitous aspects of (digital) technologies. Nonetheless, Romans had already developed in this direction by applying their art and technology connection not only to their monumental architecture and cultural interventions but to daily life, goods and contexts as well.

The findings of the study point to four models of promoting practices in the intertwining of the arts and technologies. As alternatives to an organic model of simply funding artistic practices in the stipulated field, it has been observed that bringing artists to reside for a period of time in companies or applied research organisations also leads to interesting outcomes. Allocating work time of technical personnel to resolving challenges brought up by artists is another way of nurturing developments in the field. Making real-life circumstances accessible to both artists and engineers, allowing them to figure out what might be the challenges and to find ways to overcome them, also produces relevant outcomes. Mixed models can be derived by different combinations of the four models presented above.

5. Policy options

The clear distinction of four models of art and technology collaborations resulting from the study naturally leads to the specification of four policy options for the field of practice of art and technology. The policy options presented here are designed to nurture a hybrid practice between arts and technologies that can potentially have a strong transversal impact on society and the economy in general: first, leading to innovative technological developments that, in a second step, would be the vehicle of cultural transformation towards more humanised societies and economies. The transversal aspect of the potential impact derives from the ubiquitous natures of both art and technology: they are everywhere and can assume any form.

The notion of a sustainability cycle is used to characterise and distinguish between the policies. The concept assumes that investing in artistic practices is always important and will always return results. The duration of the sustainability cycle is dependent on when the investment would produce results. The concept focuses on direct returns.

5.1. Possible actions

5.1.1. Promote artistic production *ad libitum*

The more natural policy option is to simply promote artistic creation widely. Artists have historically always been interested in novelty, especially in technology, because it allows for previously unforeseen means and forms of expression. Therefore, some of them would eventually engage with technologists to innovate their art forms and in this manner push for technological development.

The promotion of artistic creation should be focused on funding artists. Artists are normally funded through cultural institutions or by selling their artworks. Funding artists to produce ad libitum and nurture their interaction with institutions other than the cultural could lead to very unexpected results. These policies could build on top of recent investment in cultural and creative infrastructure, with a stronger note on their productive aspects.

Both costs and benefits would be potentially isometrically distributed because this is a general policy option. By widely financing artistic practices, the resulting benefits would be diverse, not necessarily technology-driven and most probably medium- or long-term. Therefore, effectiveness is not a key aspect of this policy option and feasibility would be solely dependent on budget balancing. That is, the percentage of the global budget dedicated to artistic practices would be determined by a generally commonly accepted understanding of the relevance of artistic practices for society in general.

The sustainability cycle of this policy is long, as benefits are time-uncertain and not necessarily concrete and directly measurable. In other words, this policy would be sustainable in the long-term. Return is to be expected. However, the question remaining to be answered would be: when? There is therefore the risk of failure due to potentially difficult integration into economic and financial cycles.

This policy option is broadly in line with EU policies of cohesion and social balancing because it would better integrate artists into society. It would contribute in general to virtually all EU policies but not to a specific one. It could, however, have a strong social impact through cultural transformation.

5.1.2. Promote artistic residencies in technological research centres

An alternative policy option would be to promote artistic practices in specific research and innovation contexts. Artistic practices would assume here a role of complementarity to technological research and innovation activities undertaken in those centres. Artists would work alongside other disciplines of research teams to achieve pre-determined research goals.

Costs would be reduced because this policy is of a complementary nature. It would allow for additional effort in already established research and innovation processes. This would be a very effective policy as impact and benefits would be easily assessed and measured. Feasibility is, however, dependent on the openness of research and innovation bodies to the potential benefits of such a policy. Igniting such a policy would necessarily imply strong initial efforts to demonstrate the potential benefits of such actions to hosting bodies. They would probably fear being derailed from their main targets.

The sustainability cycle of this policy is short, as activities would be focused and results and impact easily assessed. There would be of course the risk of no impact or results as this policy option is very dependent on processes of human interaction and, in extreme cases, conflict mediation. Results would not be certain.

This policy option would better fit and be in line with global EU policies such as Horizon Europe, because they are the ones designed to fund research and innovation activities. Horizon Europe already integrates artists under the umbrella of STARTS. No significant potential ethical, social or regulatory impacts would be expected more than those already expected in the hosting organisms, as this would be a complementary policy.

5.1.3. Promote artistic-driven technological challenges

This policy option is the reverse of that presented immediately above. While in the previous option, artists would be contributing to a technological innovation already under development, here engineers would be contributing to innovative artistic creations. Technological innovation would be a side effect and a consequence of the leading artistic drive.

This policy option would be costly, because it would imply not only technical expertise but also concrete materials and assembling work. Benefits would, however, be beyond interference in an ongoing process. They would be technological materialisations, communications of those technologies and, of course, innovative art forms.

Feasibility would be directly dependent on initial investment, but effectiveness would be assured because the development process would be challenge-driven.

Sustainability would be dependent on any additional process which needed to be put in place in order to capitalise on the technical innovative results. Therefore, the sustainability cycle would be medium-term and uncertain.

Risks are low, as this policy produces concrete results, new artworks and technological applications, to be expected in a determined time. However, there is the uncertainty of proliferation of results. In addition to what has already been said about additional process of technological capitalisation, the re-iteration of the innovative artwork would be improbable due to the natural technical instability of the systems developed (prototypes) and their associated operational costs.

This policy option would better fit and be more in line with global EU policies such as Creative Europe or Horizon Europe. Creative Europe will now follow the notion established by the Estonian Presidency of the EU of crossovers from the cultural and creative sector to other sectors of the economy. This context would allow for artists to bring new challenges to diverse sectors of the economy. Horizon Europe is designed to fund research and innovation activities and already integrates artists under the umbrella of STARTS.

Potential ethical, social or regulatory impacts could be expected depending on the nature and degree of the artistic intervention. For example, artistic works using biotechnology imply potentially serious risks.

5.1.4. Engage groups of artists and engineers in real-life challenges in rural and urban space

This policy would nurture the establishment of experimental conditions in rural and urban space environments for teams of artists and engineers to address real-life challenges. No preconditions would be set except contextual ones. No clear targets would be defined. They would emerge from the actions and therefore be carefully tailored to the specificities of the context.

The costs associated with this policy option would initially be low, as they would only imply artistic and engineering expertise. Subsequent costs resulting from the definition of the challenge and design of the solution would be in proportion to the needs of the context. Therefore, benefits would be suited to the specific context.

Feasibility of this policy option would be high, because initial investment is low and subsequent investment would be in proportion to the identified needs. Therefore, this policy would be highly effective.

Sustainability would, however, be dependent on the possibility of abstracting such specific results into other distinct contexts. It could therefore be a policy that is fully sustainable in each individual action but unsustainable in terms of replication.

Risks associated with this policy option would have to do with its experimental nature and its context dependency. There might be the risk of failure because local contexts might not be ready to receive the techno-artistic intervention. Results might also not be fully replicable in contexts other than the one they were developed for.

This policy would be clearly in line with EU research and innovation policies for regional development and particularly with the new Digital Transformation budget line, because it answers directly to the need of stimulating less developed regions. Again, potential ethical, social and regulatory impacts are directly dependent on each particular context addressed.

5.2. Expected effects

5.2.1. Socio-economic innovation

'No art? No social change. No innovation economy.' (Friedenwald-Fishman, 2011).

A good example of socio-economic innovation are community art projects, which are being developed around the world since the late 1960s. A variety of terms are used to describe these art projects: socially engaged art, community art, cultural mediation or participatory art. Their major aim is to use art for social change. All art forms are possible, all social groups are targets. These projects are often organised as the result of an outreach or education programme, but independent artists also include them within their practice.

5.2.2. Human development innovation

The Human Development Index (HDI), is an important tool to compare human development around the world. It focus on three basic dimensions of human development:

1. ability to lead a long and healthy life, measured by life expectancy at birth;

2. ability to acquire knowledge, measured by mean years of schooling and expected years of schooling;
3. ability to achieve a decent standard of living, measured by gross national income per capita.

The latest results show that, between 1990 and 2017, the global population increased, but the number of people in low human development fell considerably (from 3 billion to 926 million), and that the number of people in high and very high human development more than tripled (UNDP, 2018).

Among EU countries, it is worth noting that between 2012 and 2017, Ireland jumped 13 places on the HDI and now sits behind only Norway, Switzerland and Australia. Living conditions have improved faster in Ireland than anywhere else in the world over the past five years. Can this be a consequence of investing in arts education? Through a series of curricular changes over the last 20 years, today it can be said that the arts are thriving in schools in Ireland, and initiatives in the arts are numerous and innovative (INTO, 2009).

Although all 28 EU countries are in the 59 that compose the very high human development group, there is a wide gap between the 4th position of Ireland and Romania in 52nd place. These numbers show that both globally and in the EU there is still much to be done to improve human development.

5.2.3. Cultural development

The last century has seen financial and institutional capital emerging as the most important point of leverage for tackling the challenges of society. But it will be human, social and creative capital that will impact most decisively in the future and therefore, the importance of arts and culture is paramount.

Only arts and culture can nurture and or trigger the capacity for imagination or give free rein to creativity and innovation to such an extent. No other approach breaks down barriers, reconciles cultural differences and activates our feelings of shared values like arts and culture. No other investment can bring us closer together or incite us to action, and nothing enhances our capacity for making collective choices like arts and culture (Friedenwald-Fishman, 2011).

5.2.4. Balancing funds from culture to artistic production

'The arts are an even better barometer of what is happening in our world than the stock market or the debates in congress.' H. W. van Loon (1882-1944)

Western hegemony is now coming to be seen as a chapter in world history which is ready to close. China is on the verge of overtaking America as the world's most powerful economy, and thus new ways of seeing the relationship between culture and the economy are emerging which arguably could not have been imagined 20 or 30 years ago. Initial observation might show us that societies with successful economies are invariably those which are culturally confident. Higher levels of growth and productivity can be expected of creative societies, and that there will be more inward investment (Thompson, 2014).

Furthermore, this study aims to reveal that artistic practices are not only relevant as cultural or creative instruments. It is urgent to put forward and strongly support artistic practices and production as a relevant generator of knowledge, technology and driver of innovation in general. In order to achieve such an endeavour in a competitive EU, it is indispensable to understand the non-sectoral but immense value of the arts and make it quantifiable. After the success of the cultural and creative industries (CCIs) spillovers discourse, followed by that of CCIs crossovers put forward by the Estonian Presidency of the EU, it is now time for action. On the ground, in close co-creation with European citizens and the simultaneous strong support of the European Institutions, it is now time to mitigate the potential danger of the European Union transforming itself into a 'museum of the world'.

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Studying the intertwining between art and technology throughout history, helps us understand that relationship today and how it will continue in the future. Modern technology impacts significantly on art. Artists have always invented new technologies and created innovative technological applications. They tend to humanise technology by engaging with it from a human perspective.

The arts play a crucial role in the current phase of this historical cycle of intertwining of art and technology. The European Union has created Science, Technology & the Arts (STARTS); the United States of America nurtures Science & Technology, interpreted through Engineering & the Arts, all based in Mathematical elements (STEAM); and China invests heavily in creativity.

This paper aims at contributing to a better understanding of the cyclical nature of the intertwining of technology and art. It focuses on a history of that intertwining up to the transition between the 19th and 20th centuries. We seek to show that the current visibility of the intertwining of art and technology is not a new phenomenon in the policy-making world, but grounded in a long-standing historical cycle.

QA-03-19-266-EN-N

This is a publication of the Scientific Foresight Unit (STOA)
EPRS | European Parliamentary Research Service

ISBN 978-92-846-4778-1 | doi:10.2861/961315 | QA-03-19-266-EN-N